Performance Evaluation of Route Cost for Wireless Sensor Networks with a Mobile Sink

Yarmuhammat Nizamudun, Naoshi Nakaya, Yukari Hagihara, Yuji Koui

ABSTRACT— Recently Wireless Sensor Network (WSN) technology has been developing remarkably and it is expected to be applied to many applications such as plant management, crime prevention, disaster prevention, medical treatment, traffic systems, and so on. In this article, we propose a Mobile Sink node control method for Wireless Sensor Networks. These WSN Networks are composed from two types of sensor node, one a “fixed node” which is immovable, and the other one a “mobile sink node” which is movable. The fixed nodes will form the clusters, and then the Mobile Sink node by using the Nearest Addition Method of TSP (Traveling Salesman Problem) which moves around the cluster center, decides the best rotation of the communication among the clusters, following which it decides the best fixed node to make the shortest distance of communication. The chosen best fixed node will transfer its data to the Mobile Sink node when it reaches them. Moreover the mobile Sink node is also capable to sense the possibility of communication of more than a few clusters in between, from then it would identify the best path for collecting the data. This method has proved its efficiency from the results of simulation and experiments that we have conducted and it would evaluate the performance of route cost for a mobile sink node.

Index Terms—Wireless Sensor Network (WSN), route cost, mobile sink node, cluster, Traveling Salesman Problem (TSP).

1 INTRODUCTION

OVER the past few years, these studies of wireless sensor networks are remarkably active, and these technologies have been applied to many methods [1],[2],[3],[4]. A number of researchers of mobile technology are developing robotic technologies using the mobile sensor networks where a large number of sensor nodes are difficult to deploy, such as plant management, crime prevention, disaster prevention, medical treatment, and traffic systems, to mention a few [2],[3]. Such sensor networks are composed from a large number of sensor nodes and mobile sensor nodes. These mobile sensor nodes would move around the network under their own control, in order to collect the data.

In fact this is one of the problems which need to solve since the mobile sensor nodes require large power for moving around the network. These sensor nodes have limited power and depend on the moving distance which consumes its energy.

So if the distance is longer it will need more energy. Hence, it has been very challenging to accumulate the data from network in the mobile sensor efficiently.

For decades, a number of control methods for mobile sink node in mobile sensor networks have been proposed. In [1], it was investigated a special of TSPN as the high level representation of the robot routing problem in wireless sensor networks. And, in view of the strengths and weaknesses of existing approximation algorithms, a novel EA-based TSPN algorithm was proposed, which can produce significantly improved performance. In [2], it was proposed an effective mobile sensor control method DATFM for sparse sensor networks. DATFM uses fixed node and mobile node, and accumulates the acquired data on a fixed node before transferring them to the sink node. In addition, DATFM transmits the accumulated data efficiently by constructing a communication route of mobile nodes between fixed nodes. In [3], it was proposed mobile sensor networks to cope with the placement problem. Unlike conventional sensor networks, each sensor needs to dynamically change its location during exploration in mobile sensor networks. In this study, the dynamic sensor placement (SDSP) is a designed and implemented scheme to realize the mobile sensor networks. In [7], the Incremental Deployment algorithm is proposed for mobile sensor node. In the Incremental deployment algorithm, the information of move place for the mobile node is acquired from the information of other mobile nodes which are moved at before the mobile node. And the mobile sink node moves to new place.

In this study, we proposed a more efficient control method that we have developed.

Recognizing the fact that the Mobile sink node accumulates the data by moving around the Wireless Sensor Networks, we compose the two types of sensor node; one is “fixed node” which is immovable and the other one is
“mobile sink node” which is movable.

The fixed nodes will form the clusters which are already able to communicate with each other mutually, and then the Mobile Sink node decides first, the best rotation of the communication among the clusters by using the Nearest Addition Method of TSP (Traveling Salesman Problem) which moves around the cluster center and second, it decides the best fixed node to make the shortest distance of communication. The chosen best fixed nodes will transfer the data which has been collected from other fixed nodes in the same cluster to the Mobile Sink node when it reaches them. Moreover, the sink node is also capable to sense the possibility of communication of more than a few clusters in between, from then it would identify the best path for collecting the data.

