A Novel Ranging Method using Bimodal Gaussian Distributed RSSI Measurements

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***Abstract*—The ranging method based on Received Signal Strength Indicator (RSSI) widely uses indoor positioning technology of Wireless Sensing Network (WSN) because of low cost and low complexity. The primary challenge is how to overcome some of the phenomena that affect signal propagation in a real environment, such as multipath, diffraction, and absorption. Also, it makes the positioning method more accurate. We are interested in the fact that influences on RSSI measurements from indoor propagation environments can be another ranging error source. In other words, to improve the ranging accuracy, the factors influencing RSSI measurements should be minimized or compensated. In this paper, we propose a method using bimodal Gaussian distribution to get more accurate estimated RSSI. The proposed method uses RSSI measurements with bimodal Gaussian distributed characteristics in a reference position. The experimental results in the proposed method show that more precise results are achieved compared with the existing method.**

Keywords— RSSI; bimodal gaussian; attenuation log model.

I. INTRODUCTION

In recent years, wireless network technologies, such as Wi-Fi, ZigBee, Bluetooth, iBeacon have been rapidly developed and widely used [1][2][3]. According to the signal transmission intensity attenuation, phase difference, time delay based on wireless network positioning technology can estimate the location of the mobile node in the wireless network coverage area to provide positioning services. The indoor positioning technology using RSSI measurements is focused in this research area because of its high positioning accuracy. It is also compliant with GPS (Global Positioning System) in precise positioning area [4]. Due to the complexity of indoor environments, the positioning error is relatively large compared to that of outdoor GPS. Other indoor positioning methods such as Ultrasonic [5], Ultra-wideband [6] and so on, which are restricted by the cost and application condition, are hard to meet the general demands of indoor positioning.

Ranging algorithms are divided into two categories according to the method of distance measurement in wireless sensor networks. One is a ranging-based algorithm, and the other is a range-free algorithm. The former method measures RSS (Received Signal Strength), (Time of Arrival), TDOA (Time Difference of Arrival), etc. and calculates or estimates the distance between node and reference [7]. The latter one utilizes the relationship of geometric location information between receiving nodes and the transmitting nodes to estimate the distance.

The positioning algorithm based on more precisely calculated or estimated distance information can provide higher positioning accuracy. The RSSI attenuation log model, which is easily influenced by various factors in propagation environments, is generally used for distance estimation.

A suitable method that not only efficiently improves the positioning error but also expands the measurement range of indoor positioning is needed.

The rest of the paper is structured as follows. In Section II, the RSSI-based ranging method is introduced. In Section III, the statistics of RSSI measurements are analyzed. In Section IV, a new attenuation log model using RSSI measurements with bimodal Gaussian distributed characteristics in a reference position is proposed and its experimental results are given in Section V. Conclusions are given in Section VI.

II. RSSI-BASED RANGING METHOD

In positioning theory, one of the techniques related to ranging is to estimate the distance between two points by the signal strength between the transmitting point and the receiving point. Most devices can currently obtain RSSI. WSN does not require additional hardware support, and it does not affect the energy consumption, the size of the nodes and the cost of the nodes. Therefore, WSN technology and RSSI technology are very suitable for rough ranging.

In free space, RSSI is inversely proportional to the square of the distance d between the receiving point and the transmitting point. The relationship can be expressed using the famous Friis formula [8]:

$$P_r(\mathrm{d}) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{1}$$

In Equation (1), $P_r(\mathrm{d})$ is the received power, and the unit is watts. P_t is the transmit power, and the unit is watts. G_t is the transmit antenna gain. G_r is the gain of the receiving antenna. λ is the wavelength of the transmitted signal and the unit is meter. L is a loss parameter that has nothing to do with the propagation environment. In fact, the system loss parameters represent the total loss of the actual system hardware. It includes transmission lines, filters, and antennas.

In general, L is greater than one. However, if we assume that the system hardware has no loss, we can let $L = 1$. From (1), we can observe that the attenuation of the received power is exponential with the distance. So, the free-space path loss can be directly derived from Equation (1) without any system loss.

$$PL_F(\mathrm{d})[\mathrm{dB}] = 10\log\left(\frac{P_t}{P_r}\right) = -10\log\left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right) \quad (2)$$

If we ignore the antenna gain and let $G_t = G_r = 1$, Equation (2) can be written as:

$$PL_F(\mathrm{d})[\mathrm{dB}] = 10\log\left(\frac{P_t}{P_r}\right) = 20\log\left(\frac{4\pi d}{\lambda}\right) \quad (3)$$

