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Temperature and Humidity Awareness in Estimation of Distance Based on RSSI in 802.15.4 Network

Wilawan Rukpakavong, Sirikunya Nilpanich, Saowaluk Watanapa, Kannikar Subsomboon
Department of Computer Science
Faculty of Science and Technology, Thammasat University
Pathum Thani, Thailand

Abstract: Distance estimation based on received signal strength indicator (RSSI) is one of popular research topics in Wireless Sensor Network (WSN) since it is an uncomplicated and inexpensive way for localization implementation. However, fluctuation in the signal strength may cause a large error in the localization system. The RSSI changes considerably over time depending on temperature, humidity, and other factors. This decreases the accuracy of the RSSI-based estimation algorithm. This paper proposes a distance estimation algorithm using received signal strength indicator, taking into account the effect of temperature and humidity on RSSI within an indoor environment. The validity of the proposed algorithm was verified and compared to previous techniques. The results of this study demonstrate the feasibility of the RSSI based distance estimation algorithm. The proposed algorithm can reduce the error in distance estimation by 13 to 27% using temperature and humidity awareness. Thus, this confirms the effectiveness of proposed technique.

Keywords*—RSSI; Wireless Sensor Network; Distance Estimation; Temperature; Humidity*

I. INTRODUCTION

Location information is an important key of some areas of sensor networks, called emergency sensor networks (ESN) [1] such as wildlife monitoring, disaster management etc. The collected data will become worthless if the location information cannot be discerned through transactional records. Therefore, localization algorithms [2] have an important part in ESN. There are many localization approaches such as Time of Arrival (TOA) [3], [4], Time Difference of Arrival (TDOA) [5], Angle of Arrival (AOA) [6]. Even though all of them have high accuracy, they require more energy consumption and complicated hardware.

An alternative approach is the use of the received signal strength (RSS) [7], [8] which has relatively low complexity and cost. Most standard wireless transceivers provide an estimation of RSS as a built-in feature, called RSS Indicator (RSSI). It indicates the power of the received radio signal which is used for many localization techniques [9]. The RSSI-based method was developed using Log-Normal Shadowing Model (LNSM) for predicting a distance between two sensor nodes [10]. However, RSSI can be affected by several factors such as temperature, interferences, and humidity, that can result in the fluctuation and distortion of RSSI measurements. Thus, this decreases the accuracy of RSSI-based algorithms. For this reason, some works [11], [12] conclude that it is not advisable to use RSSI for location or distance estimation. Nevertheless, some domains on indoor environments such as medical, healthcare monitoring, surveillance, intrusion detection and automatic tracking applications do not require high accuracy of localization [13]. Hence, RSSI is still a good solution for a coarse but simple method of location estimation. The advantage is that it can be implemented easily on battery- powered nodes with low processing capabilities and small memory size. However, it is still challenging to investigate and analyse the interfering factors of RSSI in an indoor setting in order to improve the RSSI-based distance estimation for supporting many applications which require high accuracy of distance estimation. Temperature and humidity are the two parameters that have been proved to affect RSSI in both outdoor and indoor environments [9], [12]. This paper focuses on the indoor environment, proposing a distance estimation algorithm using RSSI with temperature and humidity taken into account.

II. RELATED WORKS

A. RSSI Based Distance Estimation

Many works focused on path loss model which is a function of distance. Rodoplu and Meng [14] proposed a simple radio propagation model between wireless sensor nodes as:

$$P_r = \frac{1}{d^n} \tag{1}$$

where P_r, d are the received power and the distance with a factor n. Normally value of n is greater than or equal to 2. The RSSI in dBm can be calculated by using the power P_r of the RF signal as the following equation [15].

$$RSSI = P_r - \text{OFFSET} \tag{2}$$

where OFFSET is a calibration offset value corresponding to the chipset design. Olasupo et al. [16] presented another technique to calculate RSSI based on multiple paths signals as:

$$RSSI = \text{RSSI}(d_0) - 10nlog_{10}\left(\frac{d}{d_0}\right) + X_\sigma \tag{3}$$

where d_0 and $\text{RSSI}(d_0)$ are the reference distance and the RSSI of that reference distance measuring by the experiment, n is a path loss index depending on propagation environment and X_σ is zero-mean Gaussian random variable. For line- of-sight (LOS) of indoor environment based on a 1 metre reference distance, the equation will be [17], [18]:

$$RSSI = \text{RSSI}(1) - 10nlog_{10}(d) + X_\sigma \tag{4}$$

where RSSI(1) is received signal at a distance of 1 metre. Then, Alawi [15] derived the distance estimation equation as:

$$d = 10^{-\frac{RSSI - RSSI(1) - X_\sigma}{\eta}} \tag{5}$$

where η is $10n$. Yang et al. [23] proposed the equation to find the distance between the human ankles for both indoor and outdoor environments as:

$$d = \lambda \frac{\sqrt{\frac{P_t + RSSI - \Delta PL}{10}}}{4\pi} \tag{6}$$

where λ is the wavelength (12.5 cm for 2.4 GHz XBee-PRO S2C chips), P_t is the transmitted power, and ΔPL is the correction factor.

