A Multifloor Path-Loss Model for 433 MHz LoRa-WAN in Concrete Buildings

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***Abstract*—LPWAN (low power wide-area network) for smart building applications will benefit positioning, energy management system, parking and so on. This paper proposes a propagation model for LPWAN 433 MHz in two different concrete buildings, 5 story laboratory and parking buildings. The path loss model in terms of RSSI (received signal strength indicator) calculation uses empirical measurement data. The path-loss exponent for LoS propagation of the proposed prediction model is found to be 2.03 and 1.99. Again, for the NLoS propagation links, the floor attenuation factors (FAF) of 1 to 5 floors are found to be 6.0, 10.8, 13.9, 17.0 and 9.8, 14.0, 17.2, 21.5 for the first and the second buildings respectively**

Keywords*—RSSI measurement, 5 story building, empirical model, WSN

I. INTRODUCTION

Deployment of indoor WSN, can control energy consumption to improve the overall energy efficiency of buildings, however the presence of walls, floors and furniture will substantially contribute to a degradation of the radio communication systems performance, causing signal attenuation. This network communicate between its nodes using wireless technologies such as LoRa, zigbee, BLE, and many others. Data can then be sent to the sink node and finally to a server for further processing automatically. They not only have the ability to reduce deployment cost but also uses low-cost sensor node and no existing infrastructure. However, they also have disadvantages such as small energy capacity, path loss, data transmission problems from interference, delay, packet loss etc.

A. Background and Related Works

There are three types of indoor path loss models which are commonly used, namely empirical model, semi-deterministic model and deterministic model. The empirical models both LOS (corridor) and NLOS (with walls and/or floors) developed from intensive measurement at interesting frequencies are often used since they need only, path loss exponent (PLE) with distance to compute the path loss for network planning. The second type, the semi-deterministic models are also often used since they need not only the parameters of the empirical model but also require some information about the propagation path such as the wall attenuation factor (WAF) and the floor attenuation factor (FAF). These models provide an accurate path loss and also is easy to use. Finally, in the last type, the deterministic models need details of digitized maps and material of buildings including take a lot of time for computing. In order to meet the requirement, this research focus on the deterministic model. there are previous studies at ultra-high frequency (UHF) band. Rao T.R. et al. proposed path loss measurement at the frequencies of 433/868/915/2400 MHz in corridor of a multi-stories building. The results were compared with the other empirical models and a ray tracing model to verify the measurement [1]. Bobkov I. et al. studied the performance of WSN at the frequencies of 433/868 MHz in nine stories building with concrete floors and shown the higher percentage of received packets of 868 MHz WSN and a stronger signal of the 433 MHz Lora module [2]. Jafer E. et al. studied the RF noise and 24 hours spectral activity which were measured for 433/2400 MHz WSN at a research building. The results show signal quality during the day and the night time. Onykiienko Y., et al. proposed certain offset coefficients in order to calculate input power of the LoRa receivers. The coefficients were obtained experimentally for LoRa platforms at frequencies of 433 MHz, 868 MHz and 2.4 GHz [3].

B. Contributions

From the above related researches, it is found that RSSI vary according to the environment and uncertainty such as type of building, spreading factors, bandwidth and noise including the blockages between nodes. These make RSSI is fading and the communication is delayed or disconnected. Therefore, this research proposes a deterministic model for two specific concrete buildings, office and parking buildings. The buildings are mainly different with height of celling and floor structure.

To address these issues, the following contributions are made.

1) A deterministic path loss model with floor attenuation factor (FAF) for office and parking buildings.

2) The measured RSSI data are captured by LoRa LPWAN at a frequency of 433 MHz with specific spreading factor (SF) and bandwidth (BW) values.

