

Intelligent RF-Based Indoor Localization through RSSI of LoRa Communication Technology

Sittikorn Muekdang and Wimol San-Um

Abstract—Requirements on high-quality indoor localization approaches and the increase in ubiquitous computing and context-dependent have led to an emphasis on a continuous search for promising localization technologies and techniques. Typical RF-Based localization technologies such as Cellular, RFID, Bluetooth, Wi-Fi, Zigbee, and UWB have been widespread studied over the past decades. Recently, LoRa communication technology has suggested as a potential alternative to those of exiting wireless communication standards with low power consumption and low implementation costs. This paper therefore presents an indoor localization technique through the use of Received Signal Strength Indicator (RSSI) of LoRa Technology. The LoRa chip from SEMTECH was implemented on a compact board with built-in antenna. The Arduino microcontroller was employed as a core processor with a step-down switching regulator. Five sets of LoRa nodes were implemented and four of which were utilized as statistic nodes, radiating a signal power from 5-meter high from the floor. The receiving node is placed in a particular coordinate on the floor. The RSS values were employed as inputs for Artificial Neural Network (ANN) for estimation of the coordinate of the receiving node. The accuracy was approximately 95%. The result provides satisfactory accuracy with cost-effective and low-power operation as for an alternative for large scales deployments of indoor localization.

Index Terms—Indoor localization, LoRa technology, received signal strength indicator, artificial neural network.

I. INTRODUCTION

An “Indoor Positioning System: IPS” generally provides a position or location of people or required objects in a closed physical space continuously and in real-time. Particularly, indoor positioning is emphasized in the fact that that the object has been moved from place to place.

“Localization”, however, emphasizes the fact that positioning is conducted in an ad-hoc and cooperative manner, and highlights that the application requires topological correctness of sensor locations whilst the absolute coordinate position is of minor importance. Localization is generally associated with rough estimation of location for optimal accuracy systems.

Unlike an “Outdoor Positioning System: OPS” in which the Global Positioning System (GPS) can suitably be utilized efficiently, the research area in indoor localization

has continuously been of much interest through both existing and emerging communication technologies due to the need for various applications such as location based services in indoor environments, medical care, environmental monitoring, guiding of the vulnerable people, or augmented reality. As a consequence of such applications, design and development of efficient indoor localization should consider some essential quality metrics involving, for instance, (i) accuracy and precision, (ii) coverage and resolution, (iii) latency in making location updates, (iv) infrastructure impacts, and (v) effects of random errors caused by signal interference and reflections.

Over the past decades, numerous approaches for IPSs have been proposed based on a variety of RF-based communication technologies such as Cellular (GSM/GPRS) [1], RFID [2], Bluetooth [3], Wi-Fi [4], Zigbee [5], UWB [6] and LoRaWAN [7]. Table I summarizes technological specification of communication technologies for IPSs. It can be considered in Table I that the cellular-based indoor localization relies on the mobile cellular network, remarkably the wireless telephone technology Global System Mobile (GSM) communication. Such cellular-based system generally estimates mobile user position in building with low accuracy, but power consumption is relatively high and the signal strength is based on a cell site under the main infrastructure. Consequently, indoor localization based on cellular network has received less attention than those of non-cellular based systems.

It is also seen in Table I that the Radio Frequency Identification (FID), which operates at a frequency 13.6 MHz, has been recognized as one of a potential technology for locating objects or people. RFID typically enables a one-way communication via noncontact and advanced automatic identification through radio signals. RFID consumes low power, and has widely been utilized a wide range of applications such as automobile assembly industry, warehouse management, supply chain network. However, RFID provides low data transfer rate and operates in a short range lower than one meter, a number of RFID tags is required and a complicated networks is ultimately required to be designed properly. Alternatively, Bluetooth, Wi-Fi, and ZigBee technologies that operate at 2.4 GHz with different protocols have also been utilized for indoor localization.

Bluetooth offers information exchange between devices with high security, low cost, low power, and small size. However, device discovery procedure is reiterated in each location finding, resulting in the increase in localization latency and power consumption and leading unsuitable for real-time operations. The Wi-Fi-Based localization system is one of the most widespread approaches for indoor

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localization due to the fact that Wi-Fi is embedded in most mobile devices without installing extra software or manipulating the hardware.