B. Effects of Temperature and Humidity on Signal Strength

There are several works that investigate the effects of temperature and humidity on the link quality in WSN. Lin et al. [19] observed that the daily variation of RSSI is around 6 dB, which may be caused by temperature, humidity, and other factors. Bannister et al. [20] studied the relationship between RSSI and temperature in the Sonoran Desert of the Southwestern United States, where temperatures in summer may vary from 25˚C to 65˚C. They found that RSSI values tend to decrease when the temperature increases, which results in link quality and connectivity reduction between nodes. Boano et al. [21] used two different radio modules, CC2420, CC2520, to study the impact of the high temperature variation on RSSI in outdoor environment with temperature variation between 0°C and 50°C. The study confirmed a negative correlation between the temperature and RSSI. After that their study has been extended by Luomala et al. [12] to explore the effects of temperature and humidity on the RSSI in the outdoor with temperature varying from -15° C to 35°C and the relative humidity varying from 40% to 100% using the Atmel ZigBit 2.4 GHz wireless module. The results showed that temperature has a strong negative correlation with RSSI when the temperature is higher than 0°C. However, this correlation is reduced at 0◦C or below. Czerwinski et al. [22] studied the path loss exponent constant based on measurement for different weather conditions. The measurements were made using Digi XBee S2 radio modules. In their outdoor experiment scenarios, it can be noticed that path loss exponent value is changing according to the weather conditions. When the temperature and humidity increases, the value of RSSI decreases, resulting in a direct impact on the path loss exponent.

III. Research Methodology

To quantify the effect of temperature and humidity on the relationship between RSSI and distance, several experiments involving two arduino with XBee S2 nodes were carried out in the controlledroom. The controlled environment is achieved through the use of air-conditioner to create fluctuated temperature and humidity. One node is used as a sender and another node as a receiver. For collecting the RSSI values, these two nodes were placed at a height of 45 cm and at distances of 1, 2 and 3 metres. The transmission power is set to its highest level (2 dBm) [24]. The analysis of the measurements was performed based on 100 samples for each experiment.

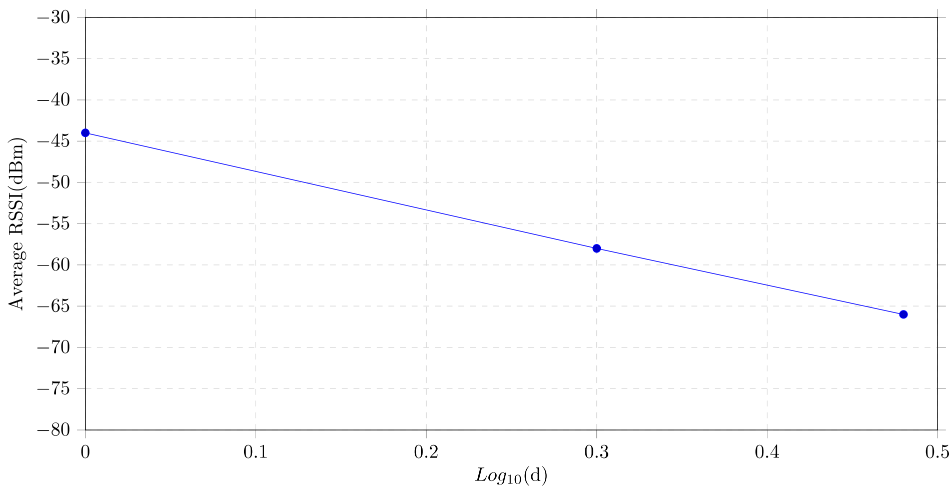

Fig. 1. Average RSSI and Log10(d)