Upon this theory we conducted simulation and experiments to evaluate the performance of route cost for a Mobile Sink node.

The remaining article is organized as follows: Section2, explanation of the system model, Section3, explanation of our method. The results of simulation and experiments are presented in Section 4, finally our conclusion is in Section 5.

2 SYSTEM MODEL

We came up with the theory of monitoring a vast area by small number of nodes in short time, which would be applicable for areas such as dangerous to do activities. For example, when an accident happens in a place like a nuclear power plant if the sensor nodes have malfunction, it is difficult to access the nodes in a potential high radiation area. But we can obtain the data by controlling the mobile nodes toward the nodes located in high radiation area without anyone entering that area.

3 EXPLORATION OF CONTROL METHOD

3.1 Fixed node

Fixed node is immovable. The fixed node can collect the data from other nodes. In addition, the fixed nodes can form clusters with other nearby nodes, they would communicate with each other so that when the sink node approaches it, it would transmit the accumulated data to the sink node.

3.2 Mobile sink node

A Mobile Sink node moves within the network area, at the same time it is capable of identifying the best routing order. Also it chooses the ideal fixed node to collect the data from. In addition, the Mobile Sink node is able to collect the data from the sensing area of the fixed node without going through the center of it.

3.3 Theory Explanation

3.3.1 Cluster

In proceeding with this study, we are setting N of fixed node in sensing area. These fixed nodes have parameter \((x_i, y_i)\) of their setting place and radius \(r\) of the sensing area, as shown in Figure 1.

![Fig.1. Fixed node](image.png)

The clusters are formed by fixed nodes which have already communicated with each other. When these nodes form the cluster, they are judged distance \(d\) from other nodes.

For example, \(d_{ij}\) is the distance from node \(i(x_i, y_i)\) to node \(j(x_j, y_j)\),

\[
d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}
\]

As shown in Figure 2.

![Fig.2 consist of cluster](image.png)

If the distance \(d_{ij} < r\), node \(i\) and node \(j\) are can communicate and they are formed on the same cluster, as shown in Figure 2(a). If the distance \(d_{ij} > r\) they did not form on the same cluster, as shown Figure 2(b). In this same way, these \(N\) of fixed nodes form \(k\) of the clusters after the each fixed node judges distance from other fixed nodes.

3.3.2 Clusters center and Clusters order

In this proceeding article, the system decides the order of cluster by using the Nearest Addition Method of TSP (Traveling Salesman Problem)[8] which moves around the cluster center, decides the way of the best rotation of the communication among the clusters. Then all of the fixed nodes form clusters, the system decides center of each clusters by using parameters of nodes. Cluster center \((x_c, y_c)\) is:

\[
x_c = n^{-1}\sum_{i=1}^{n}x_i, \quad y_c = n^{-1}\sum_{i=1}^{n}y_i
\]

\(n\) is number of node in cluster.

When sink node decides the order of cluster, the mo-
bile sink node judges distances from oneself to each cluster center. First, the mobile sink node chooses one of the cluster centers which the distance is shortest. On the way, they enter another one of the cluster centers which has the short distance and corrects the order. In the end, the order of the mobile sink node moving around the clusters in the network is decided. As shown Figure3 (a), (b), (c), (d).

4. The cluster head of each cluster is corrected once again. When cluster head of number K cluster is decided, the cluster head of number (K+1) cluster is used as the target point and the cluster head of each cluster is selected by using step 2 and step3.

For example, cluster C1 consisted of fixed node (1, 2, 3, 4), and cluster C2 consisted of fixed node (5, 6, 7, 8). The cluster order is 1, 2, 3… the mobile sink node chooses one of fixed nodes for cluster head in cluster C1. When the mobile sink node decides cluster head for cluster C1, the center of cluster C2 is chosen for target point.