In this paper, Section 2 presents path loss models for the multi-story indoor communication, Section 3 deals with experiment setup including equipment specification, building structure and measurement method. Section 4 reveals the path loss model results and discussions, and the finally part is the conclusion.

a) Floor and windows b) slab on bream

Fig. 1 Laboratory building

Fig. 2 Parking building

II. Path Loss Model

A. Same floor

An in-building propagation path loss model that includes the effect of building type as well as the variations caused by obstacles is given by [4]

$$PL\ (d) = PL(d_0) + 10n_{SF}\log\left(\frac{d}{d_0}\right) \qquad (1)$$

where $PL(d_0)$ is path loss at reference distance 1 meter from the transmitter [dB], n_{SF} is path loss exponent (PLE) for the same floor measurement and d is direct distance between the transmitting antenna and the receiving antenna [m].

B. Difference floors

The losses between floors of a building are determined by the external dimensions and materials of the building, as well as the type of construction used to create the floors (such as post tension flat slab, drop panel, waffle and so on) and the external surroundings. Even the number of windows in the building and the presence of tinting (which attenuates radio energy) can impact the loss between floors. The path loss on a difference floor can be predicted by adding an appropriate value of FAF (floor attenuation factor) in eq.(1).

$$PL\ (d) = PL(d_0) + 10n_{SF}\log\left(\frac{d}{d_0}\right) + FAF \qquad (2)$$

Alternatively, in eq.(2), FAF may be replaced by an PLE which already considers the effects of multiple floor separation.

$$PL\ (d) = PL(d_0) + 10n_{MF}\log\left(\frac{d}{d_0}\right) \qquad (3)$$

where n_{MF} is PLE on measurements through multiple floors.

In addition, Devasirvadathum, D.M.J., etc., al. [5] found that the path loss follows free space plus an additional loss factor which increases exponentially with distance by

$$PL\ (d) = PL(d_0) + 20\log\left(\frac{d}{d_0}\right) + \alpha d + FAF \qquad (4)$$

where α is the attenuation constant [dB/m].

Two difference types of building are considered, 1) laboratory building and 2) shopping mall parking for path loss measurement.

C. Laboratory building

The laboratory building of the Faculty of Engineering (Bld.# 2), Mahidol University was built in 1993. The experimental area consists of five floors with long mirror windows as shown in figure 1a). The construction of the floor is slab on bream as shown in figure 1 b). The height from the floor to the ceiling is about 3.5 m. Light plaster ceiling covering all air conditioners and service pipes, 2.6 m. height from the floor of Parking building.

D. Parking building

The mall's standalone car park was completed in 2015. It consists of eight floors. The construction of the modern building is post tension slab (no bream) and concrete columns as shown in figure 2 a). The floor to ceiling height is 2.25 m. The ceiling is smooth plastered ceiling, suspended ceiling, all air conditioners and air ducts as shown in figure 2b). The capacity about 100 car spaces per floor.

The propagation measurement device consists of a stationary 433 MHz LoRa module (transceiver and omni-directional antenna) with Arduino board as receiving station and a portable 433 MHz LoRa module transmitter. LoRa technology uses Chirp Spread Spectrum (CSS) technology, where chirps (also known as symbols) carry information. The number of chips per bit is known as spreading factor that influence on the path loss in multi-floor building. However, in this experimental, we focus on only wave propagation characteristics and path loss modeling therefore the spreading factor, SF 7 and bandwidth of 125 kHz BW were used for the best RSSI and time on air (TOA). The measured received signal strength indicator (RSSI) data were captured via a notebook computer at the receiving station. The portable was moved very 10λ trace at the same and difference floors. The parameters of equipment are summaries in Table 1.

III. Results and Discussion

A. LOS routes

The measured data for LOS routes are on the same floors in five story (with ceiling) of the laboratory building and top floor (no ceiling) of the shopping mall parking. Their path loss models are shown in figure 3 and 4 (LOS) together with eq. 5 and 6 respectively.