In the first test, the controlled environment is at room temperature 34°C and 60% relative humidity (RH). The average measured RSSI at distances of 1, 2 and 3 metres are -44, -58 and -66, respectively. A plot of the average received power in dBm versus the logarithm of the distance $Log_{10}(d)$ is shown in Figure 1 with the estimated linear regression model as:

$$y = -45.43x - 44.32 \quad (7)$$

By mapping y and x of (7) with RSSI and $Log_{10}(d)$ of (4), the values of $10n$ (or η) and X_σ can be determined as follows:

$$45.43 = \eta = 10n \quad (8)$$

$$-44.32 = \text{RSSI}(1) + X_\sigma = -44 + (-0.32) \quad (9)$$

where -44 is the RSSI(1), therefore, X_σ is -0.32. By relating to (6), ΔPL for the distance of 1, 2 and 3 metres are 4.95, 13.93 and 18.40 respectively. Thus, the average ΔPL is approximately 12.43. The effect of temperature and humidity is investigated in the second test. The controlled environment is exposed to a temperature variation from 27˚C to 34˚C and a relative humidity variation from 44% to 60%. Two nodes were placed at a distance of 1 metre. The relationship between different temperature and relative humidity values can be defined by the absolute humidity (AH) as the following function [12]:

$$AH = 216.7 \cdot \frac{\frac{RH}{100\%} \cdot A \cdot \exp\left(\frac{m \cdot t}{T_n + t}\right)}{273.15 + t} \quad (10)$$

where t is the actual temperature (˚C), RH is the actual relative humidity (%), m = 17.62, Tn = 243.12 ˚C, and A = 6.112hPa. The relation between RSSI and AH calculated from (10) is shown in Figure 2.

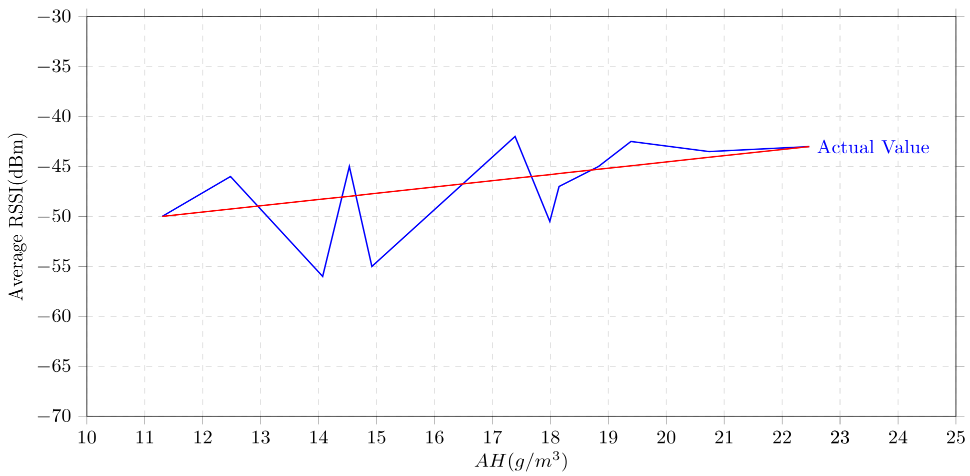

Fig. 2. Average RSSI and AH

The estimated linear regression for RSSI(1) with temperature and humidity effect, called $RSSI(1)_{ah}$, is calculated as:

$$RSSI(1)_{ah} = RSSI(1)_{min} + 0.63 \cdot \Delta AH \quad (11)$$

where $RSSI(1)_{min}$ is -50 dBm and ΔAH is the different between current AH and AH_{min}which can be calculated as:

$$\Delta AH = AH - AH_{min} \quad (12)$$

where AH_{min} is approximately 11.30. Thus, $RSSI(1)_{ah}$ can be applied in (5) as:

$$d = 10^{-\frac{RSSI_{ah} - RSSI(1)_{ah} - X_\sigma}{\eta}} \quad (13)$$

where $RSSI_{ah}$ is the measured RSSI value at the absolute humidity (AH).

IV. RESULTS AND DISCUSSION

To verify the proposed distance estimation algorithm, the controlled environment is exposed to a temperature variation from 27◦C to 34◦C and a relative humidity variation from 44% to 60%. The distances between the receiver and sender are between 1 to 3 meters. From the average measured RSSI values, the distance between the sender and the receiver can be estimated based on (5), (6) and the proposed method (13). Distance estimation comparison between the proposed model (13) and other models, (5) and (6), is shown in Figure 3.