In a free-space model, the average received signal is in a logarithmic relationship with the distance d between the transmitter and the receiver in all environments. In fact, a more general path loss model can be constructed using the environment-dependent signal attenuation factor to change the free-space path loss model. The mathematical expression of signal attenuation log model is as follows:

$$PL_{LN}(d) = \mathrm{PL}(d_0) + 10nlg\left(\frac{d}{d_0}\right) + X_0 \quad (4)$$

where d represents the distance from the transmitting node to the receiving node, and the unit is m. d_0 is the unit distance and usually takes 1m. $PL_{LN}(d)$ is the path loss after a distance of d, and the unit is dBm. $\mathrm{PL}(d_0)$ is the path loss after the unit distance, and the unit is dBm. X_0 is Gauss random number for a mean of 0, and its standard deviation range is 4~10. When the n value is smaller, the signal attenuation in the transmission process is smaller, and the signal can spread farther away. The range is generally between 2 and 4. Figure 1 shows the signal attenuation model for indoor positioning.

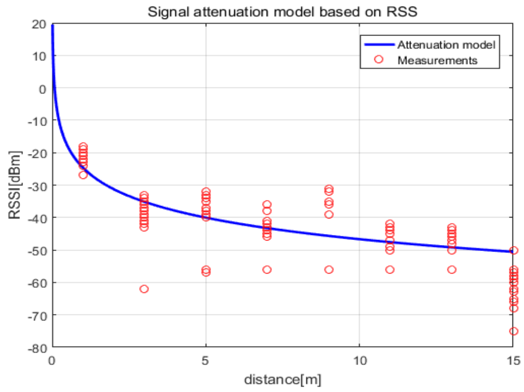

Figure 1. Signal attenuation model for indoor positioning

III. STATISTICS OF RSSI MEASUREMENTS

The relevant research shows that the relationship between the RSSI and the transmission distance of the wireless signal is closely related and stochastic characteristics of RSSI measurements follow a particular rule pattern.

From the point of view of the probability density function property，the measured RSSI data were analyzed. We collected RSSI measurements every two meters and analyzed them by comparing with the stochastic distribution model. After thorough analysis, we can find that most of the RSSI measurements at a fixed location conform to Gaussian distributions or bimodal Gaussian distributions. At the same time, there is a small part of abnormal RSSI values. Figures 2-5 give the probability density distributions of RSSI measurements at 1m, 5m, 9m, and 13m.