![Fig.3 cluster order](image)

![Fig.4 setting cluster head](image)

### 3.3.3 Cluster head

In this part, we explain that what decides the cluster head? In this study, the mobile sink node is moving around all clusters and decides the best fixed node for the cluster head to make the shortest distance of communication in network. It is decided that the fixed node for cluster head. The cluster head will be collecting data from other fixed nodes at same cluster, and will transfer its data to the Mobile Sink node when it reaches them. We have already decided the order of clusters for sensing. But the clusters are formed from some fixed nodes; it is a problem of how to decide which the cluster head from all of the fixed nodes in a cluster.

The mobile sink node selects cluster head by the following steps:

1. When the mobile sink node decides cluster head of number K cluster, the center of number (K+1) cluster is used as a target point.
2. The distance from the mobile sink node to each fixed nodes of number K cluster and from each fixed nodes of number K cluster to target point of number (K+1) cluster is judged and the fixed node of shortest distance is chosen for cluster head of number K cluster.
3. The sensing order of cluster head is selected by using the Nearest Addition Method of TSP (Traveling Salesman Problem).

On the way, the mobile sink node judges the distance $d_{mi0} (d_{mi0} = d_{mi} + d_{io})$. $d_{mi0}$ Is the distance from mobile sink node to each fixed nodes (1,2,3,4) of cluster C1 and from each fixed nodes(1,2,3,4) to center of cluster C2. $d_{mi}$ Is the distance from mobile sink node to fixed node i of cluster C1. $d_{io}$ Is the distance from fixed node i of cluster C1 to center of cluster C2.

On the way, the distance from mobile sink node to center of cluster C2 is $d_{m1o}$, $d_{m2o}$, $d_{m3o}$, $d_{m4o}$:

$$d_{m1o} = d_{m1} + d_{io}$$  \hspace{1cm}  $$d_{m2o} = d_{m2} + d_{io}$$  

$$d_{m3o} = d_{m3} + d_{io}$$  \hspace{1cm}  $$d_{m4o} = d_{m4} + d_{io}$$

The mobile sink node judges the distance $d_{m1o}$, $d_{m2o}$, $d_{m3o}$, $d_{m4o}$, and chooses one of the fixed nodes which has the shortest distance in cluster C1. The fixed node 4 is chosen for cluster head in cluster C1, as shown in figure 4. Next step, the cluster head of next cluster is chosen by distance from cluster head of cluster C1 to the target point. At that time, the cluster center of cluster C3 is chosen for target point, as shown in figure 5. The parameters of cluster head of cluster C3 has used mobile sink node’s parameters and the cluster head of cluster C3 is chosen for the target point.
After that, the mobile sink node judges the distance from cluster head of cluster C1 to each fixed node of cluster C2 and from each node of cluster C2 to the target point of cluster C3. Finally, fixed node 5 is the chosen cluster head for cluster C2. On same way, the cluster head of each cluster is decided. As shown in Figure 5.

Moreover the mobile Sink node is also capable to sense the possibility of communication of more than few clusters in middle point, from then it would identify the best path for collecting the data. First, the mobile sink node judges the distance with each cluster’s center, when the mobile sink node can sense a few cluster centers at same time, mobile sink node chooses and goes to the point in between the clusters. As shown in Figure 8 (a), (b). The point’s parameter is:

\[ x_o = k^{-1} \sum_{i=1}^{k} x_k, \quad y_o = k^{-1} \sum_{i=1}^{k} y_k \]

Where \( k \) is cluster number.

**3.3.4 The best point for data collection**

In this article, after the cluster head is decided, the mobile sink node chooses the best point of each cluster head by collecting data from each fixed node. When the Mobile sink node moves to the cluster head, it does not go to the cluster head, and Mobile sink node can collect data from the cluster center where it can communicate with the cluster head at sensing area.

When the mobile sink node moves to cluster head, the cluster head of next cluster is used as a target point, and the point \((x_0, y_0)\) is decided that the distance is \( r \) from cluster head. As shown Figure 7.