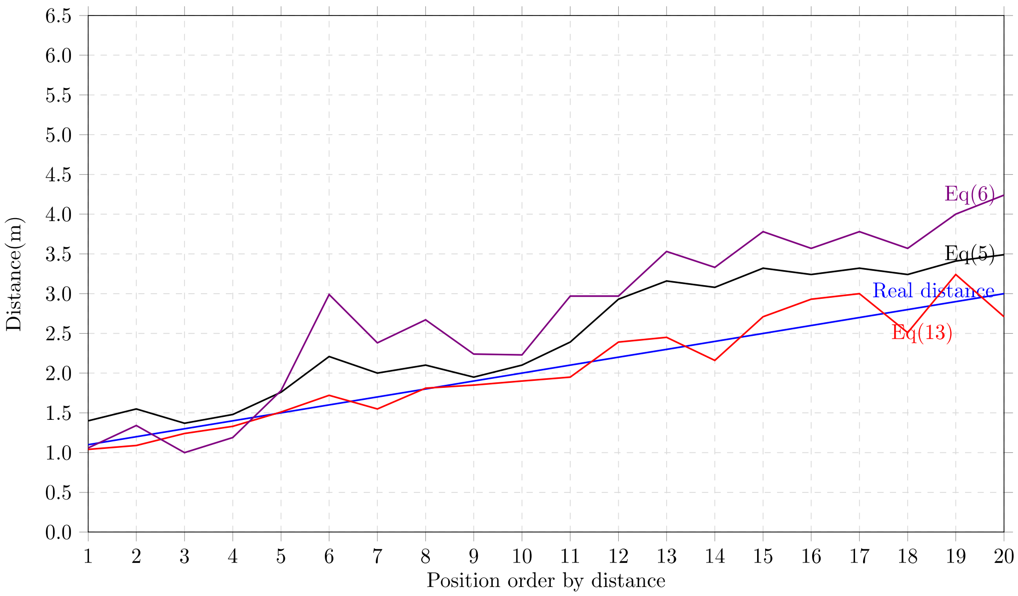

Fig. 3. Distance estimation comparison between the three algorithms

To evaluate the accuracy of the distance estimation, the absolute distance error is defined as:

$$\varepsilon = \frac{|d_{est} - d|}{d} \quad (14)$$

where d_{est} and d are the estimated distance and the real distance between the sender and the receiver, respectively. Figure 4 shows the estimated distance error ε of the three algorithms. Overall, the maximum ε values in distance estimation by (5), (6) and (13) are 0.38, 0.87 and 0.13, while average ε values are 0.20, 0.34 and 0.07, respectively. The proposed method (13) gives the most accurate result because it takes into account the influence of the weather conditions on the signal strength between two nodes. By using (13), average errors are reduced by ≈ 13% compared to (5) and 27% compared to (6). However, from observation, the accuracy of distance estimation decreases as the real distance d_0 increases. In Figure 3 and 4, when the real distance $d_0 \leq 2.5$ m, the estimation is relatively accurate, with the normalised distance error ε not exceeding 0.1. When d_0 expands more than 2.5, the ε values are greater than 0.1. The explanation for this trend is that at shorter distances, the signal is stronger with low fluctuations. Therefore, the probability of accurate distance estimation will be higher than that of longer distances.

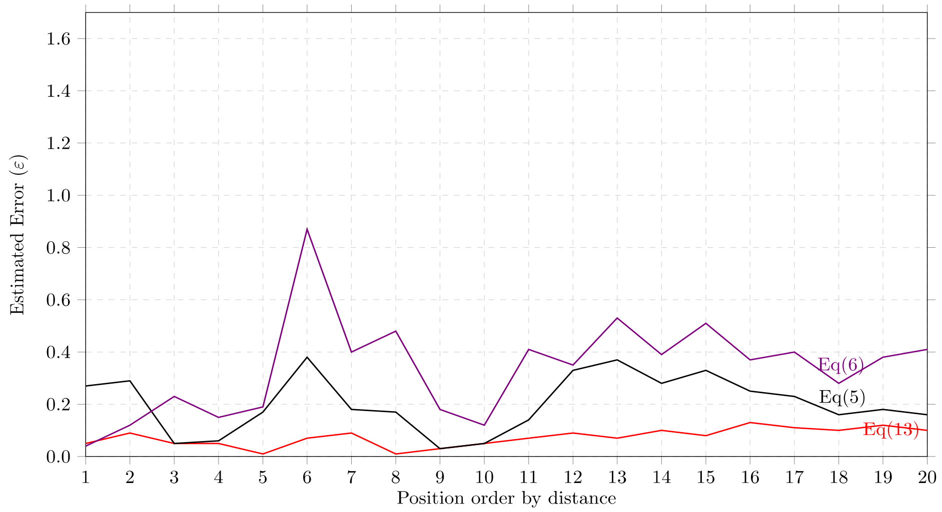

Fig. 4. Estimated error ε of the three algorithms

V. Conclusions

This study presents the distance estimation for temperature- and-humidity-variable environments. The measurements were made using Digi XBee S2 radio modules and RSSI values were recorded in different temperature and relative humidity values. The effect of temperature and relative humidity on RSSI was analyzed and the two factors were combined into the absolute humidity. Linear regression estimators were used to derive the proposed model based on the measured RSSI readings and the absolute humidity values. Based on this model, an estimation of the distance between the sender and receiver nodes was derived and compared to the previous models. The results of this work show an improved distance estimation by using RSSI measurements with temperature and humidity awareness for an indoor environment. Future work could extend to outdoor environments during different weather conditions. Moreover, it should investigate the effect of other factors such as varying the node density on the distance estimation error.

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