TABLE I. SUMMARY OF PARAMETER SET UP

No.	***Parameters***	***Value***	***Unit***
1	Tx power	14	dBm
2	Antenna gain	2.3	dBi
3	Frequency	433	MHz
4	Bandwidth (BW)	125	kHz
5	Spreading factor	7	-
6	Code rate (CR)	4/5	-
7	Antenna height	1.2	m
8	Separate distance	1- 40	m
9	Measurement trace	6.9 (10λ)	m

$$PL\,(d) = PL(d_0) + 10(2.03)\log\left(\frac{d}{d_0}\right) \quad (5)$$

And

$$PL\,(d) = PL(d_0) + 10(1.99)\log\left(\frac{d}{d_0}\right) \quad (6)$$

The LOS route for the laboratory building is in the corridor of five story where there are three dominant paths of waves including reflect wave from the ceiling and provides a PLE of 2.03 while the LOS route for the parking building is on the top of the building where there are only two dominant paths of waves, direct and reflect wave from ground and provides a PLE of 1.99 as shown in figure 3 and 4 respectively.

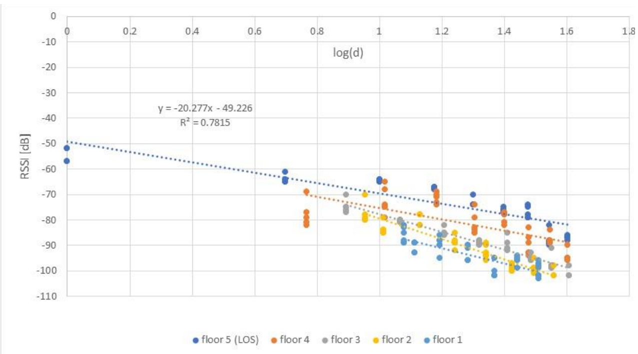

Fig. 3 LOS and NLOS for laboratory building

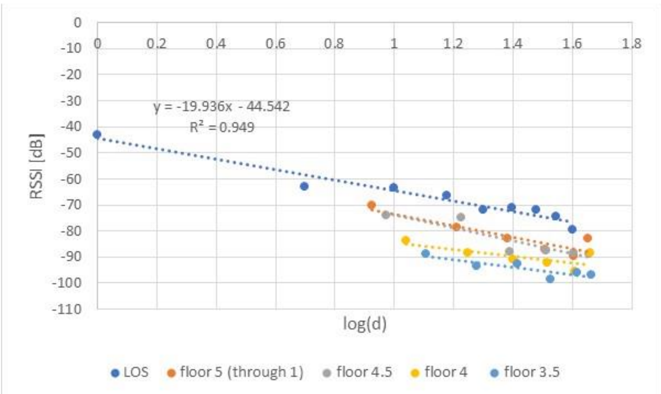

Fig. 4 LOS and NLOS for parking building

TABLE II. AVERAGE FLOOR ATTENUATION FACTOR

Building	FAF (dB)	σ (dB)	Number of locations
Laboratory:			
Through One Floor	6.0	3.16	9
Through Two Floor	10.8	3.15	9
Through Three Floor	13.9	2.8	7
Through Four Floor	17.0	2.53	6
Parking:			
Through One Floor	9.8	1.42	6
Through Two Floor	14.0	2.47	6
Through Three Floor	17.2	2.17	6
Through Four Floor	21.5	0.56	6

B. *NLOS routes*

The measured data for NLOS routes were performed through total four floors of the two buildings. The results of FAF are shown in figure 3 and 4 for laboratory and parking buildings respectively. The FAF values of parking building which was constructed from post tension slab are generally more than one of laboratory building which was constructed from slab and bream. This is because the post tension slab thickness is more than the slab and bream floor. Note that the parking building has way up and way down at the end of each floor. This make the radio waves travel to every measurement location as shown table 2.

IV. CONCLUSION

We propose characterize of LoRa 433 MHz frequency channels for wireless sensor networks in two different concrete buildings, 5 story laboratory and parking buildings. LoRa channel modeling in terms of RSSI, FAF and direct distance between the transmitting and receiving antennas. The path loss exponent for LoS propagation of the proposed prediction model is about 2.0 for buildings. In case of NLOS, the floor attenuation factors (FAF) through 1 to 4 floors of parking building is much more than the laboratory due to the post tension structure of the floors.

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