A Novel Indoor Ranging Algorithm Based on Received Signal Strength and Channel State Information*

Jing Jing Wang[1], Jun Gyu Hwang[2], and Joon Goo Park[3]

[1] Kyungpook National University,Electronics Engineering,Daegu, South Korea
wjj0219@naver.com
[2] Kyungpook National University,Electronics Engineering,Daegu, South Korea
cjstk891015@naver.com
[3] Kyungpook National University,Electronics Engineering,Daegu, South Korea
jgpark@knu.ac.kr

Abstract. With the increasing demand of location-based services, indoor ranging method based on Received Signal Strength Indicator (RSSI) or Channel State Information (CSI) has become an increasingly important technique due to its low hardware requirement and high accuracy. Due to robustness against the multipath effect, frequency domain Channel State Information (CSI) of Orthogonal Frequency Division Multiplexing (OFDM) systems is supposed to provide an excellent ranging measurement for indoor localization. In this paper, we propose a novel signal attenuation model for indoor ranging with RSSI and CSI. The proposed attenuation model scheme is implemented and validated with experiments in a typical indoor environment. Experimental results are presented to confirm that the proposed model can effectively reduce ranging error, compared with two existing methods in a typical indoor environment.

Keywords: Signal attenuation model · RSSI · CSI· indoor ranging.

1 Introduction

In recent years, the demand for location-based services (LBS)[1] has become more and more urgent with the rapid development of wireless communication technology. Therefore, it is important to study the indoor positioning technology. In order to accurately locate indoors, there are infrared, Bluetooth, ultrasonic, wireless sensor network (WSN), radio frequency tags, ultra-wideband (UWB) and wireless local area network (WLAN) Positioning technologies. WLAN-based positioning technology has become a research hotspot because of the widespread deployment and ease of use of WLAN.

* Supported by Smart City R&D project of the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant 18NSPS-B149843-01).

Due to the complex indoor environment, RSSI is often affected by multi-path effects and noise signals, and the positioning performance is not stable. With the availability of channel state information from the physical layer, Wi-Fi-based indoor positioning schemes have gradually shifted from adopting RSSI indicators to higher resolution CSI[3] indicators. In recent years, commercial Wi-Fi devices (such as the Intel 5300 wireless network card) have begun to support the acquisition of CSI at the physical layer. CSI can characterize signals with finer granularity. By analyzing the transmission of different sub-channel signals separately, CSI can avoid the effects of multipath effects and noise as much as possible. However, most current CSI-based ranging methods do not combine RSS information, thus reducing the computational resources required for ranging. Therefore, this paper uses the two different granularities of RSS and CSI to realize regional ranging and precise positioning respectively and make the best use of the advantages of different granularity information as much as possible. To improve the stability of the complex indoor environment and reduce the impact of environmental differences on positioning accuracy, this paper proposes a new indoor ranging method based on RSSI and CSI.

The rest of this paper is organized as follows. In section 2, we introduce related works. We illustrate the methodology of RSSI and CSI-based propagation model, respectively. Next is the proposed novel ranging model based on RSSI and CSI in Section 3 . The implementation of the novel model and experimental evaluations are presented in Section 4 . Finally, conclusions are presented and suggestions are made for future research in Section 5 .

2 RELATED WORKS

2.1 Difference characteristics between CSI and RSSI

RSSI is affected by multiple paths, so we hope to combine a new physical property CSI [4] to avoid the performance problem of RSSI in indoor positioning. This unique physical feature meets the following requirements:

(1) It has excellent resistance to interference in the 2.4 GHz band signal and has less fluctuation in a stable environment, and can reflect the changes in the environment;

(2) Using Orthogonal Frequency Division Multiplexing (OFDM) technology, signals of different paths can be distinguished as finely as possible.

CSI is a fine-grained attribute value of the physical layer that describes the amplitude and phase of the frequency domain corresponding to each subcarrier. The CSI can reflect the attenuation of the wireless signal as it travels between the transmitter and receiver. Table 1 demonstrates the difference between RSSI and CSI.

In this paper, RSSI values and CSI values are collected at fixed locations and the results of their effects on multipath effects were compared. The distance between these fixed locations and access points is 1 meter, 4 meters and 7 meters, respectively. Figure 1 shows the variation of the sampled RSSI value. Figure 2 shows the variation of the amplitude of the CSI sampled on channel 2.

Table 1. The difference between RSSI and CSI

Category	RSSI	CSI
Time resolution	Packet	Multipath signal cluster
Frequency resolution	None	Subcarrier
Stability	Low	High
Universality	All Wi-Fi devices	Some Wi-Fi devices

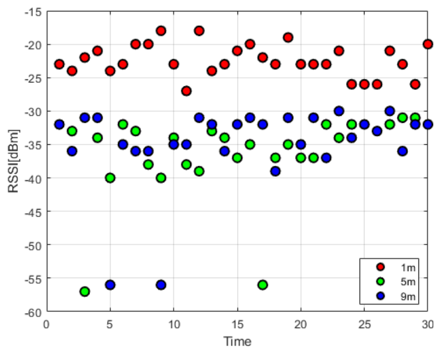

Fig. 1. The variation of the sampled RSSI value.

