무선 센서네트워크에서의 통계적 방법에 의한 실내 RSSI 측정

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Indoor RSSI Characterization using Statistical Methods in Wireless Sensor Network

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Abstract: In many applications, received signal strength indicator is used for location tracking and sensor nodes localization. For location finding, the distances between sensor nodes can be estimated by converting received signal's power into distance using path loss prediction model. Many researches have done the analysis of power-distance relationship for radio channel characterization. In indoor environment, the general conclusion is the non-linear variation of RSSI values as distance varied linearly. This has been one of the difficulties for indoor localization. This paper presents works on indoor RSSI characterization based on statistical methods to find the overall trend of RSSI variation at different places and times within the same room. From experiments, it has been shown that the variation of RSSI values can be determined by both spatial and temporal factors. This two factors are directly indicated by the two main parameters of path loss prediction model. The results show that all sensor nodes which are located at different places share the same characterization value for the temporal parameter whereas different values for the spatial parameters. Using this relationship, the characterization for location estimation can be more efficient and accurate.

Keyword: Spatial; Temporal; RSSI Characterization; Wireless Sensor Network;

I. Introduction

Wireless sensor network (WSN) has been widely used in many applications such as ubiquitous healthcare system. In ubiquitous computing research area, activity monitoring is one of the important studies especially patients' location tracking and hospital asset's localization. The basis of location tracking is the ranging technique that is used to measure the distances for trilateration estimation [1].

There are many ranging methods available to measure distances wirelessly. These ranging techniques include: Time of Arrival (TOA) [2], Time Different of Arrival (TDOA) [3] or Time of Flight (TOF), Received Signal Strength Indicator (RSSI) [4], and Incremental Stepping of Transmission Power [1].

Among these ranging techniques, TOA and TDOA are based on time measurement whereas RSSI and incremental stepping of transmission power are based on signal measurement. For time measurement, distance information can be calculated by assuming constant propagation velocity of acoustic wave and radio wave. Ultrasound transducer is used to generated ultrasound, thus required higher power consumption. For radio wave propagation time measurement, it requires long distance and high performance processors due to high propagation velocity of radio wave. Therefore, it is also not widely used in indoor localization of wireless sensor network.

Since RSSI and incremental stepping of transmission power ranging techniques control and measure the transmission and received power, it just employ the existing wireless communication facilities on the sensor node. Thus it gives the advantages of small size device and low power consumption. Both advantages fulfill the requirements of wireless sensor network implementation although less accuracy is provided. This problem can be reduced by applying various computational algorithms.

Incremental stepping of transmission power measure distance by slowly increasing its transmission power until receiver is able to detect the signal and reply to the transmitter. This method takes long time for radio signal communications. On the other hand, RSSI method directly measures the received power strength of data packet and converts the RSSI value to distance with minimum power consumption for ranging. Therefore, RSSI ranging is the most convenient and widely used method in wireless sensor network.

The challenge is that when RSSI is used in indoor environment for location estimation, the RSSI values are not exactly linearly related to distance [5]. This gives difficulty to convert the RSSI values to distance accurately. The challenge arises due to the complex and multipath propagation of radio signal in indoor environment. For each path, the radio wave may be reflected, transmitted, or absorbed by wall [6]. The resultant relationship between RSSI and distance becomes varying over space.

To solve the non-linearity problem of RSSI in indoor environment, statistical methods were used to analyse the characteristics of indoor RSSI values over distance over time. This paper presents the analysis results, which characterizes indoor environment with consideration of RSSI variation over space by observing the overall RSSI trend. Based on the characterization and analysis, ranging considerations were suggested for better parameters measurement and ranging accuracy.

II. Related Works

The study of ranging using RSSI is mainly focused on the characterization of radio signal propagation in indoor environment. Therefore, different experiments were done in different environments, and conditions. The effects that influence the radio propagation and the results of received signal strength measurement were studied in [5]. The experiments were carried out in an obstacle free indoor environment such as basketball court. The results show that the radio signal strength can be varied by several factors including transmission power variability, the receiver variability, and the antenna orientation. Useful conclusions for RSSI indoor ranging were extracted. It also helps to get better characterization of indoor environment.

