TACTICAL TROOPS TRACKING SYSTEMS TOPOLOGY
USING LORAWAN COMMUNICATIONS

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Field of Study	Engineering Technology
Thesis Advisor	Asst. Prof. Dr. Wimol San-Um

The Graduate School of Thai-Nichi Institute of Technology has been approved and accepted as partial fulfillment of the requirement for the Master's Degree

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PANSATHORN LEKBUNYASIN: TACTICAL TROOPS TRACKING SYSTEMS TOPOLOGY THROUGH LORAWAN COMMUNICATIONS ADVISOR: ASST. PROF. DR. WIMOL SAN-UM, 66 PP.

This thesis presents the deployment of a LoRaWAN communication system as an Internet-of-Things (IoT) for military applications. Such a LoRaWAN system is a relatively new wireless IoT connectivity, and is well suitable for supporting services and applications that require long-range communication to reach end devices. In addition, the LoRaWAN system consumes low power supply and can be operated several years remotely using only on single battery storage. In contrast to short-range or cellular connections, the LoRaWAN system is a promising technology for military applications in terms of highly-secured location-based tracking, and this paper consequently applies to intelligent tactical troop tracking systems. The proposed system comprises the cost-effective gateway using Raspberry-Pi, a microcontroller as a central processing unit with Global Positioning System (GPS) and other sensors for and physical tracking. The proposed system employs four gateways with bridge-to-bridge WiFi connection for communication to the server. The end devices can be integrated more than ten types of sensors such as GPS, temperature, humidity, and water sensors. Knowledge on the exact location of troops and any coalition troops in an area of operational interest can be visualized real-time at base station. The proposed system offers not only essential information for effective tactical decisions but also potentially leads victory in a battle filed.

Graduate School Student's Signature……………………….

Field of Study Engineering Technology Advisor's Signature……………………….

Academic Year 2019

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Pansathorn Lekbunyasin

Table of Contents

Table of Contents (Continued)

List of Table

List of Figures

List of Figures (Continued)

Chapter 1
Introduction

1.1 Introduction

This thesis presents the deployment of Low Power Wide Area Network (LoRaWAN) communication system as an Internet-of-Things (IoT) for military applications. Such a LoRaWAN system is a relatively new wireless IoT connectivity and is well suitable for supporting services and applications that require long-range communication to reach end devices. In addition, the LoRaWAN system consumes low power supply and can be operated several years remotely using only on single battery storage. In contrast to short-range or cellular connections, the LoRaWAN system is a promising technology for military applications in terms of highly-secured location-based tracking, and this paper consequently applies to intelligent tactical troop tracking systems. The proposed system comprises the cost-effective gateway using Raspberry-Pi, a microcontroller as a central processing unit with Global Positioning System (GPS) and other sensors for and physical tracking. The proposed system employs four gateways with bridge-to-bridge WiFi connection for communication to the server. The end devices can be integrated more than ten types of sensors such as GPS, temperature, humidity, and water sensors. Knowledge on the exact location of troops and any coalition troops in an area of operational interest can be visualized real-time at base station. The proposed system offers not only essential information for effective tactical decisions but also potentially leads victory in a battle filed.

1.2 Background

Internet of Things (IoT) has been initiated from enabling connectivity on edge devices and providing new services which have not been available with reasonable cost. Key challenges in the realization of IoT systems and applications are to minimize both edge nodes deployment and maintenance costs. It is because the number of required edge nodes is much higher than that of hand-held devices. Wireless communication protocols, which are specially designed for IoT applications, can minimize the hardware complexity and power consumption of edge nodes. Furthermore, cloud technology providing the common service frameworks can reduce maintenance cost of IoT systems.

Table 1.1 The place of LoRaWAN in IoT wireless connectivity ecosystem.

	(ii) Local Area Network for Short-Range Communications	**(ii) Low Power Wide Area (LPWAN) for Internet-of-Tings**	**(iii) Cellular Network for Machine-to-Machine**
Ratio Use	40%	45%	15%
Advantages	Well Established Standard	Low Power Consumption Low Cost	Existing Coverage High Data Rate
Disadvantages	Battery Live Time, High Cost	Emerging Standard	Autonomy, High Cost
Examples	4.0 Bluetooth Wi-Fi	LoRa	3G 4G

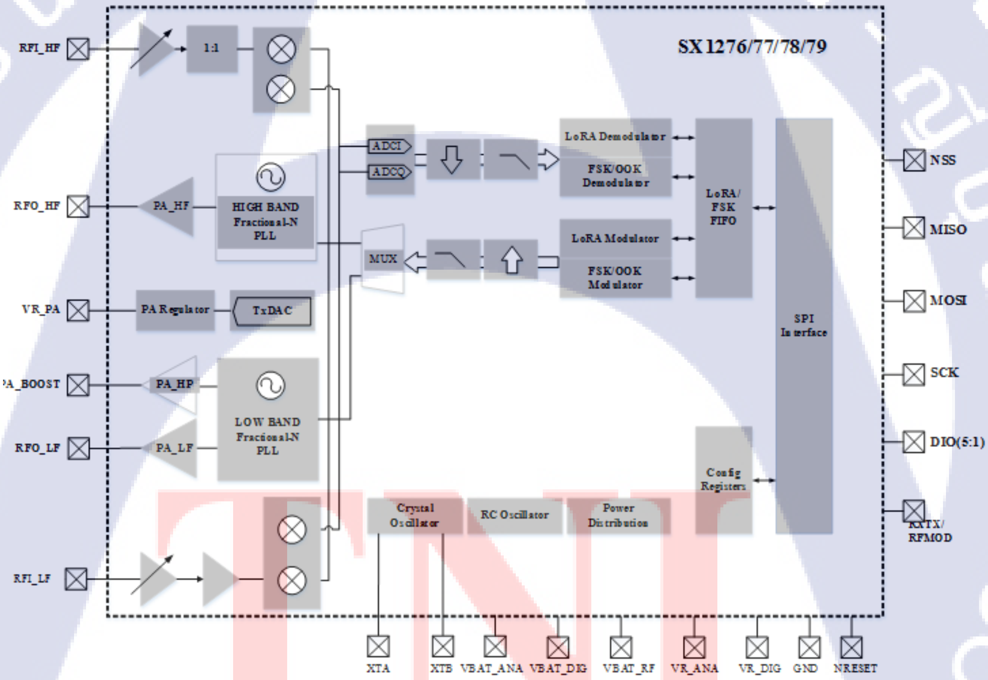

Figure 1.1 The block diagram of a low-power long-range tranciever module SX1276/77/78/79, operating at 137 to 1020 MHz.

