Abstract

How to achieve and discrete the location of sensor nodes is a key problem in WSNs. The goal of this paper is to bring forth a location scheme for WSNs in support of data collection and aggregation, which includes distance and angle discretion. At last, performance analysis is proposed to indicate that the location scheme has the properties of scalability and efficiency of energy.

1. Introduction

In WSNs hundreds, and potentially thousands of low cost tiny sensor nodes are deployed in the interested fields (i.e., battlefield, forest) unattended, which often work autonomously without access to renewable energy resource. Although the challenges in wireless sensor networks are divers in the application domains, some researches recently are particularly interested in location-aware problem in WSNs, since some sensor network applications typically are concerned more about physical phenomena or events associated with a geographical location than the raw data on a specific sensor node. Such as the following application domains are concerned with location-aware problem in WSNs[1],

1. Location tracking of moving objects;
2. Location-based routing and data collection;
3. Query processing and query optimization.

Furthermore, based on the location information, we could use self-organization to resolve the following problems, i.e. routing, deployment, data aggregation, measure the physical environment. More importantly, the location technology could be used for mobile object tracking application domain. Therefore, It is valuable to study the location scheme in WSNs.

The remaining parts of this paper are as follows: section 2 discusses related works. Section 3 introduces the location scheme proposed in this paper. Performance analysis is presented in section 4. Finally, section 5 concludes this paper and discusses about some future researches.

2. Related works

To the best of our knowledge, there are four location schemes used in WSNs. The first is The Global Positioning System (GPS) that has been suggested as a means to obtain location information in WSNs [2]. In contrast to GPS, Local positioning systems (LPS) deploy a grid of RF base stations that communicate with sensor nodes and then triangulate to determine their locations based on received signal strength (RSS), time difference of arrival (TDOA), or time-of-arrival (TOA) technologies[3][4]. Another way to obtain relative location in a WSNs is to measure a sufficient number of pair-wise distance estimates and then use multi-lateration algorithms for position estimation[5]–[9]. The last method is Proximity-based Localization. In this approach, some nodes can act as beacons for sensors such as the UCB motes that may not have the hardware capability for acoustic ranging[10][11].

For outdoor applications in which sensor density is low, and cost is not a major concern, GPS is a viable option. However, adding GPS capability to each sensor nodes in a dense WSNs is expensive, except for the size of sensor factors. Although the theory of LPS is suitable for the location of sensor nodes, traditional LPS is only used in the application of fixed station. Moreover, the key shortcoming of third scheme is that the possible combinations of pair-wise ranges will rise very rapidly with increasing numbers of sensor nodes in WSNs. Therefore, the goal of our research is to build location scheme for a generic WSN in support of data collection and aggregation without the support of GPS.

3. Location scheme
It is infeasible to obtain the precise location of each sensor a-priori. This paper adopts a location scheme to provide useful location-information: partitioning the deployment area into a set of fan shaped cell, sensor nodes within the boundaries of the same fan shaped cell have the same location information, and then discrete the location information with the considering of distance and angle factors to divide the 2-D interested field. The location scheme includes distance and angle discretion.

3.1 Distance discretion

Distance discretion uses several binary bits to stand for the real distance from sensor nodes to the sink. If we suppose that the distance from the farthest sensor nodes to the sink is 100 meters, and the number of distance discretion is two binary bits, the result of distance discretion is as in Figure 1, we could use two bits, i.e., “00”, to stand for the distance from 0 meter to 25 meters, “01” to stand for the distance from 25 meters to 50 meters, etc. Clearly, the more number of binary bits in distance discretion is, the higher accuracy we could obtain in real distance estimation.

Figure 1. Distance discretion diagram

In order to compute the real distance from sensor node to the sink, we introduce a first order radio model as discussed in [14]. In this model, a radio dissipates $E_{elec} = 50$ nJ/bit to run the transmitter or receiver circuitry and $E_{amp} = 100$ pJ/bit/m² for the transmitter amplifier. The radios have power control and can expend the minimum required energy to reach the intended recipients. The radios can be turned off to avoid receiving unintended transmissions. An $d^2$ energy loss is used due to channel transmission to calculate transmission costs and receiving costs for a $k$-bit message and a distance $d$ shown as below Formula (1) and (2).

Transition energy consumption

$$E_{Tx}(k,d) = E_{Tx-amp}(k) + E_{Tx-amp}(k,d)$$

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times k \times d^2$$

(1)

Receiving energy consumption

$$E_{Rx}(k) = E_{elec} \times k$$

(2)

Because the sink node has power control to transmit a message to the intended recipients, we could divide the interested field into several fan shaped cells. firstly the sink node using power control capability with $k=2$ and $d = 100$ meters transmits a message which includes only two binary bits as “11”, all the sensor nodes receiving the message will discrete its real distance as “11”. When the second time slot comes, the sink node transmit another message (namely “10”) using power capability with $k=2$ and $d = 75$, all the sensor nodes receiving the message will chang distance discretion number from “11” to “10” until the sensor nodes receive the binary bits “00”. The energy consumption during the four time slots could be calculated with Formula 2 ($k = 2$). We call this process as “Distance discretion phase”.

