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A SMART LOCATION ALGORITHM OF WIRELESS SENSORS

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ABSTRACT—Accurate positions of some sensor nodes need to be calculated within wireless sensor network (WSN) in many applications, such as environmental monitoring system. This paper aims at the location method of sensor nodes in small scale WSN application scenarios; several kinds of traditional positioning methods are discussed. The main contribution of this work is to propose an algorithm based on the energy attenuation model with transmitting distance, and then design a communication frame for rapid positioning on the basis of ZigBee protocol stack correspondently. The algorithm is easily applied in small scale area networks. Its quality is verified in the actual environment, the result shows that the positioning accuracy is within 2 meters; the relative error is less than 3% in small scale area of open environment.

Key Words: Wireless sensor; Location; ZigBee

1. INTRODUCTION

The demands for wireless positioning increase with the development of wireless sensor network applications, such as forest fire prevention, environmental monitoring, intelligent traffic management, warehouse management, space research and civilian fields[1]. The information of sensor node's location is helpful for routing efficiency, the quality of network coverage, network load balancing, and network topology free configuration of network management. Most of current practical positioning system based on GPS technology, resulting in higher cost applications. Therefore, to develop new positioning system with low cost and high reliability becomes very urgent. Location method in wireless sensor networks has a variety of classification [2]. Location algorithms are classified into two main categories, based on ranging (range-based) location algorithm and independent of the distance (range-free) positioning algorithm.

Positioning algorithm based on distance need to measure absolute distance or orientation between the nodes, and use the actual distance between nodes to calculate the position of the unknown node. There are many algorithms, such as TOA (time of arrival based), TDOA (time difference of arrival based), AOA (angle of arrive based) location algorithm and RSSI, etc. The distance between nodes can be calculated with the signal propagation model in TOAs which has high accuracy but requires accurate time synchronization of nodes. In TDOAs, the transmitting node simultaneously transmits two radio signal with different propagation speeds, and the receiving node calculate the distance between two nodes based on the arrival time difference of

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two signals, then the node position can be calculated through the existing basic positioning algorithm. TDOAs can locate with high positioning accuracy but high hardware requirements, cost, and power consumption also. In AOAs, the receiving node via the antenna array or a plurality of ultrasonic receivers senses the arriving direction of the transmitting node's signal. The position of the node can be obtained through the triangulation method. So it is easily influenced by the external environment and not suitable for large-scale sensor networks. Based on a received signal strength indicator (RSSI) location [3] [4], the signal propagation loss can be calculated according to the received signal strength of receiving node, then it can be converted to distance between theoretical and empirical models, and then the location of the node can be calculated by existing methods. General methods are empirical model of signal propagation methods and the theory of signal propagation model.

Distance-independent location algorithm does not need to measure the absolute distance or orientation among sensor nodes, and it only uses the estimated distance between nodes to compute node position. Many algorithms belong to this category, such as the Centroid algorithm, the DV-Hop algorithm, and the Amorphous algorithm [5]. This technology needs lower the node hardware requirements for it does not measure the absolute distance between nodes or orientation, but it increases the positioning error. Centroid algorithm is composed of anchor nodes surrounding the unknown node polygon, and polygon Centroid is the average of all the vertices coordinates of the unknown node [6]. Based on DV-Hop (distance vector-hop) algorithm, unknown nodes and anchor nodes first calculate the minimum number of hops, and then estimate the average distance of each jump. With a minimum number of hops multiplied by the average distance of the unknown node and the distance between the anchor nodes, and then use trilateration method to calculate the unknown node coordinates [7]. Amorphous algorithm and DV-Hop algorithm is similar, except the average distance to node communication radius.

These algorithms are adapted for some special application environments. This paper aims at designing a simple and efficient positioning algorithm which is easy to be implemented on some industrial applications. The main contribution of this work is to propose an positioning algorithm based on the energy attenuation model with transmitting distance in small scale area wireless sensor networks, and then design a correspondent ZigBee protocol stack.

2. A ZIGBEE FRAME FOR POSITIONING SENSOR NODES

Each nodes has a unique network address in ZigBee protocol. ZigBee endpoint is used to express the concept of the function of a node, which is an 8-bit character representing a different type of application. An endpoint for ZigBee is an application; there may be many different statuses or control logic, which corresponds to the concept of ZigBee properties, and each property has its own position value. The cluster is a collection of several attributes, and each cluster in the network is assigned a unique cluster ID.