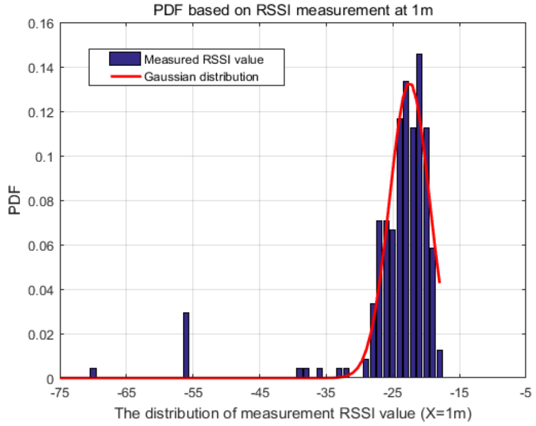

Figure. 2. Probability density function of RSSI measurements at 1m

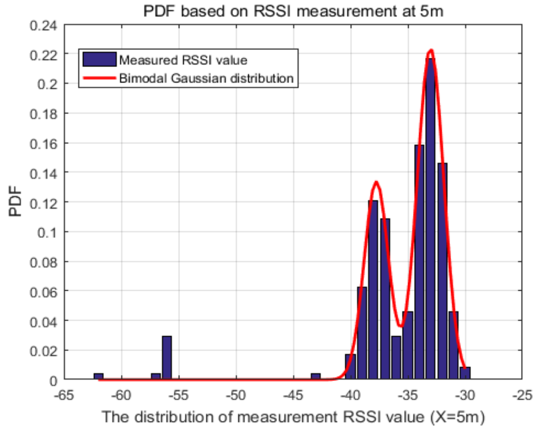

Figure 3. Probability density function of RSSI measurements at 5m

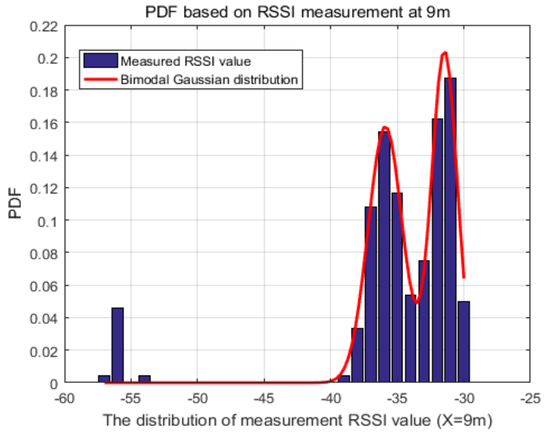

Figure. 4. Probability density function of RSSI measurements at 9m

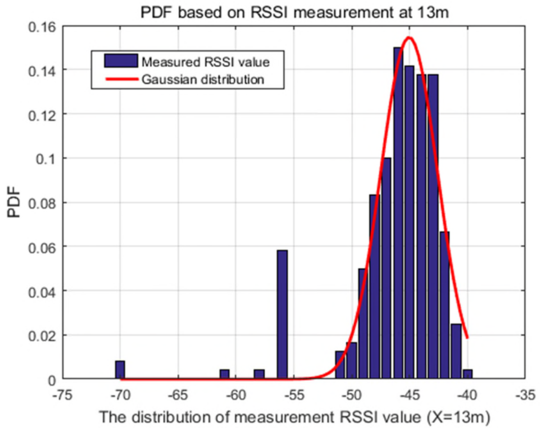

Figure. 5. Probability density function of RSSI measurements at 13m

IV. A NEW ATTENUATION RSSI LOG MODEL

The existing RSSI attenuation log model utilizes the mean value of the RSSI measurements at a reference point for its derivation. Relevant research shows that the RSSI mean value is close to the representative RSSI value at that point. Although this value is close to the representative RSSI value, we find that there is some difference caused by some error sources in indoor environments. For its analysis, we collect 240 RSSI measurements at every reference point.

By analyzing Figures 2-5, after removing a small part of outliers, we can find that the RSSI values measured at 1m and 13m show Gaussian distributed characteristics and those at 5m and 9m conform to the bimodal Gaussian distribution.

Therefore, we propose a new RSSI attenuation log model, which can provide more precise ranging information. The derivation procedures are presented below.

Firstly, we conducted an analysis based on the nature of the collected RSSI values, then filtered out the abnormal value, which produces a big difference with the average.

Secondly, according to Equation (5), we can get a Gaussian distribution model and Bimodal Gaussian distribution model of the RSSI measurements at a reference point.

Thirdly, according to Equation (7), we weigh filtered RSSI measurements which comply with bimodal Gaussian distribution to get the RSSI estimate at the reference point.

Finally, we propose a new RSSI attenuation log model, which is valid for up to 15m range.

We take out this part of the RSSI value. Then, we calculate the estimated RSSI value according to the selected RSSI measurement values at a fixed point. We obtain estimates based on bimodal Gaussian distribution or Gaussian distribution respectively by processing 240 RSSI data from 1 meter to 15 meters. The equation of mixed Gaussian distribution is expressed as:

$$\mathrm{F(x)} = a_1 \frac{1}{\sqrt{2\pi}\sigma_1} e^{-\frac{(x-\mu_1)^2}{2{\sigma_1}^2}} + a_2 \frac{1}{\sqrt{2\pi}\sigma_2} e^{-\frac{(x-\mu_2)^2}{2{\sigma_2}^2}}, \qquad (5)$$

$$where, (\sigma > 0)$$

The maximum value of the first peak is Max_1, and the maximum value of the second peak is Max_2. If

$$Min \le \frac{Max_1 + Max_2}{2} \qquad (6)$$

Min is the minimum value between two peaks in Equation (6). At this time, the 240 RSSI measurements we have obtained are Gaussian distributions. Otherwise, they are bimodal Gaussian distributions.

$$RSSI_{Bimodal\ Gauss} = \frac{a_1}{a_1 + a_2}\mu_1 + \frac{a_2}{a_1 + a_2}\mu_2 \qquad (7)$$

$$RSSI_{Gauss} = \frac{\sum_{i=1}^{m} RSSI_{max_i} P_i}{\sum_{i=1}^{m} P_i} \qquad (8)$$

where $P_i \ge 0.04$ and $RSSI_{max_i} \ge RSSI_{max_{i+1}}$

We use the above method to get the estimated value of RSSI at the reference point.

A new attenuation log model can be composed using the estimated RSSI values obtained from 240 RSSI measurement values at a reference point in linear regression model.