Based on the characterization of indoor radio propagation characteristics, several ranging models have been developed uisng ray-tracing concept. An empirically based path loss model [7] was used to model and characterize indoor wireless channels in laboratory building. This work employs the typical path loss model with analysis on the effect from different floors. A more building considered model [8] with multi-wall and multi-floor radio wave transmission was developed by improving the typical path loss model. This model was tested in experiments to characterize environments with different wall materials such as concrete, brick, stone, wood, and glass. Recently a more detail model [6], [9] was developed for characterization. This model analyze the radio propagation based on the transmission and reflection effects of the wall and obtained about 15% improvement.

III. Characterization Model

In this paper, indoor RSSI characterization for radio channel was done and analysed using path loss prediction model [5], [7] as it is the most general and widely used model. From this model, the parameters used for characterization can be easily understood. In this model, the characterization is done in the actual power of received signal instead of RSSI values. Therefore, the RSSI values must be converted into the actual power received at the RF pin of the radio transceiver in dBm:

$$P = RSSI + RSSI_{offset} \tag{1}$$

where P represents the actual power received at the receiver after the radio signal propagates through a distance and attenuatend by path loss. $RSSI$ is the value recorded in the register of the radio transceiver. $RSSI_{offset}$ is found empirically from the front end gain and it is approximately equal to -45 dBm. This is to make sure that the received power has dynamic range from -100 dBm to 0 dBm, where -100 dBm indicates the minimum power and 0 dBm indicates the maximum power.

After the RSSI is converted to power, the distance between tranmisster and receiver can be estimated as shown in the following expression:

$$P_d = P_{d0} - P_{PL} \quad (2)$$

where P_d is the power received at distance d to the transmitter in dBm. P_{d0} is the power at a reference distance d_0 in dBm. Generally, the reference distance d_0 is selected as one meter away from the transmitter. P_{PL} is the path loss caused by various attenuations between the reference point and the receiver. It has a relationship with the total distance between transmitter and receiver d, and the reference distance d_0 as shown in the following expression:

$$P_{PL} \propto \left(\frac{d}{d_0}\right)^n \quad (3)$$

where n is the attenuation exponent or decay factor. Both the power at reference distance P_{d0} and attenuation exponent n are the most important parameters to characterize an environment. All characterization works in this paper are based on these two parameters.

Since the received power is in dBm, the standard path loss prediction model is also expressed in dBm as shown in the following expression:

$$P_d = P_{d0} - 10 \times n \times \log_{10}\left(\frac{d}{d_0}\right) \quad (4)$$

where d is the total distance between transmitter and receiver. After going through characterization process, the parameters n and P_{d0} are obtained. Using these parameters, the distance between tranmitter and receiver can be estimated by converting the received power to distance using the following expression:

$$d = d_0 \times 10^{\frac{P_{d0} - P_d}{10n}} \quad (5)$$

Ⅳ. Experimental Results and Discussion

For the following experiments, wireless sensor nodes are used as transmitter and receiver. The platforms of the wireless sensor nodes used in these experiments are Telos. The radio communication between sensor nodes is based on the IEEE 802.15.4 compliant Chipcon CC2420 radio in the 2.4 GHz band.

In order to characterize radio signal propagation model in a specific environment, and experiment has been done to measure the RSSI values and convert it to actual received power in dBm. The indoor environment is in an office building. In the indoor area, most of the wall materials are glass and concrete. There are some furnitures such as partitions, office tables and chairs inside the room. The experiments were done by putting stationary sensor nodes at fixed locations and transmit signal continuously from time to time. A mobile sensor node is located arbitrary around the indoor area as shown in Figure 1. After going through measurements, the relationship of received power and distance in this environment was obtained as shown in Figure 2.

