Dynamic Sink Relocation with Fuzzy Logic for Wireless Sensor Network

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Abstract - Sink mobility is an important issue for wireless sensor network (WSN) since the nodes are power constrained. With stationary sink, the network performance cannot be maximized due to excessive energy consumption of the sink. In this paper an energy efficient sink mobility scheme is proposed, where the clusters of the nodes are effectively formed using gravitational search algorithm and fuzzy logic. The target location is decided using a two-step search mechanism. The proposed scheme minimizes the communication overhead required for sink relocation, and allows the relocation without any loss of data packets. Computer simulation reveals that the proposed scheme significantly outperforms the existing five representative sink management schemes of WSN in terms of energy efficiency, network lifetime, and throughput.

Keywords: Sink Relocation, Fuzzy Logic, QHBM, Network Lifetime, WSN

1 Introduction

Wireless sensor network (WSN) has been widely used in diverse application domains such as military, environmental or industrial monitoring, and health care [1]. In typical WSN, massive data generated by the sensor nodes are forwarded to the sink node, where the collected data are pre-processed. Here, pervasive and redundant deployment of wireless sensor nodes incurs heavy communication overhead across the network [2].

The sink mobility technique has been developed with the purpose of increasing the network lifetime by relocating the sink in real time. Generally, the sink positioning techniques are classified into two categories, namely static sink and dynamic sink [3]. Static sink is a method of keeping the sink at a fixed position during the data collection process. It requires multiple intermediate nodes to communicate with remote nodes, and a solution is needed to prevent routing failures [4]. Moreover, the sensors near sink node need to bear more traffic load, and thus deplete their energy much faster than those far away from sink node [5]. With dynamic sink the sink position is changed according to the operation condition. It is relocated at the predetermined location or an arbitrary one [6]. Compared with the static sink scheme, this strategy can effectively reduce the communication overhead, and thus prolong the network life.

A dynamic sink repositioning scheme called Queen Honey Bee Migration (QHBM) was proposed in [7], which mimics the migration process of queen honey bee to relocate the sink from the initial position towards the selected pole of cardinal direction. The sink movement is guided by the cluster header (CH) nodes having the largest remaining energy. However, it searches only the predetermined area for relocation, ignoring the distribution of the sensor nodes. In WSN the sensor nodes are usually clustered and each cluster has a CH, which is responsible for the collection of data from its member nodes, data processing, and then forwarding the data towards the sink. Therefore, utilizing the information of the CHs in the sink relocation will greatly enhance the efficiency.

In this paper an efficient sink relocation scheme is proposed, which jointly takes consideration of dynamic sink relocation and node clustering to minimize the communication overhead and thus maximize the network life. Here the clusters are reorganized in each round using the gravitational search algorithm (GSA) along with the fuzzy logic controller. The sink relocation occurs via two-step search; first, search from the sink and then search from the CHs directly connected to the sink. The proposed scheme minimizes the communication overhead required for sink relocation, and allows the relocation without any loss of data packets. Computer simulation results show that the proposed scheme allows higher energy efficiency, lifetime of the network, and packet throughput compared to five existing representative schemes.

The rest of the paper is organized as follows. In Section 2 the work related to sink mobility for WSN is discussed, and the proposed scheme is presented in Section 3. Section 4 discusses the simulation results, and the conclusion is made in Section 5.

2 Related Work

Until recently, there have been numerous researches on adjusting the sink position of the WSN to extend the life time. The two methods of sink positioning are static sink and dynamic sink. In [8] energy efficiency was achieved through a dual sink approach that employs both static and dynamic sink. The advantage of static sink is that the communication between the sink and other nodes lasts without interruption. However, it results in a lack of energy of the sink, and eventually low energy efficiency of the entire WSN. It was reported that static sink is 30% less energy efficient than dynamic relocatable sink [9].

Relocation of sink, however, has a disadvantage that collection of data is difficult during sink movement. The researchers introduced the notion of rendezvous point to reduce the delay in data collection while the sink moves [10]. Here, when the sink moves, the data from other nodes are collected at the rendezvous points. When the sink is relocated
to a new location, the data of the rendezvous points are then collected. Therefore, the problem caused by sink relocation can be effectively solved.

Three methods exist for the decision of the new position of the sink; random position, predetermined position, and position decided in real-time [11-14]. The advantage of relocating the sink to a random location is that it takes small time and energy for relocation. However, data collection might be incomplete, and it is inefficient especially in large-scale WSN environment [11]. The communication overhead with moving sink to a random location will increase over time as data loss occurs and noise intervenes. Also, in a large WSN environment, the next move could be a tremendous distance. This will increase the data collection time and result in complete loss of data.