Table.1.1 shows the place of LoRaWAN in IoT wireless connectivity ecosystem whilst Fig.1.1 demonstrates the block diagram of a low-power long-range transceiver module SX1276/77/78/79, operating at 137 MHz to 1020 MHz. In accordance to possible communication ranges, two wireless communication protocols can be classified into two categories, i.e. (i) short-range and (ii) long-range communication protocols. On the one hand, WiFi, Zigbee, and Bluetooth represent the short-range communication protocols, which are suitable for indoor environments. On the other hand, long-range communication protocols can be deployed using LoRa communications. Typically, LoRaWAN has three classes of end-point devices to address different needs reflected in wide range of applications as follows; First, class A or a bi-directional end-device in which end-devices allow for bi-directional communications whereby each end-device uplink transmission is followed by two-short downlink receives windows. This class A operation is the lowest power end-device system for applications that require downlink communication from the server shortly after the end-device has sent an uplink transmission. Second, class B or a bi-directional end-device with scheduled receive slots. Such a class B device opens extra receive windows at scheduled times. In order for the end-device to open receive window at the scheduled time it receives a time synchronized Beacon from the gateway. This allows the server to know when the end-device is listening. Last, class C or a bi-directional end-device with maximal receive slots in which end-devices have nearly continuously open receive windows, only closed when transmitting.

Table 1.2 compares LoRaWAN specifications on different regional spectrum allocations and regulatory requirements. It is apparent that the specification for Europe and North America are well-defined. However, other regions, involving China, Korea, Japan, India, and Thailand, are still being defined by the technical committee. Particularly, Thailand allows a frequency of 433 MHz as a licensed frequency, but the National Broadcasting and Telecommunication Commission (NBTC) is now considering an approval for a frequency band of 920-925MHz. in order to avoid an overlap with GSM band.

Table 1.2 Different regional spectrum allocations and regulatory requirements.

	Europe	North America	China	Korea	Japan	India	Thailand
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz	433MHz, 920-925MHz
Channels	10	64+8+8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by National Broadcasting and Telecommunication Commission
Channel BW Up	125/250kHz	125/500kHz					
Channel BW Dn	125kHz	500kHz					
TX Power Up	+14dBm	+20dBm type (+30dBm allowed)					
TX Power Dn	+14dBm	+27dBm					
SF Up	7-12	7-10					
Data rate	250bps-50kbps	980bps-21.9kpbs					
Link Budget Up	155dB	154dB					
Link Budget Dn	155dB	157dB					

1.3 Motivation

The internet of things is the interconnection via the internet of computing devices embedded in everyday objects, enabling them to send and receive data. Recently, there are many applications of internet of thing for example, smart city, smart industrial, Smart Farming and this thesis focus on Smart Military.

1.4 Objective

Design of communication systems between nodes and gateways for military by LoRa Technology.

1.5 Research Plan

The research schedules in Jun 2017 until July 2018.

Table 1.3 Research Plan

Research Methodology	Year													
	2017							2018						
	6	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Study about LoRa technology and LPWAN														
2. Study about communication system between node and gateway.														
3. Design and build communication systems between nodes and gateways.														
4. Experimental and data collection.														
5. Analysis and summary of the experimental result including the conclusion.														
6. Summary of research and presentation.														

1.6 Keyword Descriptions

<u>1.6.1 Tactical Troop Tracking System</u>

A tracking system is generally a system capable of rendering virtual space to a human observer while tracking the observer's coordinates. For instance, in dynamic virtual auditory space simulations, a real-time head tracker provides feedback to the central processor, allowing for selection of appropriate head-related transfer functions at the estimated current position of the observer relative to the environment.

1.6.2 LoRa Technology

LoRa is a 'Long Range' low power wireless standard intended for providing a cellular style low data rate communications network. LoRa is ideal for providing intermittent low data rate connectivity over significant distances. The radio interface has been designed to enable extremely low signal levels to be received, and as a result even low power transmissions can be received at significant ranges. The LoRa modulation and radio interface has been designed and optimized to provide exactly the type of communications needed for remote IoT and M2M nodes.

1.6.3 Received Signal Strength Indication

RSSI, or "Received Signal Strength Indicator", is a measurement of how well device can hear a signal from an access point or router. It's a value that is useful for determining if you have enough signal to get a good wireless connection.

1.6.4 Artificial Neural Network

An artificial neuron network (ANN) is a computational model based on the structure and functions of biological neural networks. Information that flows through the network affects the structure of the ANN because a neural network changes - or learns, in a sense - based on that input and output. ANNs are considered nonlinear statistical data modeling tools where the complex relationships between inputs and outputs are modeled or patterns are found. ANN is also known as a neural network.

1.6.5 Signal to noise ratio (SNR)

The Signal to noise ratio (SNR) is defined as the average over time of the peak signal divided by the RMS noise of the peak signal over the same time. In order to get an accurate result for the SNR it is generally required to measure over 25-50 time samples of the spectrum.

1.6.6 Received Signal Strength Indicator (RSSI)

Received Signal Strength Indicator (RSSI) is a measurement of how well your device can hear a signal from an access point or router. It's a value that is useful for determining if you have enough signal to get a good wireless connection.

Chapter 2
Related Theories and Literature Reviews

2.1 Related Theories

2.1.1 LoRaWAN Technology

LoRaWAN™ defines the communication protocol and system architecture for the network while the LoRa® physical layer enables the long-range communication link. The protocol and network architecture have the most influence in determining the battery lifetime of a node, the network capacity, the quality of service, the security, and the variety of applications served by the network as can be seen in Figure 2.1.

2.1.1.1 Network Architecture

Many existing deployed networks utilize a mesh network architecture. In a mesh network, the individual end-nodes forward the information of other nodes to increase the communication range and cell size of the network. While this increases the range, it also adds complexity, reduces network capacity, and reduces battery lifetime as nodes receive and forward information from other nodes that is likely irrelevant for them. Long range star architecture makes the most sense for preserving battery lifetime when long-range connectivity can be achieved as can be seen in Figure 2.2.