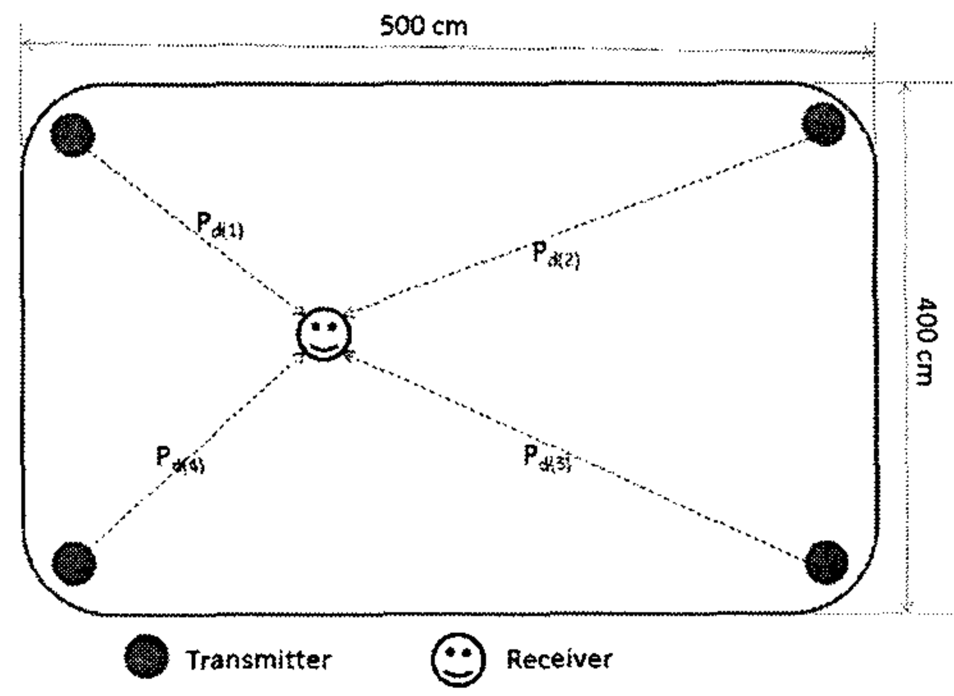

Figure 1: Allocation of stationary and mobile sensor nodes.

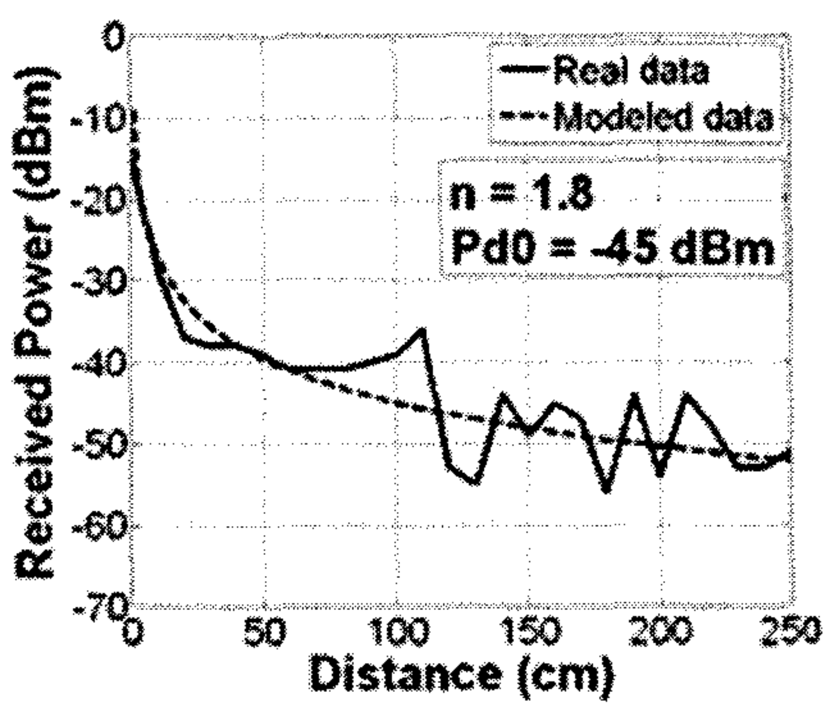

Figure 2: The relationship of received power and distance for Pd(1)

Figure 2 shows the received power of mobile sensor node from transmitter 1. When distance is increased, the received power decrease proportionally. A modeled data was plotted to compare with the real data by setting n = 1.8 and P_{d0} = -45 dBm. It can be observed that the best characterization distance is within 250 cm. If distance is longer, the decrease of power is slight. Therefore, characterization using the measurement data within 250 cm is enough for indoor applications.