The drawback of Wi-Fi-Based localization system is reliance on Wi-Fi location in building and signal attenuation caused by the static environment or movement of furniture and doors, resulting in low-accuracy localization. ZigBee is another wireless technology standard which provides short and medium range communications with low-power consumption but do not require large data throughput. Although it is possible for a communication distance of 100 m. for Line-of-Sight operation, the coverage range for in indoor environments could possibly be only 20m -30m due to obstacles in static indoor environment. As ZigBee

operates in the unlicensed ISM bands, it is therefore relatively vulnerable to interference from a wide range of signal types using the same frequency which can disrupt radio communications. In summary, several techniques for the enhancement of indoor localization based on such Bluetooth, Wi-Fi, and ZigBee technologies have been proposed in order to increase accuracy and precision, coverage and resolution, latency, and effects of random errors caused by signal interference and reflections [8]. As a consequence, a hybrid positioning system, which is defined as systems for determining the location by combining several different wireless technologies, have been suggested as an alternative solution for indoor localization quality enhancement [9].

TABLE I: COMPARISONS OF TECHNICAL SPECIFICATIONS ON RF-BASED COMMUNICATION TECHNOLOGY FOR INDOOR LOCALIZATION

Specifications	(i) Cellular Communications	(ii) Non-Cellular (Ad-Hoc and Peer-to-Peer Communications)					
		RFID	Bluetooth	Wi-Fi	ZigBee	UWB	LoRa
1. Standard	GSM/GPRS	IEEE 802.15.1	IEEE 802.15.1	IEEE 802.11n	IEEE 802.15.4	IEEE 802.15.6	LoRaWAN
2. Operating Frequency	900/1800 MHz	13.56 MHz	2.4 GHz	2.4/5 GHz	2.4 GHz	3.1GHz-10.6GHz	430/433/868/915 MHz
3. Maximum Distance	30km (LR)	1m (SR)	30m (MR)	50m (MR)	100m (MR)	10m (SR)	5km(UA), 15km(SA), (LR)
4. Data Rate Transfer	10 Mbps (High)	50 Mbps (Low)	1-3 Mbps (Medium)	54 Mbps (High)	250 kbps (Low)	55-410 Mbps (High)	50 kbps (Low)
5. Transmission Current (mA)	500-1000 mA (High)	15 mA (Low)	35 mA (Low)	238 mA (High)	32 mA (Low)	55 c mA (Medium)	25 mA (Low)
6. Operation Time 2000-mAh Battery	2-4 Hr. (SOT)	133 Hr. (LOT)	57 Hr. (LOT)	8.4 Hr. (SOT)	62 Hr. (LOT)	36 Hr. (LOT)	80 Hr. (LOT)

*LR=LONG RANGE, MR=MEDIUM RANGE, SR=SHORT RANGE, UA=URBAN AREA, SA=SUBURBAN AREA, SOT= SHORT OPERATION TIME, LOT= SHORT OPERATION TIME

TABLE II: SUMMARY OF LoRa COMMUNICATION PERFORMANCE CONFIGURATION IN FINE-TUNE PHYSICAL LAYER

Configurable Setting	Values	Effects
1. Bandwidth	125...500 kHz	Higher bandwidths allow for transmitting packets at higher data rates (1 kHz = 1 kbps), but reduce receiver sensitivity and communication range.
2. Spreading Factor	$2^6 \dots 2^{12}$ Chips/Symbol	Bigger spreading factors increase the signal-to-noise ratio and hence radio sensitivity, augmenting the communication range at the cost of longer packets and hence a higher energy expenditure.
3. Coding Rate	4/5...4/8	Larger coding rate increase the resilience to interference bursts and decoding error at the cost of longer packets and higher energy expenditure.
4. Transmission Power	-4...20 dBm	Higher transmission powers reduce the signal-to-noise ratio at the cost of an increase in the energy consumption of the transmitter.

Recently, LoRa, in Table II which stands for “Long Range”, is a promising long-range wireless communications system, fostered by the LoRa Alliance [10]. LoRa has been designed as a long-lived battery-powered device, where the energy consumption is of paramount importance. Typically, LoRa can be distinctly classified into two layers: (i) a physical layer using the Chirp Spread Spectrum (CSS) radio modulation technique and (ii) a MAC layer protocol (LoRaWAN). The LoRa physical layer, developed by Semtech, allows for long-range, low-power and low-throughput communications. It operates on the 433-, 868- or 915-MHz ISM bands, depending on the region in which it is deployed. The payload of each transmission can range from 2–255 octets, and the data rate can reach up to 50 Kbps when channel aggregation is employed. The modulation technique is a proprietary technology from Semtech.