In a LoRaWAN™ network nodes are not associated with a specific gateway. Instead, data transmitted by a node is typically received by multiple gateways. Each gateway will forward the received packet from the end-node to the cloud-based network server via some backhaul (either cellular, Ethernet, satellite, or Wi-Fi). The intelligence and complexity are pushed to the network server, which manages the network and will filter redundant received packets, perform security checks, schedule acknowledgments through the optimal gateway, and perform adaptive data rate, etc. If a node is mobile or moving there is no handover needed from gateway to gateway, which is a critical feature to enable asset tracking applications–a major target application vertical for IoT.

<table>
<tr><th colspan="5">Application</th></tr>
<tr><th colspan="5">LoRa® MAC</th></tr>
<tr><td colspan="5">MAC options</td></tr>
<tr><td colspan="2">Class A
(Baseline)</td><td>Class B
(Baseline)</td><td colspan="2">Class C
(Continuous)</td></tr>
<tr><th colspan="5">LoRa® Modulation</th></tr>
<tr><td colspan="5">Regional ISM band</td></tr>
<tr><td>EU 868</td><td>EU 433</td><td>US 915</td><td>AS 430</td><td>-</td></tr>
</table>

Figure 2.1 Built on the LoRa® PHY, the LoRaWAN media access control (MAC) defines the message formats for different device classes

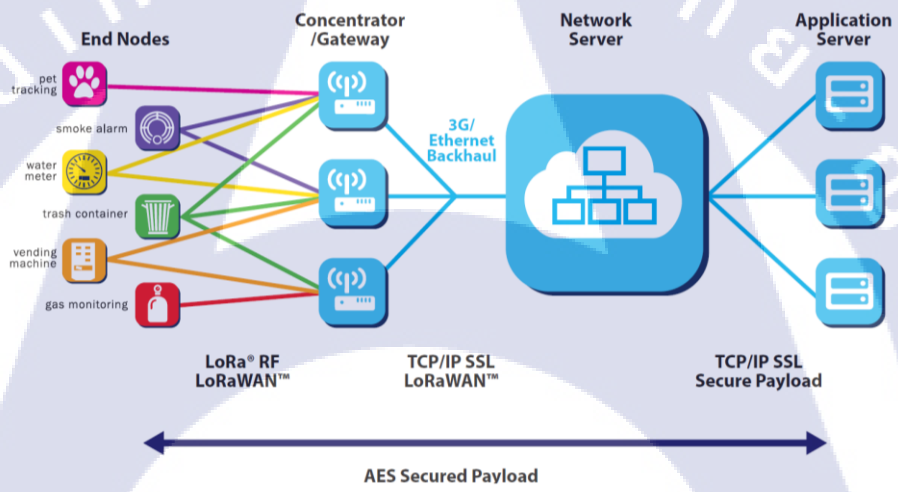

Figure 2.2 The LoRa network architecture

A typical LoRa® network is "a star-of-stars topology", which includes three different types of devices, as shown in Figure 2.3.

The basic architecture of a LoRaWAN network is as follows: end-devices communicate with gateways using LoRa® with LoRaWAN. Gateways forward raw LoRaWAN frames from devices to a network server over a backhaul interface with a higher throughput, typically Ethernet or 3G. Consequently, gateways are only bidirectional relays, or protocol converters, with the network server being responsible for decoding the packets sent by the devices and generating the packets that should be sent back to the devices. There are three classes of LoRa® end-devices, which differ only with regards to the downlink scheduling. A Study of LoRa®: Long Range & Low Power Networks for the Internet of Things.

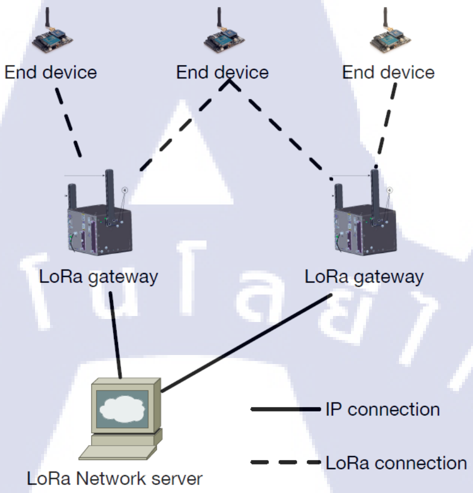

Figure 2.3 The basic architecture of a LoRaWAN network

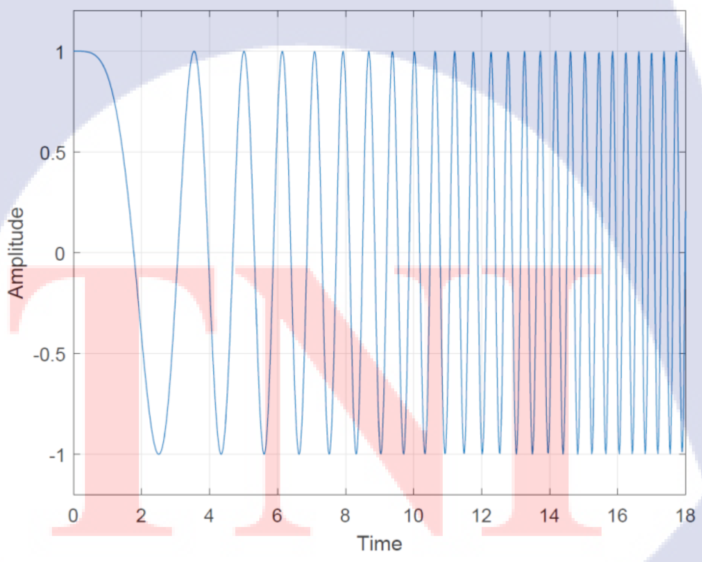

Figure 2.4 Visualization of the up-chirps used in the LoRa® modulation

2.1.1.2 Modulation

The key enabling factor in the LoRa® modulation standard. The LoRa® modulation uses a proprietary Chirp Spread Spectrum (CSS) scheme, which creates wideband linear frequency modulated chirps. The chip rate of these chirps are equal to the spectral bandwidth of the signal and uses 125, 250 or 500 kHz of bandwidth. The gains of using CSS are twofold, the first being that chirps are noise resistant and the second that these chirps can be generated with high precision using a cheap crystal, which leads to low chip costs. Because of the relative broadband characteristics of the chirps, multi-path fading is typically not an issue [1]. Doppler spread causes a frequency shift, which also only have a small effect on the channel thanks to the time-varying frequency of the chirps. as shown in Figure 2.4.