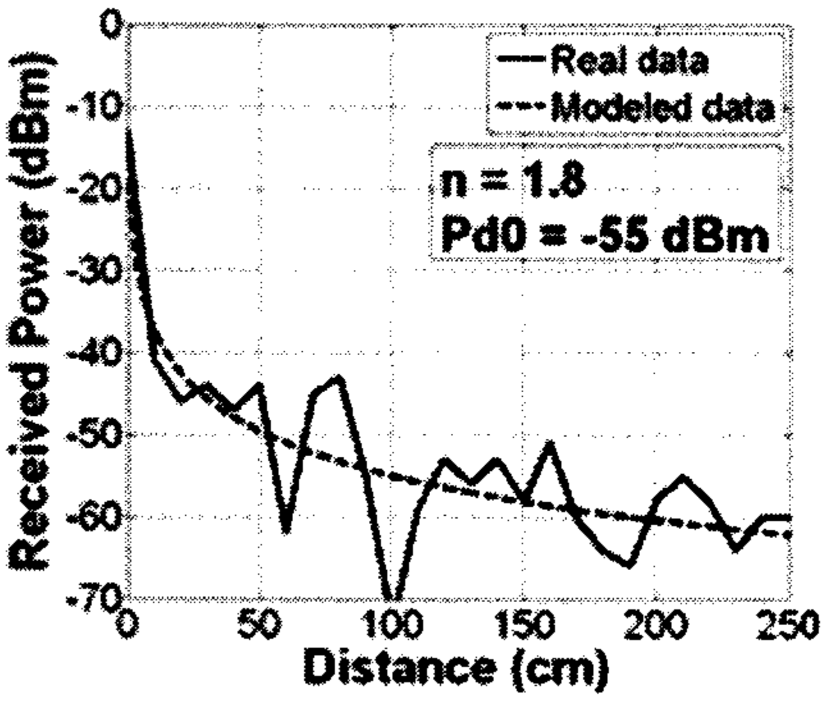

Figure 3: The relationship of received power and distance for Pd(2)

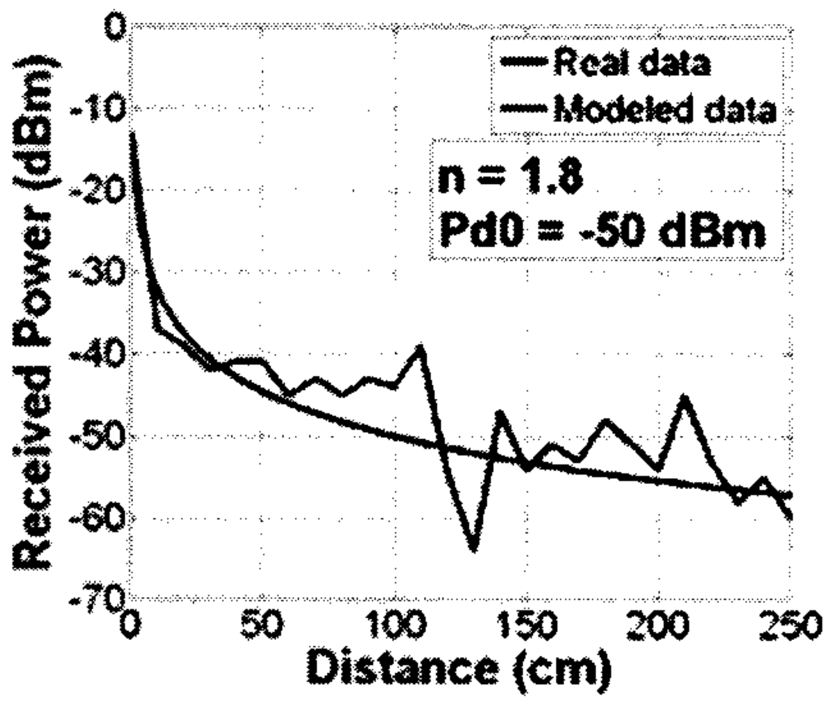

Figure 4: The relationship of received power and distance for Pd(3)