ZigBee protocol stack based on the IEEE 802.15.4 standard defines two lower layers: the physical layer (PHY) and media access control sublayer (MAC). ZigBee Frame is protocol data unit, which consists of three parts: the header, the data part and the frame end. Among them, the header and the end contain control information; data section contains other layers transmitted data. This paper designs a variety of frames, such as network discovery data frame and positioning information frame. Network discovery data frame format is as follows:

```
struct NF_UARTBUF{//ZigBee frame of network discovery
    UINT8 Head;        //frame header
    UINT8 HeadCom[2]; //command header
    UINT8 Style;       //node type
    UINT8 Laddr[4];   //physical address
```

```
        UINT8 Saddr[2];   //network address
        UINT8 PLaddr[4];  //parent physical address
        UINT8 RSSI[2];    // Signal strength
        UINT8 Power[2];   //power
        UINT8 DataBuf[11];  //data buffer
        UINT8 LastByte;    //end of frame
    }NF_DATA
```

Through the network discovery data frames, broadcasting this command, the relevant section of the whole network information can be received by the coordinator. Location information acquisition frame format is as follows:

```
    struct POS_UARTBUF{//ZigBee frame of location acquisition
        UINT8 Head;   //frame header
        UINT8 HeadCom[2];  // command header
        UINT8 Laddr[4];     //physical address
        UINT8 AnchorLaddr[4];  //anchor physical address
        UINT8 RSSI[2];     //RSSI value
        UINT8 DataBuf[18];  //data buffer
        UINT8 LastByte;     //end of frame
    }POS_DATA
```

In the positioning process, the frame is used to calculate the environmental parameters when the positioning information acquisition command of the frame header is “Pan”, and for positioning when the positioning information of the frame header is the “POS”.

3. A LOCATION ALGORITHM BASED ON ENERGY OF RECEIVED SIGNAL

3.1 The Relationship Between RSSI Energy Attenuation and Distance

RSSI (Received Signal Strength Indication), an optional part of the wireless transmission layer in ZigBee protocol stack, is used to determine the link quality. RSSI value indicates the distance between the received signal transmitting nodes and the receiving node by measuring the received signal strength, so RSSI can be used for positioning.

As for the empirical model, it selects reference nodes according to a certain density, and then builds a mapping matrix about the signal intensity and the distance of nodes. In the actual process, the measured signal strength is compared with the mapping matrix to determine the distance about the measured nodes to anchor nodes. Wireless signal propagation model mainly includes free-space propagation model, logarithmic distance path loss model, log-normal distribution models and number-normal distribution model which is the most widely used. The power of signal *PL* in distance d is given by Log-normal distribution model as Eq.(1) [8]:

$$PL(d)[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n\lg(\frac{d}{d_0}) + X_\sigma \tag{1}$$

n in Eq.(1) is the path loss exponent, indicating that the path loss with the growth rate of the distance range form 2 to 6. d_0 is close to the reference distance, determined by the test. The parameter X_σ is a zero-mean Gaussian variable caused by random environment effectors. The relation between *LQI* and *RSSI* is shown in Eq.(2) [9]:

$$RSSI = -[81 - LQI \times 91/255] \tag{2}$$

LQI variation ranges from 0 to 255 according to the received signal. So the LQI value calculated through RSSI (denoted as RSSIL) into the distance estimation algorithm than solely through RSSI (denoted as RSSID) distance estimation algorithm in accuracy is further improved [10]. Suppose $\overline{PL}(d_0)$ = A, then with Eq.(1) and (2) , the distance d can be obtained as follows:

$$d = 10\hat{}((\mathrm{ABS}(81 - LQI \times 91/255) - A)/(10 * n)) \quad (3)$$

The parameters A and n are generally given from experience. A represents the signal strength at 1 meter from the sender, which is an empirical parameter; n represents the loss factor of environment.

In the open playground, the CC2430 coordinator is connected to the upper computer system. The coordinator broadcasts a testing frame; each testing endpoint returns its RSSI value of received signal of the broadcasted frame. Each endpoint node needs to be tested at every 1 meter interval in 5 meters and every 5 meters interval till the limitation of signal transmission. According to Eq.(2), the relationship between distance and LQI can be obtained, and then we can convert it into the relationship between the RSSI and distance. Experimental data shows that: without increasing the magnification power of the premise, the CC2430 nodes can be used in the experiments with the effective communication distance of 110 meters. Endpoint more than 110m is difficult to join the network, and thus is impossible to communicate. The measured according to the multiple sets of data, averaging at the same distance, the RSSI can be drawn between the distance attenuation curves shown in Figure 1.