The frequency increases as a linear function of time using the LoRa® modulation, 15 km of range can be achieved in urban environment and up to 30 km with good line-of-sight. Additionally, LoRa® uses a Frequency-Hopping Spread Spectrum (FHSS) scheme to switch frequency between available channels according to a pseudo-random distribution. This helps to further mitigate interference.

A key thing to note with the CSS modulation scheme is that it produces a very sharp peak when auto-correlated, and has previously been deployed in radar applications [2]. The high peak helps to identify the correct time that the signal is received, and thus can be used to give a good estimate of the time it takes for a transmission to travel between two nodes.

2.1.1.3 Network Capacity

In order to make a long-range star network viable, the gateway must have a very high capacity or capability to receive messages from a very high volume of nodes. High network capacity in a LoRaWAN™ network is achieved by utilizing adaptive data rate and by using a multichannel multi-modem transceiver in the gateway so that simultaneous messages on multiple channels can be received. The critical factors effecting capacity are the number of concurrent channels, data rate (time on air), the payload length, and how often nodes transmit. Since LoRa® is a spread spectrum-based modulation, the signals are practically orthogonal to each other when different spreading factors are utilized. As the spreading factor changes, the effective data rate also changes. The gateway takes advantage of this property by being able to receive multiple different data rates on the same channel at the same time.

2.1.1.4 Device Classes

End-devices serve different applications and have different requirements. In order to optimize a variety of end application profiles, LoRaWAN™ utilizes different device classes. The device classes trade off network downlink communication latency versus battery lifetime. In a control or actuator-type application, the downlink communication latency is an important factor as can be seen in Figure 2.5.

Bi-directional end-devices (Class A): End-devices of Class A allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlinks receive windows. The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol). This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.

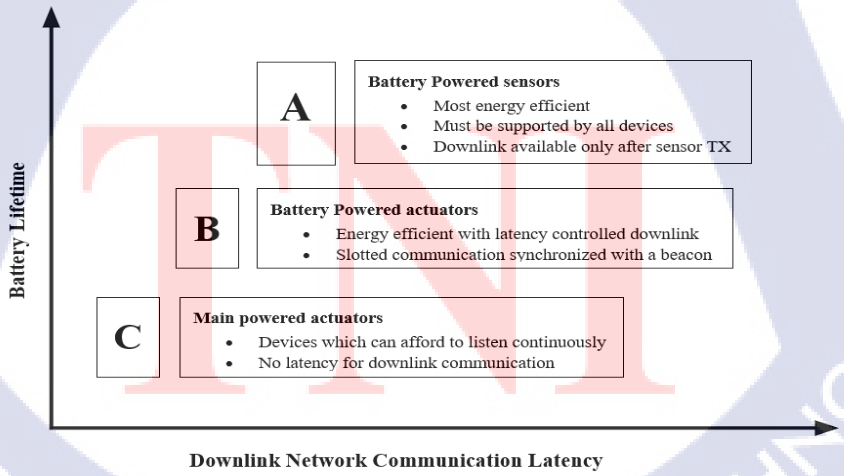

Figure 2.5 Device class of LoRa®

Class name	Intended usage
A (<< all >>)	**Battery powered sensors,** or actuators with no latency constraint Most energy efficient communication class. Must be supported by all devices
B (<< beacon >>)	**Battery powered actuators** Energy efficient communication class for latency controlled downlink. Based on slotted communication synchronized with a network beacon.
C (<<continuous>>)	**Mains powered actuators** Devices which can afford to listen continuously. No latency for downlink communication.

Figure 2.6 LoRaWAN communication profiles classes

Bi-directional end-devices with scheduled receive slots (Class B): In addition to the Class A random receive windows, Class B devices open extra receive windows at scheduled times. In order for the end-device to open it receive window at the scheduled time, it receives a time-synchronized beacon from the gateway. This allows the server to know when the end-device is listening as can be seen in Figure 2.6.

Bi-directional end-devices with maximal receive slots (Class C): End-devices of Class C have almost continuously open receive windows, only closed when transmitting.

Three different classes (A, B, C) of communication profiles are available in LoRa® networks between devices and applications. Each class serves different application needs and has optimized requirements for specific purposes. The key difference between A, B and C profiles is the trade-off made between latency and power consumption.

Class A, The figure 2.7 illustrates default configuration in LoRaWAN standard in SF12. Values can be adjusted.

Figure 2.7 Class A default configuration profile

Class A devices implement a bi-directional communication profile whereby each end-device's uplink transmission is followed by two short downlinks receive windows. The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis. This Class A operation is the lowest power consuming option for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time has to wait until the next scheduled uplink. Class A covers the vast majority of use cases, and is the most power efficient mode of LoRa® as can be seen in Figure 2.7.

Class B**,** The below figure illustrates default configuration in LoRaWAN standard in SF12. Values can be adjusted.

Devices should implement a Class B communication profile when there is a requirement to ensure low latency of downlink communication, while keeping the power consumption as low as possible. Class B emulates a continuously receiving device by opening receive windows at fixed time intervals for the purpose of enabling server-initiated downlink messages.

LoRaWAN Class B option adds a synchronized reception window on the remote device. Class B is achieved by having the gateway send a beacon on a regular basis to synchronize all the end-point devices in the network. It allows devices to open a short extra reception window (called "ping slot") at a predictable time during a periodic time slot.

Class B is currently still in experimental status at the LoRa® alliance, but most use cases can already be covered by combination of class A and class C. For example, devices requiring periodic rendezvous points to receive configuration data (e.g. room reservation display) may periodically request time from the LPWA network, then synchronize their internal clock and periodically open rendezvous windows for downlink messages as can be seen in Figure 2.8.

Figure 2.8 Class B default configuration profile

Figure 2.9 Class C default configuration profile

Class C, The below figure illustrates default configuration in LoRaWAN standard in SF12. Values can be adjusted.