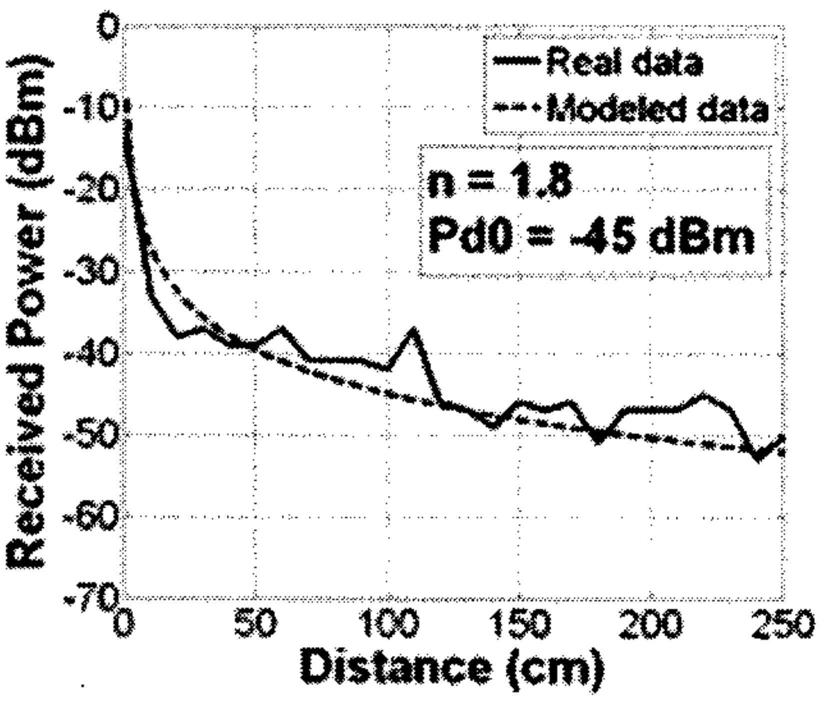

Figure 5: The relationship of received power and distance for Pd(4)

Figure 3, Figure 4, and Figure 5 show the received power of mobile sensor node from transmitter 2, 3, and 4. The modeled data is also plotted for each measurement. By comparing the received power from all the four directions: Pd(1), Pd(2), Pd(3) and Pd(4), the truth can be found by examining the characterization parameters for modeled data. For attenuation exponent *n*, the modeled data from all figures are using the same value, which is 1.8. However, the received signal P_{d0} at reference points are different. This proves that the received signal at reference point is a spatial parameter. This parameters vary depends on the location or direction of transmitter and receiver.