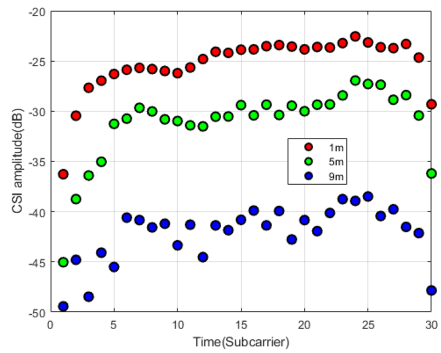

Fig. 2. The variation of the amplitude of the CSI sampled on channel 2.

Although the CSI value collected on a certain channel will change, the CSI value collected compared with the collected RSSI value varies little with time and remains basically stable.

2.2 RSSI-based ranging method

In a free-space model, the average received signal is in a logarithmic relationship with the distance d between the transmitter and receiver in all environments.The relationship can be expressed using the famous Friis formula[5]. Basically, a more general path loss model can construct using the environment-dependent signal attenuation factor to change the free-space path loss model. The mathematical expression of the signal attenuation log model is as follows:

$$RSSI = A - 10n\lg(\frac{d}{d_0}) + X_0 \tag{1}$$

Where, RSSI indicates the received signal strength indication value and the unit is dBm. A is the signal strength at 1 m from the source. 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. $X_{(0)}$ is the error correction term, subject to a normal distribution with 0 as the mean.. 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.

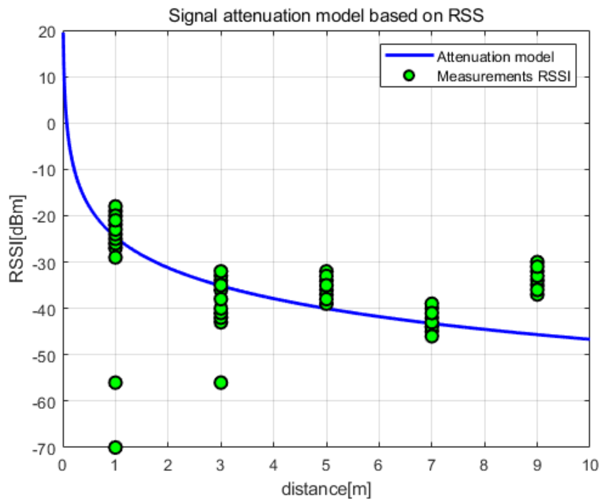

Fig. 3. RSSI-based Signal attenuation model for indoor ranging.

Figure 3 shows a signal attenuation model for indoor positioning. According to the received signal strength and the distribution of fixed nodes, the classical logarithmic distance attenuation model can be used to infer the distance between the current mobile node and each fixed node. Then the positioning is completed, and the distance (2) can be calculated.

$$d = 10^{\frac{A-RSSI}{10*n}} \tag{2}$$

In practical applications, an appropriate value of n is selected based on the actual measured wireless signal strength.

2.3 CSI-based ranging method

Currently, WLAN protocols such as 802.11n use Orthogonal Frequency Division Multiplexing (OFDM) technology and Multiple Input Multiple Output (MIMO) technology as their standard technologies. MIMO technology enables the diversity transmission and reception of signals. These two technologies play an important role in the formation of CSI data.Wu et al.[6] propossed a fine-grained indoor localization based on CSI data.FILA[6] weights the filtered CSI and normalizes the power to the center frequency in the band:

$$CSI_{eff} = \frac{1}{K}\sum_{k}\frac{f_k}{f_c} \times ||A||_k \tag{3}$$

where CSI_{eff} is the effective CSI for distance estimation. K is the number of subcarriers. f_c is the calculated center frequency, and $||A||_k$ is the amplitude of the filtered CSI on the kth subcarrier. The propagation distance between the transmitting end and the receiving end can be represented by effective channel state information.

$$d = \frac{1}{4\pi}[(\frac{c}{f_0 \times |CSI_{eff}|})^2\sigma]\frac{1}{n} \tag{4}$$

Where d is the distance between the transmitter and receiver in indoor environments c is the radio velocity, f_0 is the central frequency of CSI. n is the path loss attenuation factor, and σ is the environmental factor.

3 A NOVEL RANGING METHOD

For accurate ranging, this paper proposes a propagation model based on RSSI and CSI. Through analysis, it is found that even in the same indoor environment, the degree of attenuation of each signal transmission is different. Based on this, this paper defines a new indoor ranging model with excellent stability and can reflect environmental changes, based on which distance calculation is performed.