LoRaWAN provides a medium access control mechanism, enabling many end-devices to communicate with a gateway using the LoRa modulation. While the LoRa modulation is proprietary, the LoRaWAN is an open standard being developed by the LoRa Alliance.

This paper therefore studies an indoor localization technique through the utilization of Received Signal Strength Indicator (RSSI) of LoRa Technology. The methodology employs five sets of LoRa nodes and four of which were utilized as statistic nodes, radiating a signal power from 2-meter high from the floor. The receiving node is placed in a particular coordinate on the floor. The RSSI values were employed as inputs for Artificial Neural Network (ANN) for estimation of the coordinate of the receiving node. The LoRa frequency is 915 MHz and the microcontroller is Arduino Pro-Mini that processes all

signals with Lithium-Ion Battery.

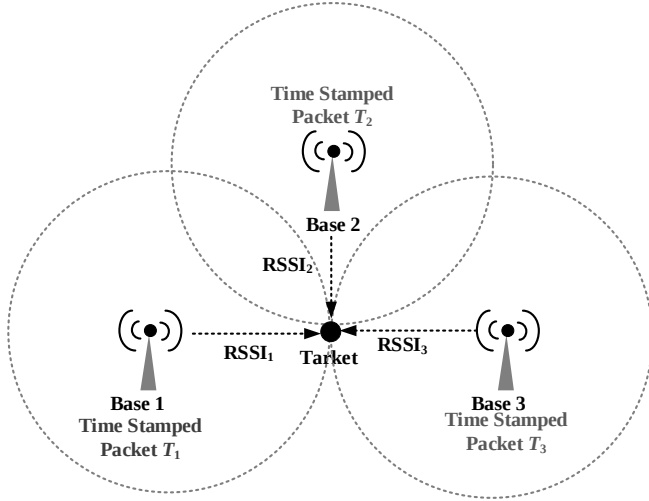


Fig. 1. A generic visualization of indoor positioning techniques with three base stations, demonstrating both RSSI and time stamped packets.

II. REVIEWS ON TYPICAL INDOOR LOCALIZATION APPROACHES

Several wireless technologies have been realized for indoor localization approaches, depending on performances and also limitation of mathematical models for location estimation. Typically, major performance metrics associated with localization systems involve the following areas, i.e. (i) an accuracy that can be described as an error distance between estimated and actual locations, (ii) The responsiveness that determines speed of updating time of estimated location, (iii) coverage that determined the network coverage under a designated area of localization, (iv) adaptiveness which refers to an ability of the localization system to cope with environmental influence changes that affect to overall system performances, (v) Scalability in which a localization system can potentially operates with a larger number of location requests and a larger coverage, and (iv) cost and complexity, which are on of practical concerns, involving extra infrastructure, additional bandwidth, money, lifetime, weight, energy, and nature of deployed technology. Based upon the above mentioned performances and suitability of localizing environments, this paper particularly summarizes indoor localization approaches with two categories, i.e. proximity and triangulation [5], [11].

A. Proximity Detection Approach

Proximity detection is the simplest positioning method for implementing localization of a target. This method provides relative position between a target and a cell of origin, such as GSM, RFID, or Bluetooth, with known position and limited range. Typically, this method detects the target via the nearest position where the strongest signal is received. In recent years, this method has been deployed using beacon with short-range communications. However, the proximity-based method has a high variance which may not satisfy the need for localization.

B. Triangulation

Triangulation utilizes geometric properties of triangles to

determine the target location, which typically has two derivations, i.e. angulation and lateration. On the one hand, angulation method refers to as Angle-of-arrival (AoA) method which determines the angle of arrival of the signal receiving from a known location at which it is received at multiple base stations. Geometric relationships can subsequently be utilized in order to estimate the location of the intersection of line angles. Although the angle of signal can be retrieved straightforwardly through directional antenna technology, the angle of stations may not exactly be the angle of received single due to the existence of multi-path and environmental reflections.