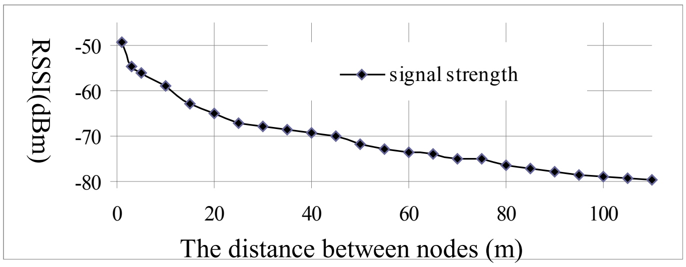

Figure 1. RSSI energy attenuation with distance relationship

The relationship of energy attenuation and distance from the RSSI graph shows that CC2430 chip without enlarged transmitting power can used to locate sensor node effectively within distance of 110m. With distance increasing, RSSI energy attenuation consistent with theoretical decay curve; same distance changes in the distance is small (less than 30 meters), RSSI energy decay faster, and far away in the effective communication distance range, RSSI energy attenuation becomes more gentle.

This experiment tested the CC2430 effective communication distance, verify RSSI energy attenuation versus distance, and with the theoretical RSSI attenuation curves coincide, to achieve the desired experimental results. These tests for subsequent positioning experiments carried out smoothly laid a solid foundation.

3.2 An Improved Algorithm Model

Generally, in the known case of two nodes link quality or signal strength, according to the Eq.(3), parameter A and n given by the empirical value help to calculate the distance between the nodes. However, due to large differences in the real environment, the desired value of A and n may experience the actual environment quite different. Therefore, the algorithm calculates the environmental parameters A and n according to the actual situation, which values of more environmental adaptability than experience model. Then the object location can be deduced as follows: Suppose that there are three anchor nodes, represented as $M(x_m, y_m)$, $N(x_n, y_n)$, $P(x_p, y_p)$ respectively, then the distance between anchor nodes M and N is denoted as d_{mn}, and the distance between anchor nodes M and P is denoted as $d_{mp.}$

The signal intensity values between anchor nodes M and N or P can be obtained from the actual communication, which is denoted as $RSSI_{mn}$ or $RSSI_{mp}$, the two values are computed as the following equations:

$$\begin{cases} (10\times\lg d_{mn})n - A = |RSSI_{mn}| \\ (10\times\lg d_{mp})n - A = |RSSI_{mp}| \end{cases} \tag{3}$$

Then:

$$A = (|RSSI_{mn}| - |RSSI_{mp}|)\lg d_{mn} / \lg(d_{mn}/d_{mp}) - |RSSI_{mn}| \tag{4}$$

$$n = 10(|RSSI_{mn}| - |RSSI_{mp}|)\lg(d_{mn}/d_{mp}) \tag{5}$$

After RSSIs of several senders being obtained, the parameters A and n can be calculated subsequently. In practical applications, RSSI value is deduced from the measured LQI value.

3.3 The Algorithm Design and Experimental Test

As mentioned above, the first thing during positioning is to calculate the environmental parameters, and then using the calculated environmental parameters for positioning. The program of computing environment parameters process is shown in Figure 2.