3.2 Angle discretion

Angle discretion also uses binary bits to stand for the real angle from sensor nodes to the sink node according to anticlockwise direction in right angle coordination. As we all know, the total angle in two dimension is 360 degrees. If we assume that the number of angle discretion is 2, We could use two binary bits to stand for the angle (i.e., “00” represents the angle from 0 degree to 90 degrees, and “01” from 90 degree to 180 degrees, etc). Clearly, the more number of binary bits in angle discretion is, the higher accuracy we could get in real angle estimation according to anticlockwise direction in right angle coordination.

Figure 2. Angle discretion diagram

In order to implement the angle discretion, we can use the concept of time slots as distance discretion phase. As in Figure 2, because the number of angle discretion is 2, there are four time slots used for completing angle discretion. with the first time slot coming, the sink node transmits two binary bits as “00” with the angle from 0 degree to 90 degrees in right angle coordination. All the sensor nodes which could receive this message will store “00” as its angle discretion number. We call this process as “Angle discretion phase”.

3.3 Location discretion
In a two dimension environment, we define the position of sensor node as a tuple $<\text{distance}, \text{angle}>$. If an environment of WSNs is as Figure 3, the black solid circle stands for sink node, and we use two binary bits for the distance and angle discretion respectively according to the discretion principle in section 3.1 and 3.2 above, the region of this environment could be divided into 16 parts, everyone of which is called as a fan shaped cell. Then we could use four bits to discrete the location of any sensor node which belong to a fan shaped cell in WSNs. The first two binary bits stand for distance discretion information, and the rest two binary bits for angle discretion information. For example, if the real position of a sensor node is depicted as $<32, 40>$, we could clearly know that this means the sensor node is 32 meters far from the sink node, and the angle is the degree of 40 according to the anticlockwise direction in right angle coordination. In order to reduce the length of location information we could discrete the location information as four bits. Therefore, the tuple $<32, 40>$ could be represented as “0100”. Clearly, all the sensor nodes which belong to a fan shaped cell have the same location discretion through above two phases (i.e., Distance discretion phase and Angle discretion phase).

![Figure 3 Position discretion diagram](image)

### 3.4 Location scheme

In this section, location scheme will be presented which comprises synchronous phase, location scheme and task phase.

**3.4.1 Synchronous phase.** When thousands of sensor nodes have been deployed in the interested field, the WSNs enter into a synchronal phase. At first, every sensor nodes are in the sleep state in order to reduce the energy consumption. Next the sink node broadcasts a synchronal signal (abbreviated for SS) in the field, the sensor nodes having received SS message will automatically enter into receive state from sleep state.

**3.4.2 Location scheme.** After synchronous phase, the WSNs enter into the distance discretion phase. If the number of distance discretion is $x$, the sink node will allocate $x(x = 2^k)$ time slots for distance discretion. When every time slots of distance discretion come, the sink node will send a distance discretion message (abbreviated for DD) to all the sensor nodes in WSNs. When $y$ time slots go by, then all the sensor nodes enter into the angle discretion phase. If the number of angle discretion is $y$, the sink node will allocate $y(y = 2^k)$ time slots for angle discretion. When every time slots of angle discretion come, the sink node will send a angle discretion message (abbreviated for AD) to the sensor nodes with a angle of certain degree in the interested field. With $y$ time slots going by, all the sensor nodes in the interested field have stored its location discretion information which includes $x$ binary bits distance discretion information and $y$ binary bits angle discretion information. We call the state of dealing with distance discretion and angle discretion as discretion state. When all the sensor nodes complete location discretion, they will change its state from discretion into sleep state again.

Therefore, The location scheme in this paper is only related to the precision requirement of application, and there is no direct relationship between distance discretion and the range of area. That is, my scheme has the property of scalability that could be used not only for large area, but also for small area deployment of sensor nodes.

**3.4.3 Task phase.** When the location discretion phase has completed, all the sensor nodes in WSNs change its state from discretion state to sleep state again. If the sink node has a task to sense the interested field (i.e., temperature, quality of air or water, etc.), it will send a TS(namely task setup) message to tell all the sensor nodes. Then all the sensor nodes will enter into sensing state from sleep state to implement sensing task, and broadcast the data to its neighbour in its sending state changed from sensing state.

At first, all the sensor node which broadcasts its original sensing data to all its neighbours in sending state as the format in figure 4. For example, if we want to sense the temperature of the interested field, assuming that the number of distance discretion and angle discretion are all two respectively, and we could use 8 bits to discrete the temperature from -100 to 155 degree.