On the other hand, lateration method refers to a position determined from distance measurements obtained from multiple reference points. Fig. 1 demonstrates a generic visualization of indoor positioning techniques with three base stations, demonstrating both time stamped packets and RSSI. It can be considered from Fig. 1 that lateration methods can be classified into two types, including (i) time-based triangulation, and (ii) RSSI-based triangulation. General techniques for time-based triangulation are generally Time-of-Arrival (ToA) which directly measures time stamped packet transmitted from base stations or versa vice. Meanwhile, Time Difference of Arrival (TDoA) is a measure between multiple pairs of reference points with known locations and exploits relative time measurements at each receiving node in place of absolute time measurements. Besides, Received Signal Strength (RSS) as also shown in Fig. 1 has been used to represent received signal property. The distance can be obtained and the location can be calculated based on by receive signal strength property.

III. RECEIVED SIGNAL STRENGTH

Received Signal Strength Indication (RSSI) typically refers to as a measurement of the power existent in a received radio signal. The RSSI values are generally measured in dBm and have typical negative values ranging from 0 to approximately -120 dBm, which is a noise floor. As wireless Radio Frequency (RF) signals traverse air, a number of effects, such as noises and air resistance, directly affect signal degradation, resulting in attenuation of a received power. Based upon the standard definitions of terms for antennas, i.e. IEEE Standard 145-1993 [1], the Free-Space Path Loss (FSPL) can be modeled as

$$P_R = P_T \left(\frac{\sqrt{G_R} G_T \lambda}{4\pi d} \right)^2 \quad (1)$$

where P_R is a received power, P_T is a transmitted power, G_R is a transmitting antenna gain, G_T is a receiving antenna gain, λ is a signal wavelength, and d is the distance between the two antennas. Eq. (1) can also be described in Decibel (dB) as follows:

$$P_R [\text{dBm}] = P_T [\text{dBm}] - 20 \log_{10}(d) - 20 \log_{10} \left(\frac{4\pi}{\lambda} \right) \quad (2)$$

It should be noted that real model of (2) should involve a signal loss caused by shadowing effect, which is a result of

fluctuations in measurements due to various disturbances such as interference from transmissions, weather effects or scattering. This paper therefore proposes the RSSI-based triangulation through the use of fingerprint database technique for indoor localization.

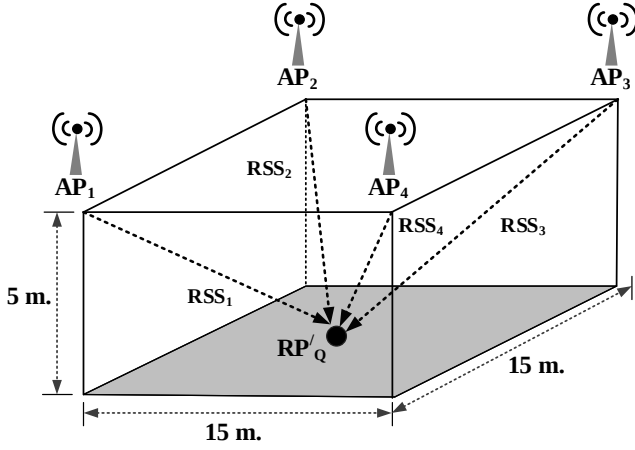


Fig. 2. System model geometry and area coverage, involving four APs and a single target in a reference point RP_Q .

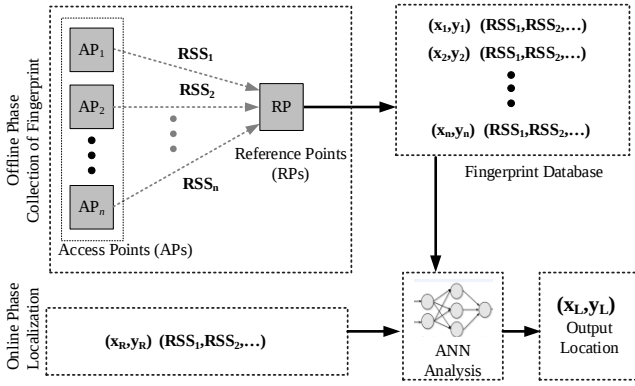


Fig. 3. The overall architecture of the proposed RSSI-based indoor localization using LoRa technology with fingerprinting database.