Moreover the mobile Sink node is also capable to sense the possibility of communication of more than few clusters in middle point, from then it would identify the best path for collecting the data. First, the mobile sink node judges the distance to each cluster’s center, when the mobile sink node can sense a few cluster centers at same time, mobile sink node chooses and goes to the point in between the clusters. As shown in Figure 8 (a), (b). The point’s parameter is:

\[ x_o = k^{-1} \sum_{i=1}^{k} x_k, \quad y_o = k^{-1} \sum_{i=1}^{k} y_k \]

Where \( k \) is cluster number.
3.3.5 Explanation of the algorithm

The key theory is monitoring a vast area by small numbers of nodes. Figure 9 presents the image of the system based on our theory; here we used ten fixed nodes (shown as from 1 to 10) and one mobile sink node.

In Figure 10, the simulation environment is consisted of 100 of fixed sensor node and one mobile sink node. Each fixed nodes have parameter of setting place and sensing area and can communicate with each other which is in sensing area.

![Diagram of the system](image)

**Fig.9 the system image**

These fixed node’s parameters of the setting place are as follows: 

\[(x_0, y_0), (x_1, y_1), \ldots, (x_{10}, y_{10})\]

The clusters from C_1 to C_5 are formed by fixed nodes which are already communicated each other, and it decides the center of the cluster by using each one’s parameter. Then the sink node decides the best routing order as follows:

\[C_1 \rightarrow C_2 \rightarrow C_3 \rightarrow C_4 \rightarrow C_5\]

Second the mobile sink node chooses one of the fixed nodes for cluster head to collect the data from each cluster. Shown as node 1, 3, 5, 7, 9 in Figure 9. Then, the mobile sink node chooses the best point of each cluster head like red point in figure 8. Moreover, the mobile sink node can communicate with node 5 and node 7 at same time, so, the best point is chosen between node 5 and node 7.

4 EVALUATION OF PERFORMANCE

4.1 Simulation for Control Method

To evaluate the performance of route cost of mobile sink node, We’ve conducted a simulation experiment.

The simulation was conducted using 100 of fixed sensor node and one mobile sink node in MATLAB, as shown in Figure 10.

Setting parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing area</td>
<td>100m×100m</td>
</tr>
<tr>
<td>(r_f) (Radius of sensing area for fixed node)</td>
<td>6m</td>
</tr>
<tr>
<td>(r_m) (Radius of sensing area for mobile sink node)</td>
<td>6m</td>
</tr>
</tbody>
</table>

![Diagram of sensor nodes](image)

**Fig.10 Sensor nodes**

The clusters are formed by fixed nodes which have already communicated each other, and it decides the center of cluster by using each one’s parameter, as shown in Figure 11.
In Figure 11, each fixed node of the same cluster is represented with the same color and different cluster is represented by a different color. Furthermore, these 100 fixed sensor nodes are forming 46 clusters. There are some clusters formed from one fixed node or from some other fixed nodes.

Moreover, the cluster center point of each cluster is decided by using parameters of each fixed nodes in clusters. The black point is shown in Figure 11.

We've conducted three types of simulations using 100 of fixed sensor node which are forming 46 clusters, and one mobile sink node, which are:

One let the mobile sink node go through the network choosing the center of clusters only.

The yellow line indicates simulation 3 and the red point indicates the best point for collecting data, as shown in Figure 13. In type three, after the cluster head is decided, the best point is chosen where the mobile sink node can communicate with the cluster head. Then, the mobile sink node collecting data from each fixed node at the best point of cluster head in each cluster when the mobile sink node arrive the cluster. The red point is shown as in figure 14.

As shown in Figure 12, the Red line indicates the simulation 1. After the cluster center is decided, the sensing order of each cluster is decided by using the Nearest Addition Method of TSP (Traveling Salesman Problem) which moves around the cluster center.

The mobile sink node collecting data from each fixed node at the cluster center in each cluster when the mobile sink node arrived the cluster.

Two let the mobile sink node go through the network choosing the best fixed nodes for cluster head from each cluster to collect the data. As shown in Figure 13.

Three let the mobile sink node go through the network collecting the data from the sensing area of cluster head without reaching its center. As shown in Figure 14.
4.2 Evaluation of route cost and Energy

In this part, we have conducted to evaluate the route cost of the simulation experiment for mobile sink node by using 50, 100, 150 fixed nodes. The simulation result is shown as below table 1.

The distance of mobile sink node is shown for the three types, in table 1.