With the predefined relocation, the location depends on how to determine the path to the sink [12]. This has the advantage of acquiring complete data and extending the lifetime of WSN. A routing scheme was proposed in [13] based on the Hilbert Space Filling Curve that determines the path to the sink depending on the network size. In order to determine the path to the sink in advance, however, various factors of the network need to be collected and analyzed. As a result, the computation overhead is very high.

The real-time sink relocation method utilizes the parameter values dynamically obtained from the network, unlike the random and predetermined method [14]. Therefore, the new position of the sink depends on the condition of the nodes including the remaining energy, distance to the sink, size of the network, etc. Reference [7] proposed the Queen honey bee migration (QHBM) algorithm, a sink relocation scheme dynamically reflecting the network condition. Here sink relocation takes various factors into account to choose an optimal location. Since the computation overhead is very high with this method even though it provides a good relocation position, an approach alleviating such overhead needs to be developed.

In this paper we propose a scheme extending the lifetime of the network using the method of dynamically relocating the sink in real-time. The proposed scheme operates in two phases; search phase for collecting parameter data and selection phase for deciding the best location to move. The search phase is performed in two steps; search from the sink and then search from the CHs directly connected to the sink. This two-step search is to collect important information required to decide the sink location maximizing the energy efficiency.

3 The Proposed Scheme

As mentioned above, the proposed scheme consists of two phases. In the search phase the parameter data are collected in real-time, and in the second phase new location is selected based on the data collected and the sink is relocated. In each iterative operation of the proposed scheme, the clusters are reorganized including the CH for energy efficiency. Here modified GSA is applied to the fuzzy logic controller [15].

3.1 Search Phase

3.1.1 Energy Model

Before describing the algorithm proposed in this paper, the energy model used in this paper is discussed. The major portion of the energy of a node is consumed for data transmission and reception. $L_{RC}$ is required by node $p$ to send $N$ bit data to node $q$ as given by Eq. (1):

$$L_{RC} = N\left( E_{\text{trans}} + E_{\text{rec}} \cdot d_{pq}^4 \right) \tag{1}$$

The energy consumption for receiving $N$-bit data in each sensor node is computed as follows.

$$L_{Rx} = N \cdot E_{\text{rec}} \tag{2}$$

The energy consumed by a node for data transmission depends on the distance to the destination node. The energy consumption for short and long distance data transmission are a factor of $d_{pq}$ and $d_{pq}^4$, respectively. The total energy consumption for transmitting $N$ bits to the destination of $d$ distance from a source node is thus computed by the following equation.

$$L_s = L_{Rx} + L_{Ts} = N\left( E_{\text{trans}} + E_{\text{rec}} \cdot d_{pq}^4 \right) \quad \text{if} \quad d_{pq} < d_0 \tag{3}$$

$$L_s = L_{Rx} + L_{Ts} = N\left( E_{\text{trans}} + E_{\text{rec}} \cdot d_{pq}^4 \right) \quad \text{if} \quad d_{pq} \geq d_0 \tag{4}$$

Next, initialization of sink, sensor node, cluster, and CH is required. With the initialization, each sensor node is assigned an energy of 2J.

3.1.2 Clustering

The clusters are restructured and the CHs are selected prior to the search phase, which are achieved using the GSA with fuzzy logic controller. The GSA is to decide a proper number of CHs which minimizes the energy consumption. The following objective functions are defined in forming the clusters.

$$h_1 = \frac{s}{c} \tag{5}$$

Here $s$ is the number of clusters and $c$ is the size of the cluster. To maximize the communication quality in each cluster, $s$ needs to be determined such that the sum of transmission distances between the sensor nodes in a cluster is minimized. Therefore, the following objective function is obtained.

$$h_2 = \sum_{i=1}^{c} \frac{d(n_i, CH_i)}{\min_{n \in \text{CH}} d(n, CH_i)} \tag{6}$$

where $d(n, CH_i)$ is the Euclidean distance between sensor node, $n_i$, to its CH, $CH_i$. The purpose of function $h_1$ is to minimize the number of active CHs and function $h_2$ is to maximize the communication quality. The node of the maximum remaining energy in each cluster is selected as the CH using the following equation.

$$h_3 = \frac{\sum_{i=1}^{c} E(n_i)}{\sum_{i=1}^{c} E(CH_i)} \tag{7}$$
\[ h_k = \max_{i=1,...,t} \sum_{j \in C_k} d(n_i, CH_j) \]  
(8)

Here \( T \) is the total number of sensor nodes, \( E(n_i) \) and \( E(CH) \) are the remaining energy of \( n_i \) and \( CH \), respectively. \( c_i \) is the number of sensor nodes belonging to \( CH \). Eq. (7) is for calculating the ratio of the total energy of all sensor nodes to that of all CHs, while Eq. (8) for the maximum average distance between the nodes and the associated CH. Note that the modified GSA has four objective functions for finding the best solution. Each of the parameters obtained using the four objective functions of the GSA are divided according to the following fuzzy logic controller to form the clusters and select the CH.