Devices implementing Class C communication profiles are used for applications that have sufficient power available and thus do not need to minimize reception time windows. This is the case of most actuators (smart plugs, remote control of powered devices, etc.). Class C devices will listen with RX2 windows parameters as often as possible. The device listens on RX2 when it is not either (a) sending or (b) receiving on RX1, according to Class A definition. To do so, it will open a short window on RX2 parameters between the end of the uplink transmission and the beginning of the RX1 reception window and it will switch to RX2 reception parameters as soon as the RX1 reception window is closed; the RX2 reception window will remain open until the end-device has to send another message as can be seen in Figure 2.9.

2.1.1.5 Security `

It is extremely important for any LPWAN to incorporate security. LoRaWAN™ utilizes two layers of security: one for the network and one for the application. The network security ensures authenticity of the node in the network while the application layer of security ensures the network operator does not have access to the end user's application data. AES encryption is used with the key exchange utilizing an IEEE EUI64 identifier. There are trade-offs in every technology choice but the LoRaWAN™ features in network architecture, device classes, security, scalability for capacity, and optimization for mobility address the widest variety of potential IoT applications.

2.1.1.6 Battery Lifetime

The nodes in a LoRaWAN™ network are asynchronous and communicate when they have data ready to send whether event-driven or scheduled. This type of protocol is typically referred to as the Aloha method. In a mesh network or with a synchronous network, such as cellular, the nodes frequently have to 'wake up' to synchronize with the network and check for messages. This synchronization consumes significant energy and is the number one driver of battery lifetime reduction. In a recent study and comparison done by GSMA of the various technologies addressing the LPWAN space, LoRaWAN™ showed a 3 to 5 times advantage compared to all other technology options.

2.1.1.7 Microcontroller

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter as can be seen in Figure 2.10, Figure 2.11and Figure 2.12.

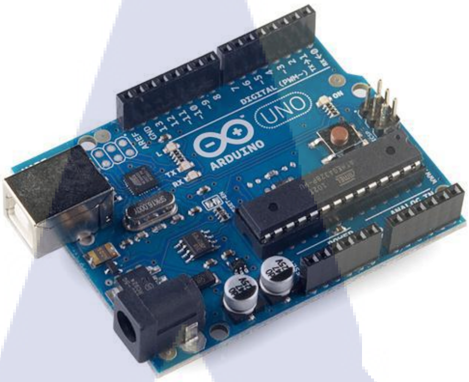

Figure 2.10 Arduino Uno board

Table 2.1 Arduino Uno Board Specification

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by boot loader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

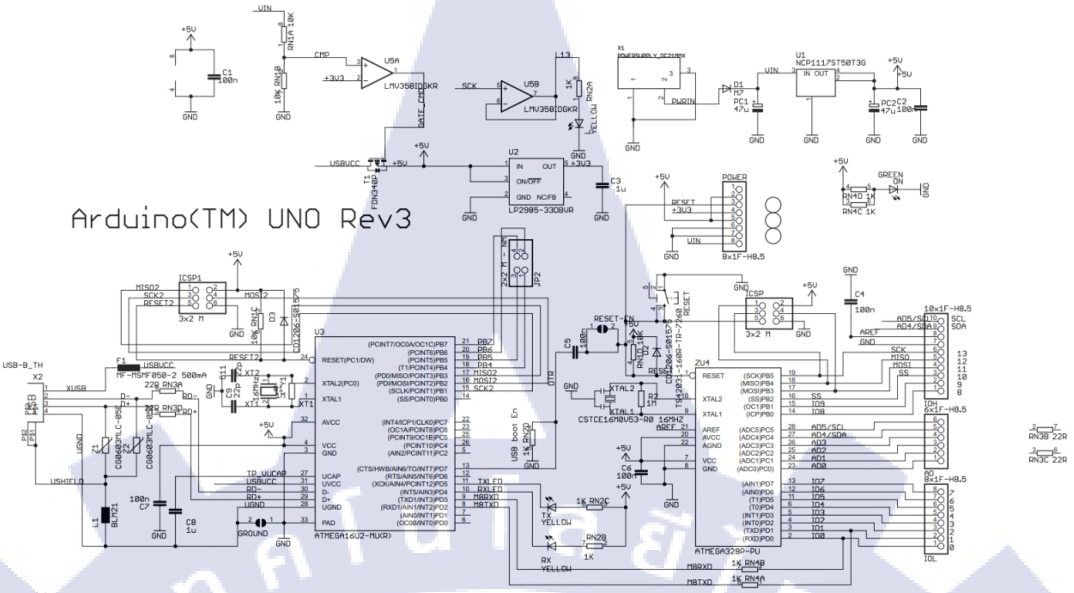

Figure 2.11 Schematic & Reference Design of Arduino Uno board

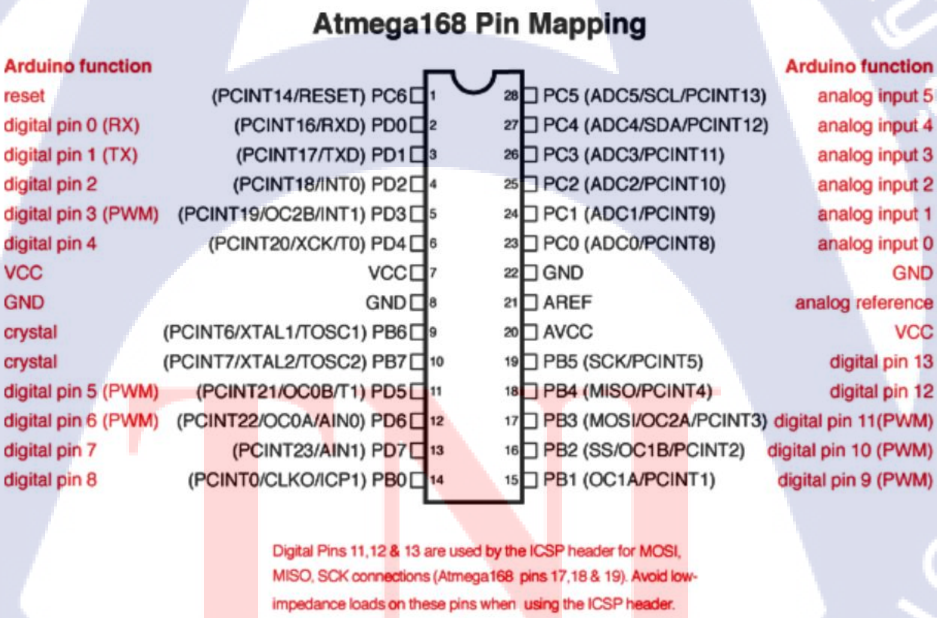

Figure 2.12 Atmega 168 pin mapping

2.1.1.8 Dipole Antenna and Radiation Pattern

A dipole antenna is a radio antenna that can be made of a simple wire, with a center fed driven element. It consists of two metal wire-rod conductors, in line with each other, with a small space between them. The radio frequency voltage is applied to the antenna at the center, between the two conductors. These antennas are the simplest practical antennas from a theoretical point of view.