IV. PROPOSED RSSI-BASED INDOOR LOCALIZATION USING LoRa TECHNOLOGY WITH FINGERPRINT DATABASE

Fig. 2 depicts system model geometry and area coverage, involving four APs and a single target in a reference point RP_Q . The designed system employs four Access Points (APs) which are all LoRa transmitters. A single receiving module RP_Q is also a LoRa receiver located at a particular Reference Points (RPs). The width and length of a floor are 15m. and 15m., respectively, and hence the area is 225 m². The height of those four APs is 2m. The coordinate (x,y) is 1m². Fig. 3 shows the overall architecture of the proposed RSSI-based indoor localization using LoRa technology with fingerprinting database. It can be considered from Fig. 3 that location fingerprinting comprises off-line and the on-line phases. The off-line phase constructs a map for the targeted area, and coordinates of RPs are designated. Subsequently, RSS values received from each RP from all APs are collected and stored in a fingerprint database. In the on-line positioning phase, the unknown position of a target is estimated Artificial Neural Network (ANN) which has been trained by a fingerprint database. In this paper, RSS probability distributions of all APs at all RPs are required to

be stored for training ANN. The fingerprint of the i^{th} RPs can be defined as follows:

$$R_i = \begin{bmatrix} P(A_1 T_1 | L_i) & P(A_2 T_1 | L_i) & \cdots & P(A_N T_1 | L_i) \\ P(A_1 T_2 | L_i) & P(A_2 T_2 | L_i) & \cdots & P(A_N T_2 | L_i) \\ \vdots & \vdots & \ddots & \vdots \\ P(A_1 T_M | L_i) & P(A_2 T_M | L_i) & \cdots & P(A_N T_M | L_i) \end{bmatrix} \quad (3)$$

where $A_n, n=1 \cdots N$, is the n^{th} of AP, T is the measurement of RSS, L_i is i^{th} RP, and P can be expressed as follows;

$$P(A_1 T_M | L_i) = \frac{C_{T_m}}{N_i} \quad (4)$$

where N_i is the total number of training samples collected at the i^{th} RP, and C_{T_m} is the number of T_m appearing in the training data at the i^{th} RP. Consequently, the fingerprint database D is given by

$$D = [R_1, R_2, \dots, R_w] \quad (5)$$

where w is the total number of RPs in the coverage area. In addition to fingerprinting database, this work alternatively employ ANN instead of other common techniques such as database matching or search algorithm. The supervised learning ANN with Back-Propagation Learning Algorithm was chosen for training the database D . Fig. 4 shows the structure of a realized ANN for determining the location of an output coordinate (x, y) . It is apparent in Fig. 4 that the four inputs are RSS_1 to RSS_4 , which are normalized to be in a region of (0,-1) dBm. The optimized hidden layer comprises 30 nodes and the two output nodes provide the coordinate (x,y) .

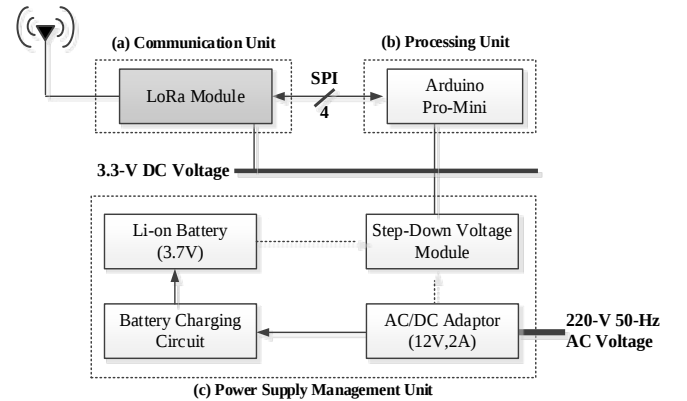


Fig. 4. Block diagram of LoRa module equipped with Arduino Pro-Mini, and Regulator, and a built-in antenna.

V. CIRCUIT DESIGNS AND EXPERIMENTAL RESULTS

A. Circuit and System Designs

The proposed LoRa module has been designed as a stand-alone device, which can be equipped with other microcontroller. Fig. 4 shows the block diagram of the proposed LoRa End-Node. It can be seen from Fig.4 that the

end-node comprises a LoRa Module with built-in an antenna. This LoRa module is connected to the Arduino Pro-Mini that processes all signals both inputs and outputs. The power supply system is a Lithium-Ion Batter (3.7V) that connects to a battery charger module TP4056, which supplies a power to a step-down voltage regulator module of 3.3V.