Table 1
The moving distance of mobile sink node

<table>
<thead>
<tr>
<th>Simulation type</th>
<th>distances number of node</th>
<th>Type one (m)</th>
<th>Type two (m)</th>
<th>Type three (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>638.35</td>
<td>627.09</td>
<td>477.13</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>732.71</td>
<td>653.05</td>
<td>523.47</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>745.19</td>
<td>693.83</td>
<td>538.42</td>
</tr>
</tbody>
</table>

Through the simulation experiments, the result by using the method of type three is the most efficient. Also, the energy consumption is the most important for WSN. In mobile sensor networks, we can compute the energy consumption for mobile sink node by using:

\[ E = \alpha mS \]  \hspace{1cm} (4.1)

\( E \) is energy, \( \alpha \) is coefficient of kinetic friction, \( m \) is mass of mobile sink node, \( S \) is the moving distance of mobile sink node. \( \alpha, m \) is constant, so relation of energy consumption and moving distance is:

\[ E \propto S \]  \hspace{1cm} (4.2)

If the distance is longer it will need more energy. The energy consumption is showed in figure 15.

2. Search for a set of \( n \) hitting points (corresponded to our best point) based on the permutation found in Step 1[1].

After the order of each fixed node is decided, the mobile sink node goes to the sensing point of each fixed node and collected data from them. The route cost of the simulation experiment for mobile sink node is showed in figure 16.

From the simulation experiment, we know the distance of our algorithm is more efficient than EA-based TSPN algorithm. If the number of sensor nodes is increased, the moving distance of mobile sink node is also increased in EA-based TSPN algorithm at same setting area. However, when the number of sensor nodes is increased, the rate of moving distance is gentle slope in our algorithm.

4 Conclusion

In this paper we have proposed the Mobile Sink node control method for Wireless Sensor Networks. These networks are composed from two types of sensor node, one is “fixed node” which is immovable and the other one is “mobile sink node” which is movable. The fixed nodes will form the clusters; the Mobile Sink node decides the best rotation among the clusters, after it decides the best fixed node to make the shortest distance of communication. The chosen best fixed nodes will transfer its data to the Mobile Sink node when it reaches them. The mobile Sink node is also capable of sensing the possibility of communication of more than few clusters in between, and it would identify the best path of collecting the data.

We have conducted simulation experiments to evaluate the performance of route cost for a mobile sink node.

Based on the results, we came to the conclusion that the most efficient way is let the mobile sink node go through the network collecting the data from the sensing area of fixed node without reaching its center. This method makes the route cost shorter than let the mobile sink node go through the network, choosing the fixed node in center of clusters only or choosing the best fixed nodes from each cluster to collect the data.
In future studies, we would dig deeper into the controlling method of more than few of mobile sink nodes. We are convinced that our study would lead to a new stage of WSN technology.

REFERENCES


Yarmuhummat Nizamudun obtained a Master of Engineering (M.E) degree in 2009 from the department of Computer and Information Sciences, Iwate University, Japan. Currently, he is a Ph.D. candidate in Graduate School of Engineering, Iwate University. His research interests include Mobile Wireless Networks, Wireless sensor Networks, Cooperative communications, Multi Channel operation, pattern recognition and its applications.

Naoshi Nakaya obtained a Ph.D. in Mathematical Science, Department of Science and Engineering, Saitama University, Japan. Presently he is working as an assistant professor in the Iwate University, Japan. His research interests are computer networks, wireless networks security, computer viruses, and Evolutionary algorithms.

Hagihara Yukari graduated from the Department of Information on System Fundamentals, the University of Electro-Communications, Japan. She is working as a technical staff in the Iwate University, Japan. Her research interests are wireless networks, mobile robot and computer vision.

Yuji Koi worked as Department Chief, Mitsubishi electric corporation, Information Technology R&D Audio-Visual Information Technology. He obtained a Ph.D. degree in Information Engineering from Tohoku University, Japan. Presently he is working as a professor in the Iwate University, Japan. His research interests are wireless sensor networks, wireless networks security, Unknown computer viruses, and Remote control protocols.