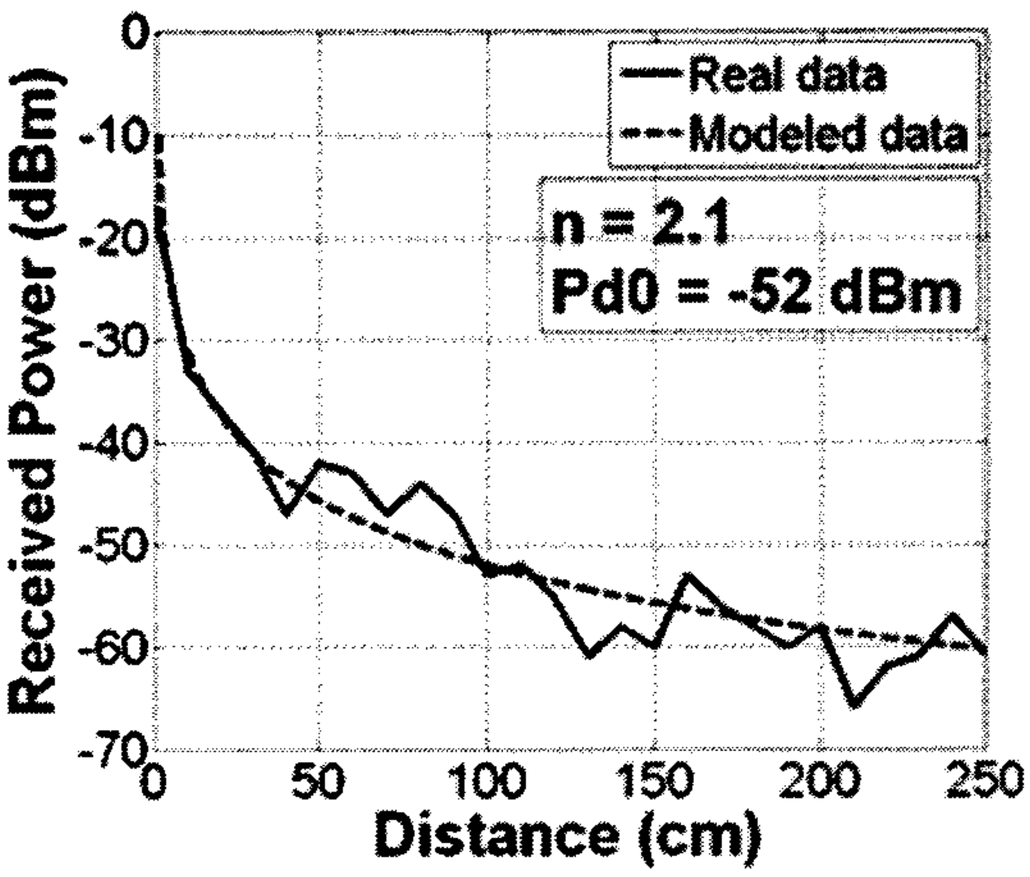

Figure 6: The measurement was done after a long time period

Figure 6 illustrates the measurement result obtained after a long period of time from measurement of the previous four cases in Figure 2 to 5. The modeled data was achieved to model the real data by setting n = 2.1 and P_{d0} = -52 dBm. By comparing Figure 6 with any of the figures from Figure 2 to 5, it can be found that the modeling parameter for attenuation exponent *n* is different. This prove that the radio channel is slowly time varying to this temporal parameter.

Based on this result, a discussion can be made for helping characterization procedure efficient and accurate. Most researches consider both the temporal and spatial parameters different in for each transmitter and receiver pair. If the location of receiver is changed, the characterization becomes invalid anymore. In addition, it is impractical to characterize the environment for each location of receiver to each location of transmitter.

In fact, the reason of getting different characterization values at different location in indoor environment is the enhancement and attenuation effects of radio signal strength at neighbor locations. The experiments show that the overall trend of received power from short distance to long distance is still consistent although it is varied over short distance spaces. Based on this concept, all transmitter and receiver should hold the same temporal characterization parameter. The only difficulty is to solve the received power variation over space for spatial parameters. Another truth is that the temporal paramters must keep tracking the channel's slowly time variation so that the estimation result is up to date.

Ⅴ. Conclusions

In this paper, statistical methods were used to analyze RSSI values collected from different directions, different locations of transmitter, and different locations of receiver. The experiments shown that the traditional characterization skill which employs two points measurement is not able to accurately describe the environment due to variation of RSSI values over space and time. The overall trend of RSSI decrement must be analyzed. From results observation, it has been shown that the characterization of environment should consider both temporal and spatial factors. For temporal factor, the characterization should keep tracking of the channel variation all the time while all sensor nodes from different locations should share the same temporal parameters. For spatial factor, the characterization should not based on just two points measurement. Instead, the overall trend of the RSSI is prefered by finding the moving average of the values.

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