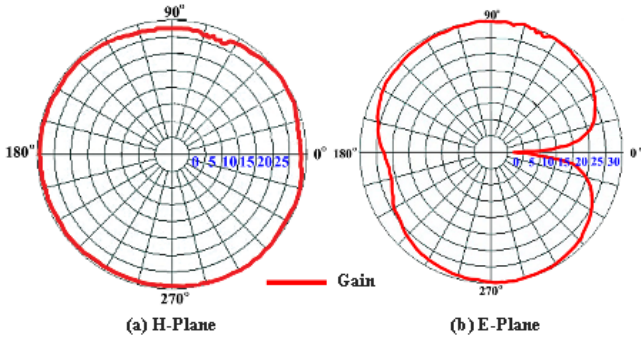


Fig. 5. The radiation pattern of an antenna: (a) H-Plane, (b) E-Plane.

Table III summarizes technical specifications of circuit modules. The LoRa is apparently not only offers high efficiency of +14 dBm but also minimizing current consumption of 9.9 mA. In particular, the LoRa module provides high dynamic range RSSI of 127 dB with whilst excellent blocking immunity, which is suitable for indoor localization. It is also seen in Table III that the antenna is a typical for LoRa communication at a center frequency of 915 MHz and the gain is 2-dBi with a maximum Voltage

Standing Wave Ratio (VSWR) of two. In accordance to the antenna, Fig. 5 depicts the radiation pattern of an antenna both in H-plane and E-plane. As the polarization is vertical, the directivity in H-plane provides a full gain of approximately 40 dBi in all direction whilst the gain drops to zero for E-plane at 0° . The experiment shall be carefully considering a vertical polarization in order to receive a RSS properly. Finally, Table III also indicates that the Arduino Pro-Mini MEGA328P was chosen as a processing unit with 14 digital I/O pins and 6 analog input pins and sufficient memory for application in indoor localization, i.e. Flash Memory of 32kB, SRAM of 2 kB, and EEPROM of 1 kB. Fig. 6 illustrates the assembled two-layer circuit prototype of the LoRa-based communication module with built-in monopole antenna. As for experiment on indoor localization 5 boards were assembled, four of which will be employed as APs and one for RP.

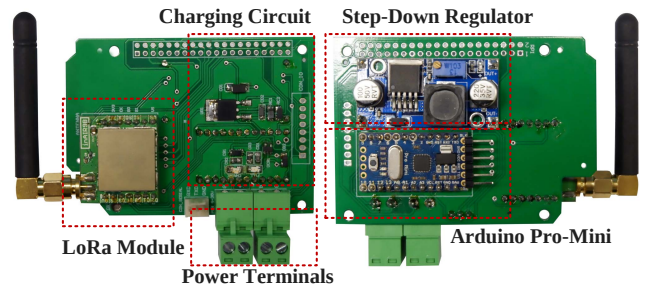


Fig. 6. The assembled two-layer circuit prototype of the LoRa-based communication module with built-in monopole antenna.

TABLE III: TECHNICAL SPECIFICATION OF CIRCUIT MODULES

Circuit Modules	Specifications
LoRa Chip SX1276/77/78	168 dB maximum link budget +20 dBm - 100 mW constant RF output vs. Supply +14 dBm high efficiency PA Programmable bit rate up to 300 kbps High sensitivity: down to -148 dBm Bullet-proof front end: IIP3 = -11 dBm Excellent blocking immunity Low RX current of 9.9 mA FSK, GFSK, MSK, GMSK, LoRaTM and OOK 127 dB Dynamic Range RSSI
Antenna ANT-RA57-915	890-915MHz, Center Frequency at 915 MHz 2-dBi Gain VSWR ≤ 2 Vertical Polarization 50- Ω Impedance
Arduino Pro-Mini MEGA328P	Operating Voltage at 3.3V or 5V 14 Digital I/O Pins and 6 Analog Input Pins Flash Memory of 32kB SRAM of 2 kB EEPROM of 1 kB