Note that when the neighbour has broadcasted its original sensing data before receiving the data from other sensor node, they act only as a mediator to forward the receiving data to its own neighbour with same format as in Figure 4. Otherwise, the neighbour will compare the receiving data with its original sensing data and broadcasts the results to other neighbours with the following format as in Figure 5.
We agree with the following rules in the process of task phase,

1) If the receiving data is bigger than its original data, Then Max field equals to receiving data, and Min field equals to original sensing data, vice versa.

2) The sensor nodes could not receive the data from sensor nodes with different angle discretion information.

3) The sensor nodes could only forward (or aggregate) the data from its neighbours with the same angle discretion information (and same distance discretion information).

We call the above three rules as “aggregation rule” and the state of implementing the these rules as the aggregation state. The aggregation data format as Figure 5. Thus it can be seen, when all the sensor nodes in receiving state have received the data from its neighbour and implemented data aggregation according to aggregation rule, they will send the result to its own neighbour again which will deal with data according to aggregation rule again. We call all states which include sensing state, sending state, receiving state and aggregation state as “active states” during task phase. That is, active states include four child states.

<table>
<thead>
<tr>
<th>Position discretion (distance + angle)</th>
<th>data</th>
</tr>
</thead>
<tbody>
<tr>
<td>x + y bits</td>
<td>(x = 2, y = 2)</td>
</tr>
</tbody>
</table>

| 0000-1111 | 00000000~11111111 |

**Figure 4. Sensing data format**

<table>
<thead>
<tr>
<th>Position discretion (distance + angle)</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>x + y bits</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 0000~1111 | 00000000~11111111 |

**Figure 5. Aggregation data format**

When the sink node has received the data from all the interested field and the number of received data is enough for specific application, which will broadcast a TF (task finish) message, and the task phase finishes. Having received the TF message, sensor node will enter into sleep state from any child state of its active states, and wait for another task period coming when receiving a TS message. The state transition during task phase is depicted as Figure 6.

**Figure 6. State transition diagram during task phase**

3.4.4 State of sensor node. As we can see from section 3.1 to section 3.3, when sensor nodes are deployed in the interested field, all sensor nodes enter into sleep state. When synchronous phase comes, all the sensor nodes are waked from sleep state into receiving state by receiving SS message. With the distance discretion phase coming, all the sensor nodes will change from receiving state into discretion state. That is, during distance discretion phase and angle discretion phase, all the sensor nodes are in the discretion state in order to execute location scheme which includes distance discretion and angle discretion. When task phase comes, all the sense nodes at first change its state from sleep state into active states in order to sense the interested data of interested environment (i.e., temperature etc.) , complete simple data aggregation and transmit the results to sink nodes with broadcast communication mode. All the above state transition can be depicted as in Figure 7.

**Figure 7. State transition diagram during all phases**

4. Performance analysis

In this paper, we only consider a general model of WSNs, supposing that \( N \) sensor nodes are deployed evenly in a circle region around the centre of sink node. The distance of the farthest sensor node to the sink is \( R \). The transmission range of each sensor node is \( r \). The number of binary bits in distance discretion and direction discretion is \( x \) and \( y \) respectively. All the control messages have \( x \) binary bits (i.e. SS, DD, AD, TS, and TF, etc.). The number of binary bits about data discretion equals \( z \). We have the following approximations,
1) The consumed energy for sleep state and state transition is ignored.
2) The energy consumption for the control data transmission originated from the sink is also ignored.
3) For the sensor-to-sink transmissions, the consumed energy only includes both the receiving and the transmitting operations.
4) All the sensor nodes are deployed in the interested field evenly.

According to above assumptions, we could achieve the following results. The energy consumption increases with the parameter $N$, $K$, and $X$ during synchronous phase and location discretion phase as $O(N)O(K)O(X)$. Otherwise, the energy consumption during task phase is concerned not only with the parameters of $N$ and $K$, but also with the parameter with $x, y, z, r$ and $R$ as $O(N)O(x+y+z)O(R^2)O(r^2) + O(N)O(K)$.

At last, according to comparing the location scheme with other methods forth recently by researchers, the location scheme in this paper Outperforms other ones (i.e. [3][4], [6]~[11]) in some certain. For example, the location scheme in this paper has the property of scalability. In addition, It use discretion technique to reduce the length of position information without considering of GPS.

5. Conclusion

We propose a location scheme to achieve the location of sensor nodes and discrete its local position. This scheme does not use GPS aided for achieving the location information for the factors of size and expensive cost of sensor nodes. Our future researches will focus on some detail technologies, such as location-based routing algorithm and make a simulation to compare the difference of performance analysis in theory with results from practical environment.

6. Acknowledge

The authors acknowledge the support of SeT Laboratory of Belfort Montbéliard Technology University (UTBM) in France and the China-France doctoral school project.

7. References