**Table 1. Fuzzy rules for the fuzzy logic controller.**

<table>
<thead>
<tr>
<th>Rule</th>
<th>IMP(t)</th>
<th>ITER</th>
<th>a(t-p)</th>
<th>a(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>2</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>3</td>
<td>If</td>
<td>L</td>
<td>H</td>
<td>H then M</td>
</tr>
<tr>
<td>4</td>
<td>H</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>5</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>L</td>
</tr>
</tbody>
</table>

\[ \text{ITER} = \frac{t}{\text{Max}_t} \]  
(9)

\[ \text{IMP}(t) = 1 - \frac{\text{Best}(t)}{\text{Best}(t-p)} \]  
(10)

where \( \text{Max}_t \) is the maximum number of iterations repeated to decide the four parameters, \( h_1, h_2, h_3, \) and \( h_4 \) in the GSA. Therefore, the lower the value of \( \text{ITER} \), the shorter the time required to obtain the CH using the Fuzzy logic controller. \( \text{IMP}(t) \) is also used over time by multiplying the four parameters of the GSA. According to the rules of the fuzzy logic controller, a new cluster is formed based on \( a(t) \) and the cluster member having the largest residual energy is selected as the CH.

### 3.1.3 Search for Relocation

Next, search for sink relocation is started. The search occurs in two steps. In the first step, a CH of the largest remaining energy is searched residing inside a circular area with the current sink as the center, which is called ‘sink search scope’. In the second step, another circular search of smaller radius occurs with the selected CH as the center, which is called the CH search scope. This two-step search approach is to find the node for sink relocation allowing the maximum energy efficiency while minimizing the relocation distance.

For the sink search scope, a circle of a radius of 40m is set with the sink as the center, where the radius is equal to the communication range of the sink. This circle delimits the sink search scope. Refer to Figure 1. Then, the circle is divided into eight sectors, and one CH is selected in each sector. The residual energy of the nodes in the sector is collected and averaged which is expressed by the following equation.

\[ A_j = \frac{1}{b} \sum_{j=1}^{L_{s(j)}} E_{n_j} \]  
(11)

Here \( A_j \), \( L_{s(j)} \), and \( b \) are the average remaining energy of node \( j \), remaining energy of node \( j \) in sector \( j \), and number of nodes in sector \( j \), respectively.

Then, a circle of 20m radius is formed for the CH search scope with the CH selected with the sink search scope as its center. The residual energy of the nodes excluding the redundant nodes in the CH search scope is obtained according to the following equations.

\[ L_{s(j)} = N \left( E_{n_j} + E_{d_j} \cdot d_{ij} \right) \]  
(12)

\[ L_g = L_{g_x} + L_{g_y} + L_{g_z} = N \left( E_{n_j} + E_{p_j} \cdot \left[ 1 + \frac{1}{2} \left( d_{pq}^2 + d_{ij}^2 \right) \right] \right) \]  
(13)

\[ L_{g} = L_{g_x} + L_{g_y} + L_{g_z} = N \left( E_{n_j} + E_{d_j} \cdot \left[ 1 + \frac{1}{2} \left( d_{pq}^2 + d_{ij}^2 \right) \right] \right) \]  
(14)

where \( L_{s(j)} \) is the energy required to transmit \( N \)-bit data from the outer node \( t \) to node \( g \). The average residual energy of each sector and the residual energy of the outer nodes are also calculated. Then the probability of each sector for sink relocation, \( p_j \), is calculated using the average residual energy as follows.

\[ p_j = \frac{A_j}{\sum_{j=1}^{L_{s(j)}} A_j} \]  
(15)

![Figure 1. The two-step search for sink relocation.](image)

### 3.2 Selection Phase

After the search phase is over, the sink is moved to the CH of the sector having the highest \( p_j \). If the energy of some CHs falls below a certain threshold in the course of communication, the sink is relocated to the new location through scope search again. The procedure of the proposed sink relocation scheme is presented below.
Procedure 1. Sink relocation

1. \( k = 0, \ E_i = 2J; \)
2. REPEAT
3. get parameter of sensor nodes using GSA  
4. Judgment and Represented cluster and CH using Fuzzy logic controller

//Search
5. for \( i = 1 \) to the length of group \( N \)
6. Add Chi to group\([id, x, y, E_d]; \)
7. Group each \( v(i, d) \) in \( N \) into \( \text{scope}(i, d) \);  
8. for \( i = 1 \) to number of CHs
9. Add \( O_i \) to group\((id) \) in \( N \) into \( \text{scope}(i, d) \);  
10. end for
11. for \( i = 1 \) to number of scope
12. \( R_o = \text{average of remaining energy of group } N(E_o) \)
13. in the same \( \text{scope}(i, d) \);  
14. \( P_s = \text{probability of scope}(id, E_s) \);  
15. create \( \text{scopeMember}(i, R_o, P_s) \);  
16. end for
17. end for