Compared with RSSI, CSI describes multipath propagation to a certain extent, and does not represent the superimposed amplitude response of all subcarriers like RSSI. The channel response of CSI not only reflects the amplitude of each subcarrier but also the phase information of the subcarrier. In this way, CSI expands the single-valued RSSI into a matrix composed of multiple information of multiple channels, so CSI provides richer and finer channel state information for wireless sensing. CSI benefits from multipath effects. In different propagation environments, subcarriers exhibit different amplitude and phase characteristics. In the same indoor environment, the multipath effect the RSSI and the characteristics of subcarriers remain relatively stable. Compared with the significant features, CSI maintains a steady trend.

The origal amplitude information is extracted from multiple antennas and multiple subcarriers of the IEEE 802.11n network interface card by accessing the modified device driver of the Intel Wi-Fi Wireless Link 5300. The indoor RSSI value and the CSI value and their corresponding distance measured data are collected, and then the average amplitude of the RSSI and CSI calibrated using the mean value filter is used for indoor ranging. A signal attenuation ranging model based on RSSI and CSI is established by using the attenuation factor propagation model, and the measured values of RSSI and CSI are converted into distance values by using the ranging model. According to Equation 2 and Equation 4, we propose a novel RSSI and CSI based ranging model:

$$d = a * 10^{\frac{A-RSSI}{10*n}} + (1-a)\frac{1}{4\pi}[(\frac{c}{f_0 \times |CSI_{eff}|})^2\sigma]^{\frac{1}{n}} \tag{5}$$

Where, $a \in [0, 1]$

Where c is the radio velocity, f_0 is the central frequency of CSI. a is the coefficient of the attenuation model, which varies according to the complex situation of the indoor environment. CSI_{eff} is the effective CSI, n is the path loss attenuation factor, and σ is the environmental factor. In fact, the parameters

n and σ pertain for each indoor scenario. We can fit the attenuation equation to find these two parameters. The parameters A is -23.84 and n is 2.206 in the proposed model. The value of a can be adjusted according to changes in the experimental environment.

4 EXPERIMENTAL RESULTS

The experiments were carried out in the third-floor corridor of Kyungpook National University IT1 Building, as shown in Figure 4.

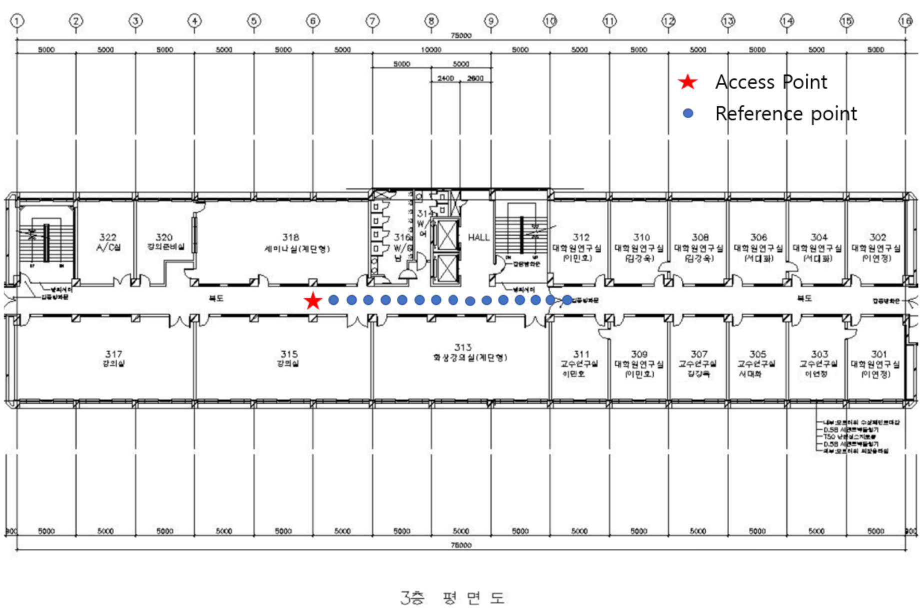

Fig. 4. Kyungpook National University IT-1 building.

Since the Intel 5300 is open source for the solution to obtain CSI data [7], this article gets the original CSI data by using the data acquisition module of the Intel 5300 wireless network card. The equipment required for the ranging solution is: (1) A laptop with an Intel 5300 installed, the operating system is Ubuntu 10.04 LTS, and the kernel and wireless network card drivers are customized; (2) an 802.11n wireless AP device. Connect the laptop to the Wi-Fi hotspot provided by the wireless AP, run a customized program on the notebook, and ensure that there is data traffic in the direction of the wireless AP to the laptop, and the CSI data of the physical layer can be obtained through the Intel 5300 wireless network card.