The half-wave dipole antenna is the basis of many other antennas and is also used as a reference antenna for the measurement of antenna gain and radiated antenna density. At the frequency of resonance, i.e. at the frequency at which the length of the dipole equals a half-wavelength, we have a minimum voltage and a maximum current at the termination in the center of the antenna, as shown in Figure 2.13. The impedance is minimal. This is a simple antenna that radiates its energy out toward the horizon (perpendicular to the antenna). The resulting 3D pattern looks kind of like a donut or a bagel with the antenna sitting in the hole and radiating energy outward as can be seen in Figure 2.14. The strongest energy is radiated in the plane perpendicular to the antenna. The gain of the half-dipole is approximately 2.2 dBi.

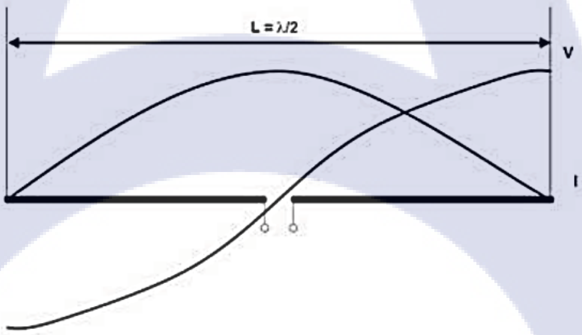

Figure 2.13 Half-wave dipole antenna voltage and current distribution

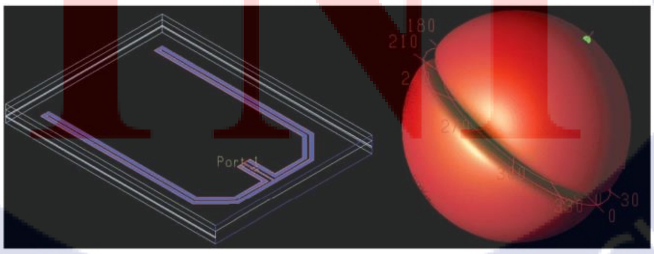

Figure 2.14 Half-wave dipole antenna model and radiation patterns

When the frequency is quite low, the wavelength becomes very long, so the half-wave dipole antenna is unpracticable. In this case a short dipole antenna can be used. The short dipole antenna is the simplest of all the antennas. It is an open circuited wire fed at its center. The word short always implies relative to a wavelength. So, the absolute size of the above dipole antenna does not matter, only the size of the wire relative to the wavelength of the frequency of the operation is important. Typically, a dipole is short if its length is less than a tenth of a wavelength. The directivity of the center fed short dipole antenna depends only on the sin of the polar angle component. It is calculated to be 1.76 dB, which is very low for realizable antennas. The polarization of the short dipole antenna is linear, as for all dipole type antennas. When evaluated in the x-y plane, this antenna is described as vertically polarized, because the Enfield is vertically oriented as can be seen in Figure 2.14.

2.1.1.9 Protocols

LoRaWAN is a MAC protocol, built to use the LoRa® physical layer. It is designed mainly for sensor networks, wherein sensors exchange packets with the server with a low data rate and relatively long-time intervals (one transmission per hour or even days). This section describes the LoRaWAN V1.0 specification, as released in January 2015.

Components of a LoRaWAN Network Several components of the network are defined in the LoRaWAN specification and are required to form a LoRaWAN network: end-devices, gateways and the network server.

End-device: the low-power consumption sensors that communicate with gateways using LoRa®.

Gateway, the intermediate devices that forward packets coming from end-devices to a network server over an IP backhaul interface allowing a bigger throughput, such as Ethernet or 3G. There can be multiple gateways in a LoRa® deployment, and the same data packet can be received by more than one gateway.

Network server, responsible for de-duplicating and decoding the packets sent by the devices and generating the packets that should be sent back to the devices.

Unlike traditional cellular networks, the end-devices are not associated with a particular gateway in order to have access to the network. The gateways serve simply as a link layer relay and forward the packet received from the end-devices to the network server after adding information regarding the reception quality. Thus, an end-device is associated with a network server, which is responsible for detecting duplicate packets, choosing the appropriate gateway for sending a reply (if any), consequently for sending back packets to the end-devices. Logically, gateways are transparent to the end-devices.

A LoRa® frame begins with a preamble. The preamble starts with a sequence of constant upchirps that cover the whole frequency band. The last two upchirps encode the sync word. The sync word is a one-byte value that is used to differentiate LoRa® networks that use the same frequency bands. A device configured with a given sync word will stop listening to a transmission if the decoded sync word does not match its configuration. The sync word is followed by two and a quarter downchirps, for a duration of 2.25 symbols. The total duration of this preamble can be configured between 10.25 and 65,539.25 symbols. The structure of the preamble can be seen in Figure 2.15.

After the preamble, there is an optional header. When it is present, this header is transmitted with a code rate of 4/8. This indicates the size of the payload, the code rate used for the end of the transmission and whether or not a 16-bit CRCfor the payload is present at the end of the frame. The header also includes a CRC to allow the receiver to discard packets with invalid headers. The payload size is stored using one byte, limiting the size of the payload to 255 bytes. The header is optional to allow disabling it in situations where it is not necessary, for instance when the payload length, coding rate and CRC presence are known in advance. The payload is sent after the header, and at the end of the frame is the optional CRC. A schematic summarizing the frame format can be seen in Figure 2.16.