V. EXPERIMENTAL RESULTS

In experiments, we use ipTIME N3004 as a node and place those nodes at the height of 0.2m on the ground. To reduce the impact of ground reflection on the received RSSI value and the ranging error, the reference node is also placed at 0.2m height. Broadcom 802.11 wireless network card built-in notebook computer is used as a mobile node and is located 1m away from a fixed node for measurement start. The considered reference points are 2m apart sequentially to each other. At each reference point, 240 times measurement processes are executed. The experiments were carried out in the third-floor corridor of Kyungpook National University IT1 Building, as shown in Figure 6.

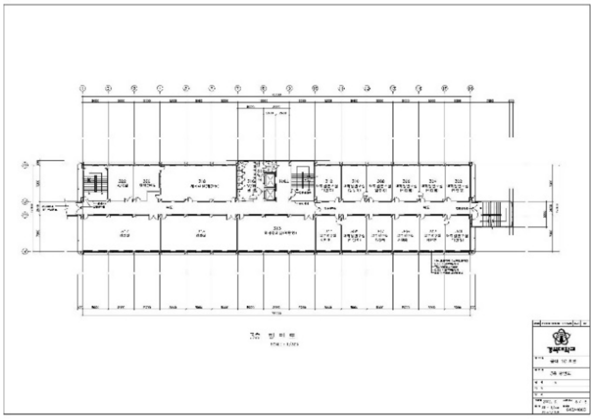

Figure 6. Kyungpook National University IT-1 building

We compare the performance of the proposed RSSI attenuation log model with that of an existing attenuation log model.

We calculate RSSI values at reference points using mean filtering and bimodal Gaussian filtering for 240 measurement samples at each reference point. Then, we can obtain an existing RSSI attenuation log model and the proposed RSSI attenuation log model like below

Parameters of existing RSSI model: A = -23.84, n = 2.206

Parameters of proposed RSSI model: A = -21.81, n = 2.326

The attenuation log model curve is fitted according to filtered RSSI values at reference points. After that, we can obtain a proposed RSSI attenuation log model, which is valid in range of 1m to 15m, as shown in Figure 7. The red line is the proposed RSSI attenuation log model.

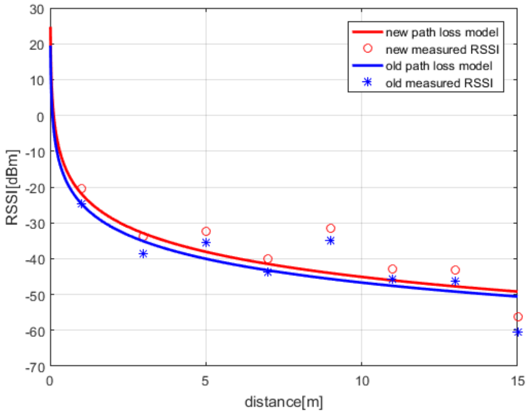

Figure 7. Fitted RSSI-distance curve using the proposed method and mean filtering

According to Figure 7, we can calculate distances of unknown nodes by obtaining RSSl values of those corresponding nodes. For performance, we compare distances of unknown nodes calculated by the proposed method and the existing one. The comparison results are shown in Table 1.

TABLE 1. COMPARISON OF THE DISTANCE MEASUREMENT ERRORS OF THE PROPOSED METHOD AND MEAN FILTERING METHOD

Distance (m)	Measure Distance Mean Filtering Method(m)	Measure Distance The Proposed Method(m)	Improved The Range Error(m)	Reduction rate (%)
1m	0.234	0.105	0.129	12.9%
3m	1.724	1.4621	0.2617	8.73%
5m	1.564	1.2521	0.311	6.23%
7m	1.5	0.9076	0.5924	8.46%
9m	5.746	4.3488	1.3976	15.53%
11m	1.613	0.909	0.704	43.7%
13m	2.667	1.802	0.864	32.4%

From Table 1, we can find that the proposed RSSI attenuation log model provides more accurate distance information compared with an existing RSSI attenuation model. Experimental results show that the range error decreases more evidently beyond the range of 10m, which indicates that the proposed method can extend the applicable range. At the same time, the proposed method reduces the distance error at 11 meter reference point by 0.704m.

From the comparison results, we can conclude that the proposed method improves the ranging accuracy to a certain extent and reduces the influence of more substantial ranging errors due to other factors, such as obstacles.

V. CONCLUSION

In this paper, we propose a novel RSSI attenuation model based on bimodal Gaussian filtering. The proposed method produces more accurate distance information and is applicable for more extended ranging case compared with an existing RSSI attenuation log model method, which is based on simple mean filtering.

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