In experiments, we use ipTIME N3004 as a node and place it at the height of 0.2m on the ground. The reference node place on 0.2m high to reduce the impact of ground reflection on RSSI value and CSI value. An Intel 5300 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. Considered reference points are 2m apart sequentially to each other. At each reference point, 1000 times measurement process are executed. We calculate filtered mean RSSI values and filtered mean CSI values at reference points. After that, we obtain a proposed attenuation log model, which valid in range of 1m to 10m, as shown in Figure 5.

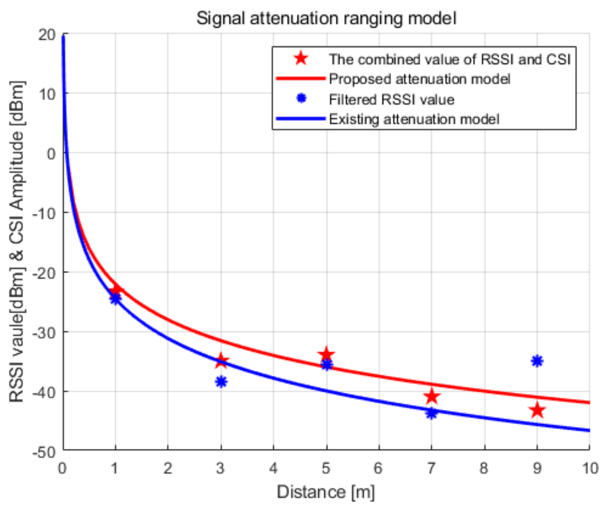

Fig. 5. Compared to the proposed ranging method and RSSI-based ranging method.

We compare the performance of the proposed attenuation model with that of an existing attenuation log model. We collected 20 data at each reference point for performance verification.Table2 shows the comparison of the distance measurement errors of the proposed method and exciting method.

Table 2. Comparison of the distance measurement errors of the proposed method and existing method

Distance (m)	Measure Distance of Mean Filtering Method(m)	Measure Distance of The Proposed Method(m)	Improved The Range Error(m)	Reduction rate (%)
1m	0.234	0.209	0.025	10.68%
3m	1.724	1.427	0.297	17.23%
5m	1.564	1.304	0.26	16.62%
7m	1.5	1.424	0.076	5.07%
9m	2.746	3.6545	0.092	3.33%

From Table 2, we can find that proposed RSSI attenuation log model provides more accurate distance information compared with an existing RSSI attenuation model. Experimental results show that range error decreases more evidently beyond the range of 9m. At the same time, the proposed method reduces the distance error at 1 meter reference point by 0.025m. At the same time, because the CSI is more stable in the indoor environment, the proposed ranging algorithm can improve the ranging stability. This method can ensure effective indoor ranging with a high probability.

5 CONCLUSION

In this paper, we propose a novel ranging model based on RSSI and CSI. 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. In summary, the main contributions of this article are as follows. First, a novel indoor ranging model combining channel state information with an attenuation factor model is obtained. Secondly, the use of ordinary notebooks and Intel 5300 network card does not require other specialized equipment to implement the proposed indoor positioning algorithm. And experiments have been carried out in a typical indoor environment, which has more significant advantages in accuracy and stability than traditional methods, and the system realizes lower cost and is accessible for popularization. In the future, we intend to study indoor fingerprint localization algorithms based on RSSI and CSI.

References

1. A. Küpper, Location-Based Services: Fundamentals and Operation. 2005.
2. M. Sugano, T. Kawazoe, Y. Ohta, and M. Murata, “Indoor Localization System Using Rssi Measurement of,” in Proc IASTED Int Conf WSN, 2006, vol. 7, pp. 54–69.
3. K. Wu, J. Xiao, Y. Yi, D. Chen, X. Luo, and L. M. Ni, “CSI-based indoor localization,” IEEE Trans. Parallel Distrib. Syst., 2013.
4. Q. Song, S. Guo, X. Liu, and Y. Yang, “CSI Amplitude fingerprinting-based NB-IoT indoor localization,” IEEE Internet Things J., 2018.
5. H. T. Friis, “A Note on a Simple Transmission Formula,” Proc. IRE, 1946.
6. K. Wu, J. Xiao, Y. Yi, M. Gao, and L. M. Ni, “FILA: Fine-grained indoor localization,” in Proceedings - IEEE INFOCOM, 2012.
7. Linux 802.11n CSI Tool Homepage, http://dhalperi.github.io/linux-80211n-csitool/index.html
8. D. Halperin, W. Hu, A. Sheth, and D. Wetherall, “Tool Release: Gathering 802.11n Traces with Channel State Information,” ACM SIGCOMM Comput. Commun. Rev., 2011.