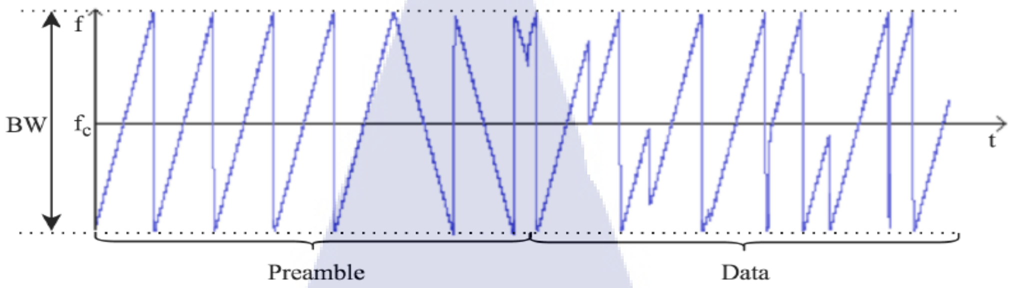

Figure 2.15 Frequency variation over time of a sample signal emitted by a LoRa® transmitter

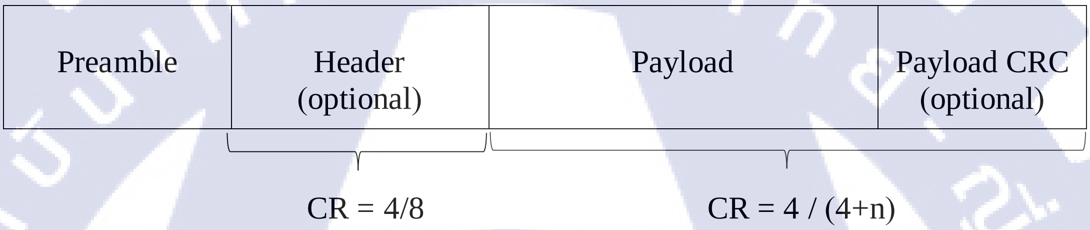

Figure 2.16 Structure of a LoRa® frame

Equation (1), derived from Semtech's datasheets [3], gives the number of symbols required to transmit a payload ns, as a function of all of these parameters. This number should be added to the number of symbols of the preamble, in order to compute the total size of the packet in symbols. In this equation, PL is the payload size in bytes, CRC is 16 if the CRC is enabled and zero otherwise, H is 20 when the header is enabled and zero otherwise and DE is two when the low data rate optimization is enabled and zero otherwise. This equation also shows that the minimum size of a packet is eight symbols.

$$N_s = 8 + \max\left(\left\lceil \frac{8PL - 4SF + 8 + CRC + H}{4 \times (SF - DE)} \right\rceil \times \frac{4}{CR}, 0\right) \tag{1}$$

The header and CRC are mandatory for uplink messages, which makes it impossible to use a spreading factor of six in LoRaWAN. Downlink messages have the header, but not the CRC. The code rate that should be used is not specified and neither is when the end-devices should use the low data rate optimization.

The message format is detailed in Figure 2.17. DevAddr is the short address of the device. FPort is a multiplexing port field. The value zero means that the payload contains only MAC commands. When this is the case, the FOptsLen field must be zero. FCnt is a frame counter. MIC is a cryptographic message integrity code, computed over the fields MHDR, FHDR, FPort and the encrypted FRMPayload. MType is the message type, indicating among other things whether it is an uplink or a downlink message and whether or not it is a confirmed message. Acknowledgments are requested for confirmed messages. Major is the LoRaWAN version; currently, only a value of zero is valid. ADR and ADRAckReq control the data rate adaptation mechanism by the network server. ACK acknowledges the last received frame. FPending indicates that the network server has additional data to send and that the end-device should send another frame as soon as possible so that it opens receive windows. FOptsLen is the length of the FOpts field in bytes. FOpts is used to piggyback MAC commands on a data message. CID is the MAC command identifier, and Args are the optional arguments of the command. FRMPayload is the payload, which is encrypted using AES with a key length of 128 bits. The minimal size of the MAC header is 13 bytes; its maximal size is 28 bytes. Knowing this, it is possible to compute the maximum channel capacity available for application data payloads with

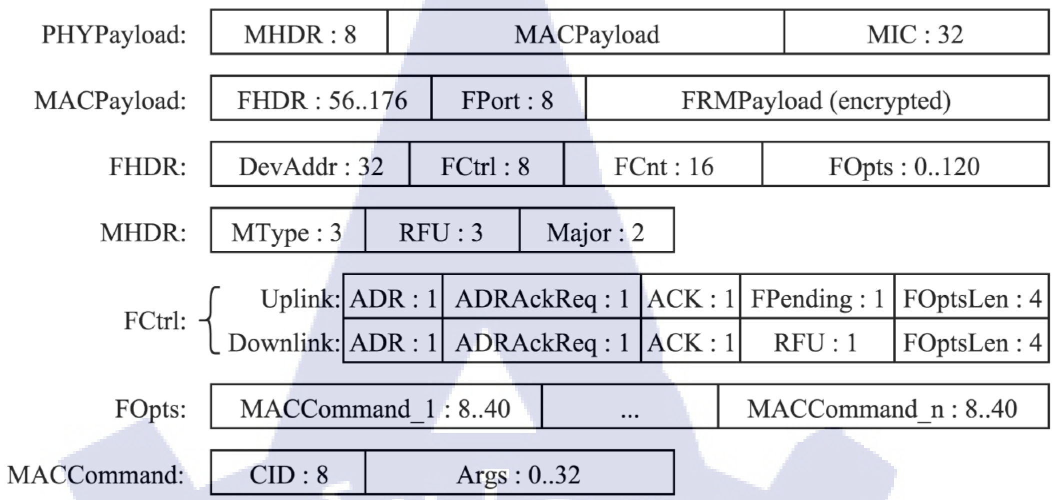

Figure 2.17 LoRaWAN frame format. The sizes of the fields are in bits

given modulation parameters thanks to Equations (1). As packets are sent from a device to the network server and vice versa, there is no destination address on uplink packets, and there is no source address on downlink packets.

LoRaWAN MAC Commands LoRaWAN defines many MAC commands that allow customizing end-device parameters [4]. One of them, LinkCheckReq, can be sent by an end-device to test its connectivity. All of the others are sent by the network server. These commands can control the data rate and output power used by the device, as well as the number of times each unconfirmed packet should be sent, the global duty cycle of the device, changing parameters of the receive windows and changing the channels used by the device. One command is used to query the battery level and reception quality of a device.

2.1.1.10 Technical Comparisons

Table 2.1 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 2.2 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 network 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 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 [5]. 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.