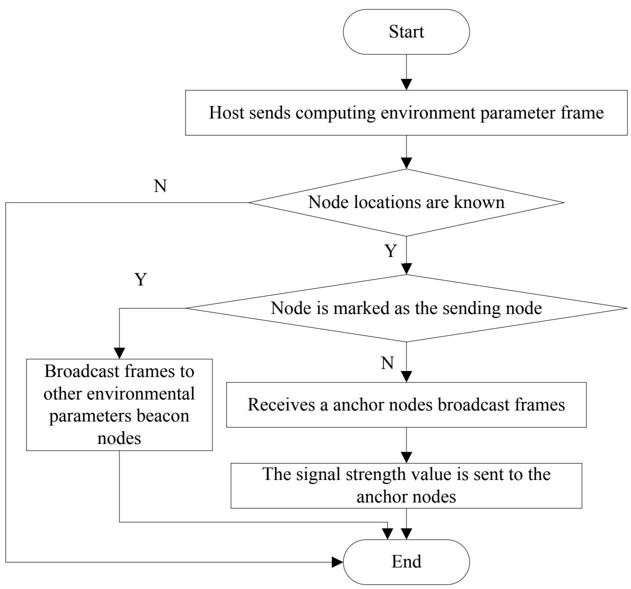

Figure 2. Program flowchart of computing environment parameters

When sensor nodes receive a order frame of environmental parameters acquisition, each if then returns an acknowledgement frame to the coordinator, then the upper computer reads data to get the corresponding LQI value. When the environmental parameters are calculated, a node can be positioned by the location algorithm.

When the unknown node O receives the positioning request sent by an anchor node, it answers location request to anchor nodes, as shown in Figure 3. Anchor nodes M, N, P receives this request respectively, and the coordinator broadcasts the location information the frame, then the coordinator handles the received location information and initialization configuration information to calculate the coordinates of the unknown node. Positioning flow chart is shown in Figure 4.

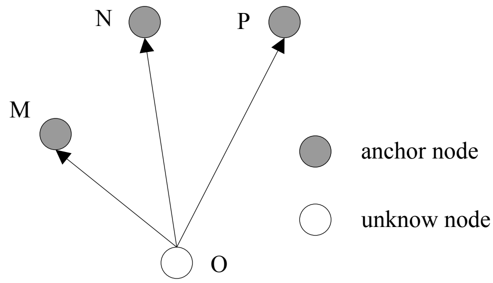

Figure 3. Schematic of Node Location

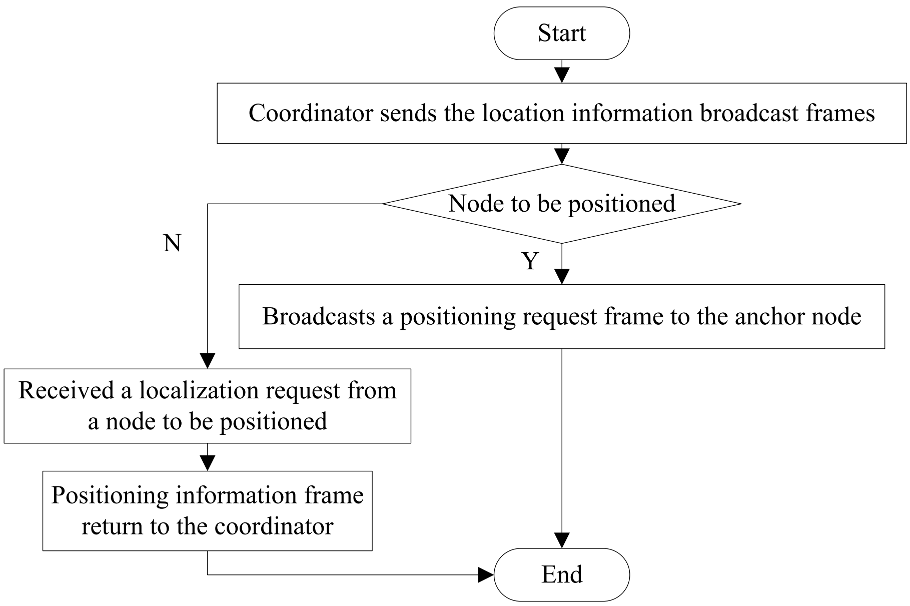

Figure 4. Flow Chart of Node Location

Experiments are set in the open playground, in 100 × 100 m^2 in the region, deploying three anchor nodes, the coordinates are (0, 0), (100, 0), (100, 100) respectively. Unknown nodes are randomly distributed in the area, and environmental parameters are calculated according to the actual environment. The experimental area is divided into 25 regions of 20 × 20 m^2, and there is a tested node randomly set in each area. To reduce the noise effect, each LQI value is average value of several tested results. The experiments with the actual coordinates of nodes coordinate measuring results are shown in Figure 5.

During the experiment measuring, the coordinates of the unknown nodes are measured three times at each position obtained by averaging the measurement coordinate, denoted as D. Real world and the absolute value of between D. The absolute error of the experimental data is get from the difference between of measurement coordinates and each real location. From 75 test results, it shows that the present algorithm accuracy is 2 meters in Figure 6.