//Selection
18. locate\( [k+1, \text{selected} \_ \text{scope}]^{k+1} \) ← select \( \text{scopeMember}[id, d] \) by max \( \text{scopeMember}[P_s] \);  
19. locate\( [k+1, \text{selected} \_ \text{scope} \_ \text{direction}]^{k+1} \) select \( \text{direction} \) by max \( \text{scopeMember}[R_o] \);  
20. // Relocation
21. if \( \{ \text{group}[E_d] > \text{threshold} \} \) then
22. move sink towards \( \text{locate}[\text{direction}] \) with length of \( R_o^{k+1} \)  
23. Else
24. data collection();  
25. end if
26. end if
27. UNTIL

4 Performance Evaluation

The performance of the proposed scheme is evaluated by computer simulation with a WSN having up to 200 sensor nodes randomly located in a 1000m x 1000m area. Table 2 lists the parameters of the simulation environment adopted in the paper.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Value</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>100, 150, 200</td>
<td>Number of nodes</td>
</tr>
<tr>
<td>( W )</td>
<td>1000m</td>
<td>Length of the network</td>
</tr>
<tr>
<td>( L )</td>
<td>1000m</td>
<td>Width of the network</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_i )</td>
<td>2J</td>
<td>Initial energy of each node</td>
</tr>
<tr>
<td>( E_{\text{trans}} )</td>
<td>1.0000e-7 nJ/bit</td>
<td>Energy for transmitting one bit</td>
</tr>
<tr>
<td>( E_{\text{rec}} )</td>
<td>1.0000e-7 nJ/bit</td>
<td>Energy for receiving one bit</td>
</tr>
<tr>
<td>( E_{\text{agg}} )</td>
<td>1.0000e-6 nJ/bit</td>
<td>Data aggregation energy</td>
</tr>
<tr>
<td>( E_{\text{fs}} )</td>
<td>0.3400e-9 pJ/bit/m²</td>
<td>Energy of free space model amplifier</td>
</tr>
</tbody>
</table>

In order to investigate the relative effectiveness of the proposed scheme, it is also compared with five representative existing sink management schemes such as LEACH, random walk, rendezvous, EASR, and QHBM scheme. LEACH is one of the most popular schemes employing static sink, and the random walk algorithm is used to collect data from the nodes by moving the sink randomly.

In the simulation, first, the energy consumed by the sensors per hour are compared which is the most important factor deciding the network lifetime. Then the lifetimes of WSN and packet throughputs achieved by the schemes are compared.
Fig. 2 shows the energy consumption of the sensor nodes as time passes with each of the schemes while the number of sensor nodes is changed from 100 to 200. Observe from the figure that the proposed scheme consistently consumes less energy than the other schemes. Therefore, more residual energy will remain in the sensor nodes, which results in extended lifetime of the network. According to the simulation results, it is found that dynamic sink relocation is beneficial for the communication between the sensor nodes distributed with high density in a limited space. It is also expected that the proposed scheme performs well for the WSN covering a wide range. This will be important for various applications requiring high communication performance regardless of the space constraints.

Fig. 3 compares the number of surviving sensor nodes with the schemes. Note that the number of surviving sensor nodes will decrease over time since they gradually deplete the energy for the operation and communication. Notice that the longer the network operates, the more the proposed scheme shows more live nodes. This is because the energy of the nodes can be more uniformly consumed by relocating the sink.
Observe from the figure that the proposed scheme always allows more packets processed per time. This indicates that the communication is seamless and continuous by effective sink relocation, and consequently reduces the time for the communication with the node. This also reduces the energy cost, and eventually extends the lifetime of WSN.

5 Conclusions

In this paper we have proposed scheme moving the position of the sink according to the operation condition to extend the life of WSN. In order to move the sink to a new location, the status of the nodes were collected in a two-step search operation, search based on the sink to select a CH in each sector and then search based on the CH. By performing the two-step search, it is ensured that the nodes on the periphery are excluded and the selection of the position to move next is more accurate and efficient. Also, during the movement of the sink, the rendezvous points are used to temporarily store the data so that the flow of data collection is not interrupted. Computer simulation results show that the proposed scheme allows higher energy efficiency, lifetime of the network, and packet throughput compared to five existing representative schemes.

In the future a formal model will be developed with which the performance of the proposed approach can be maximized. The proposed scheme will also be extended for the network of multiple sinks for supporting a large-scale WSN.

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7 References