B. Evaluations of Reliability of LoRa Communications

Preliminary evaluation of the LoRa communication module was conducted at Thai-Nichi Institute of Technology where the gateway was installed at the 6th floor of C-building with a height of 550 meters. Fig. 7 shows a physical map for testing signal strength with an increment of 100 meters. The performances were investigated by RSSI, which is usually expressed in dBm from 0 to approximately lowest at -120 dBm. In addition, Signal-to-Noise Ratio (SNR) defined as the ratio of signal power to the noise power has also been investigated. Fig. 8 shows plots of

measured RSSI in dBm and SNR in dB versus a distance. The RSSI decreased from 0 to around -90 dBm within the first 100 meters. From the distance of 100 meters to 500 meters, the values of RSS decreased from -90 dBm to approximately -100 dBm before signal lost. Meanwhile, the SNR is positive till the distance of around 160 meters and the SNR was then decreases to -18 dB at 500 meters. Such results indicate that the LoRa communication is reliable with satisfied SNR values for further implementations. As mentioned earlier, the width and length of a floor are 15m. and 15m., respectively. Therefore, the overall performance is sufficient for indoor localization implementation.



Fig. 7. Test for signal strength coverage area at C-Building of Thai-Nichi Institute of Technology.

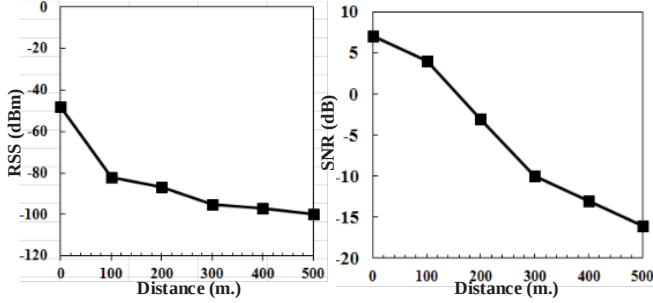


Fig. 8. The measured RSSI in dBm and SNR in dB versus a distance.

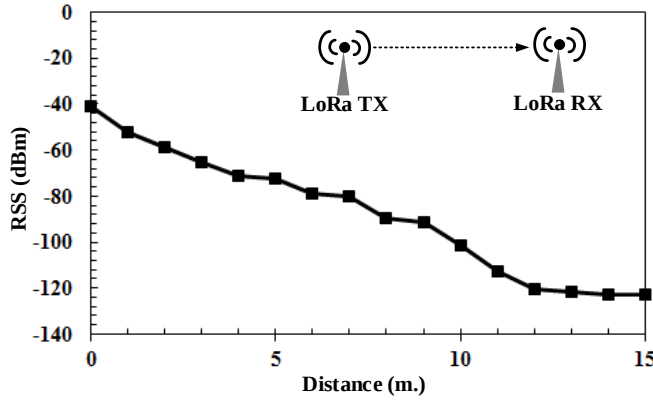


Fig. 9. Plots of RSS versus a distance for one-to-one communication tests.

C. Experimental Results for Indoor Localizations

The proposed indoor localization system has been conducted based on the system model depicted in Fig. 2. First, a one-to-one communication using two LoRa modules was investigated in terms of RSS for evaluating a characteristic curve of RSS values versus a distance as shown in Fig. 9. The plots reveal that the values of RSS decreases from -40dBm to approximately -120dBm over an entire distance range of 15 meters. The characteristics is relatively linear with sufficient different in RSS values, and therefore it can be concluded that the utilization of RSS from LoRa technology is applicable for indoor localization within 15 meters.

Second, each of location in the coverage area was recorded as a fingerprint database, and it was trained by ANN. Fig. 10 shows ANN-Based Indoor Localization with output processing system. The system comprises 255 module of trained ANN in order to distinguish each location where the output system determines the location. The ANN is a back propagation and each block was trained with customized number of hidden nodes with a golden error of less than 10^{-3} . Activation functions of a hidden layer is a

sigmoidal function while the output function is a piecewise-linear function, i.e. $f(x) = 0$ for $x < 0$, $f(x) = 0$ for $0 < x < 1$ and $f(x) = 1$ for $x > 1$. The output activation function assists a precise location on the area of experiments.