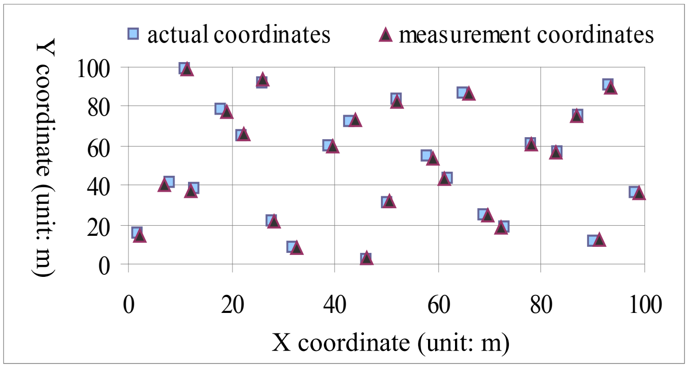

Figure 5. Comparison of actual coordinates and measurement result

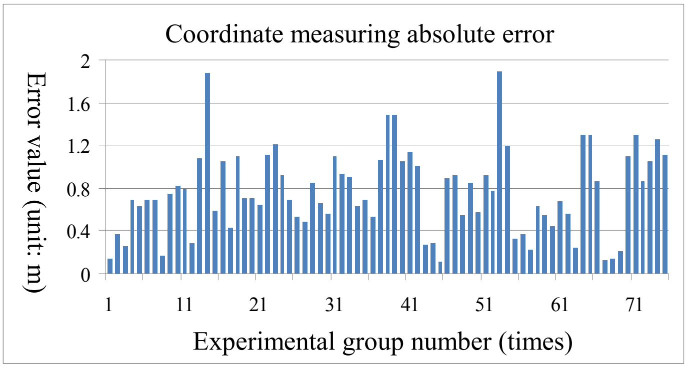

Figure 6. Nodes coordinate measuring absolute error

Relative accuracy is represented by the ratio of absolute error by the average absolute distance between the tested node and three anchor nodes. The relative accuracy of the experiment result is shown in Figure 7

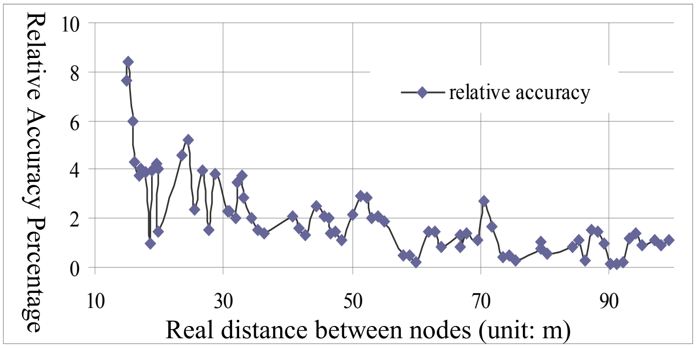

Figure 7. Nodes coordinate positioning relative accuracy

As shown in Figure 7, the relative accuracy of node location experiments is at 9% or less. Since there are random interference factors which can reduce the accuracy of positioning occasionally, such as interference of walking pedestrian, instability of battery-powered, and some electromagnetic interference, the accuracy performs not stable enough. The experimental results show that the relative positioning accuracy of less than 6% up to 96% probability. This experiment is for the specific environmental parameters and calculates the corresponding environment, rather than empirical estimation of signal loss values, which improves the positioning accuracy of the algorithm effectively. After calculation, the average relative node positioning accuracy is less than 3%. From Figure 6, it can be concluded that the effective communication between nodes within the scope of energy-based environmentally adaptive positioning algorithm has better positioning accuracy.

4. CONCLUSIONS

In WSN applications, the node location information is the base of event position reporting, target tracking and other system functions. In order to provide effective location information, sensor nodes must be able to conduct real-time location after deployment. Based on the analysis of the various existing location algorithms, an improved WSN location algorithm based on energy has been proposed and implemented in this paper. The experimental results show that the proposed location algorithm has good accuracy of node location in the real environment in the case of without increasing the hardware cost and communication power it is adapted to large number of wireless sensor network node positioning applications.

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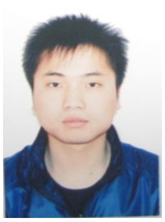

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