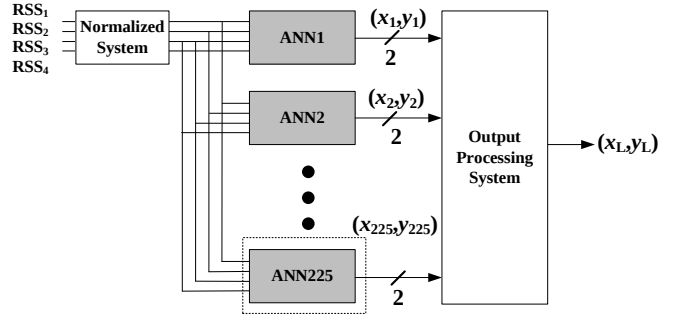


Fig. 10. ANN-Based Indoor Localization with output processing system.

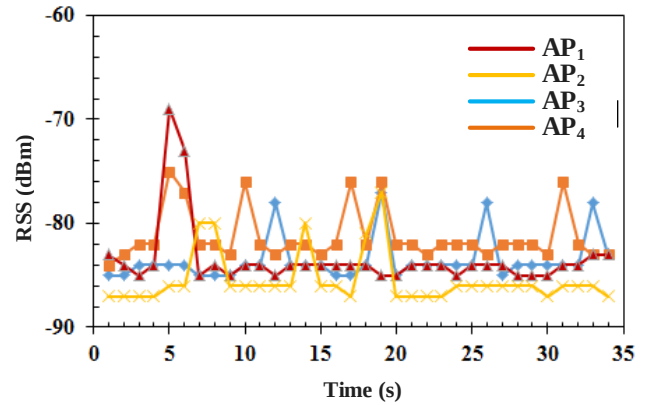


Fig. 11. Examples of a received RSS in dBm of the four APs in time-domain.

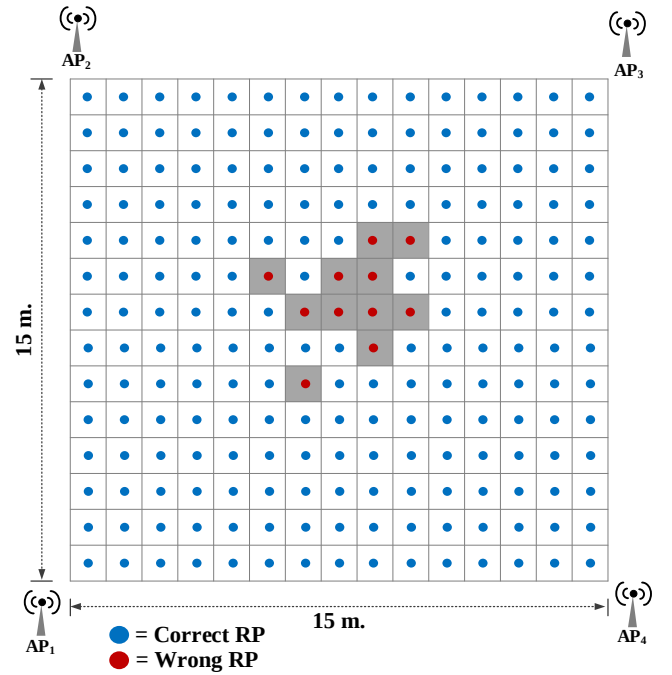


Fig. 12. Results of correct and wrong indoor localization over 15 m^2 .

Third, Fig. 11 depicts Examples of a received RSS in dBm of the four APs in time-domain at a particular location. It can be seen in Fig. 11 that the RSS are relative different. As a result, Fig. 12 illustrates correct and wrong indoor localization over 15 m^2 . There are 11 locations that the proposed system cannot be localized and there in a middle

of an area. This is because of close values of RSS received from the four APs. Therefore, the error is 4.88%, yielding the accuracy of 95.22%.

VI. CONCLUSIONS

This paper has introduced an indoor localization technique through the use of Received Signal Strength Indicator (RSSI) of LoRa Technology. The LoRa chip from SEMTECH has been implemented on a compact board with built-in antenna. The Arduino microcontroller was employed as a core processor with a step-down switching regulator. Five sets of LoRa nodes were implemented and four of which were utilized as statistic nodes, radiating a signal power from 5-meter high from the floor. The localization has exploited 255 module of trained ANN in order to distinguish each location. The resulting error the error is 4.88%, yielding the accuracy of 95.22%. The result provides satisfactory accuracy with cost-effective and low-power operation as for an alternative for long-range deployments of indoor localization.

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