Table 2.2 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)**

Table 2.3 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	$2^6 ... 2^{12} \frac{\text{Chips}}{\text{Symbol}}$	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®, which stands for "Long Range", is a promising long-range wireless communications system, fostered by the LoRa® Alliance [6]. 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.

2.1.2 LoRa spread spectrum principles

2.1.2.1 Spread spectrum

On the one hand, a Traditional Direct Sequence Spread Spectrum (DSSS) system [7] has been existed as for an alternative to those of existing modulation techniques. In DSSS system, a carrier phase of a transmitter changes correspondingly to a code sequence. This process can typically be achieved through a multiplication of an original data with a chip sequence. The chip sequence rate is much faster than the data signal, and consequently such a chip sequence spreads a signal bandwidth beyond the original bandwidth occupied by the original data. In order to effectively recover an original data at a receiver, the regaining process is performed by re-multiplying with a locally generated replica of the spreading sequence. In other words, this multiplication process in the receiver compresses the spreading signal back to its original un-spread bandwidth. Typically, the amount of spreading is dependent upon "Chips per Bit", which is a ratio of the chip sequence to the preferred data rate referred to as the processing gain (Gp) in dB, which can be described as

$$G_p = 10\log\left(\frac{R_c}{R_b}\right) \tag{2}$$

where Rc and Rb are a chip rate (chips/s) and a bit rate (bits/s), respectively. Although DSSS has been extensively utilized in data communications, low-cost or power-constrained devices and networks are main concerns in such a DSSS since a highly accurate and expensive reference clock source is required. Moreover, a long spreading code essentially requires time in order to perform a correlation over the entire length of the code sequence, and hence repeatedly and rapidly synchronization is necessary, leading to high power consumption [8].

On the other hand, Chirp Spread Spectrum (CSS) system was also developed in parallel particularly for secure communications. The CSS system provides not only low transmission power requirements but also inherent robustness from channel degradation mechanisms, including as multipath, fading, Doppler, and in-band jamming interferers. Therefore, IEEE has alleviated CSS PHY for Low Range Wireless Personal Area Networks (LR-WPANs) through the standard 802.15.4 with the OQPSK DSSS PHY mode [9]. Of particular interest in LoRa Spread Spectrums (LoRa SS), a LoRa modulation addresses all difficulties associated with DSSS systems in order to afford a low-cost, low-power, and robust modulation technique comparing to that of the DSSS communications techniques in LoRa modulation, the spectrum is spread through a generation of a chirp signal that continuously varies in frequency. Consequently, the frequency bandwidth of the chirp signal is equivalent to the spectral bandwidth, leading to equivalence in timing and frequency offsets between transmitter and receiver and significantly reducing the complexity of receiver designs. Subsequently, the original data is chipped at a higher data rate and modulated onto the chirp signal. In particular for LoRa modulation, a variable error correction scheme that enhances the robustness of the transmitted signal at the expense of redundancy is also included, and therefore the nominal bit rate of the data can be re-defined as follows.

$$R_b = SF \times \frac{RC}{\left[\frac{2^{SF}}{BW}\right]} \tag{3}$$

where RC is a rate code, and generally equal to RC=4/(4+CR) where CR is a code rate, generally in a range of 1-4 (Semtech Application Note AN1200.13, 2013).

2.1.2.2 Received Signal Strength Indication (RSSI)

Equation (2), the received signal strength (RSS) based approach is one of the simplest and widely used approaches for indoor localization [8-12]. The RSS is the actual signal power strength received at the receiver, usually measured in decibel-milliwatts (dBm) or milliwatts (mW). The RSS can be used to estimate the distance between a transmitter (Tx) and a receiver (Rx) device; the higher the RSS value the smaller the distance between Tx and Rx. The absolute distance can be estimated using a number of different signal propagation models given that the transmission power or the power at a reference point is known. RSSI (which is often confused with RSS) is the RSS indicator, a relative measurement of the RSS that has arbitrary units and is mostly defined by each chip vendor. For instance, the Atheros Wi-Fi chipset uses RSSI values between 0 and 60, while Cisco uses a range between 0 and 100. Using the RSSI and a simple path-loss propagation model, the distance d between Tx and Rx can be estimated from (4) as

$$RSSI = -10n \log_{10}(d) + A \tag{4}$$

where n is the path loss exponent (which varies from 2 in free space to 4 in indoor environments) and A is the RSSI value at a reference distance from the receiver. RSS based localization, in the DBL case, requires trilateration or N-point literation, i.e., the RSS at the device is used to estimate the absolute distance between the user device and at least three reference points; then basic geometry/trigonometry is applied for the user device to obtain its location relative to the reference points as shown in Figure 2.18. In a similar manner, in the MBL case, the RSS at the reference points is used to obtain the position of the user device. In the latter case, a central controller or ad-hoc communication between anchor points is needed for the total RSS collection and processing. On the other hand, RSS based proximity-based services (such as sending marketing alerts to a user when in the vicinity of a retail store), require a single reference node to create a geofence 3 and estimate the proximity of the user to the anchor node using the path loss estimated distance from the reference point.

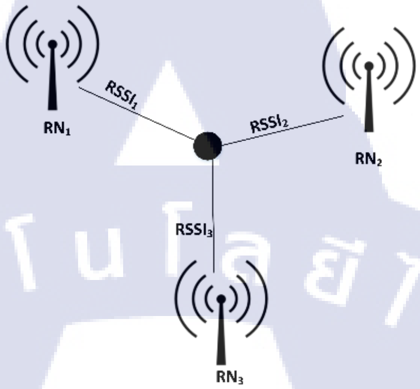

Figure 2.18 RSSI based localization

While the RSS based approach is simple and cost efficient, it suffers from poor localization accuracy (especially in non-line of-sight conditions) due to additional signal attenuation resulting from transmission through walls and other big obstacles and severe RSS fluctuation due to multipath fading and indoor noise [10], Different filters or averaging mechanisms can be used to mitigate these effects. However, it is unlikely to obtain high localization.

2.1.2.3 Time of Arrival

Time of Arrival is the process of determining distance from the time a transmission takes from anchor node to target node. In theory this is a straight forward procedure since the speed of light is well known. The distance between two nodes are calculated from the time difference between transmitting and receiving, and as a result the position can be determined by trilateration in the same way as in the RSS case. However, in practice, this becomes a lot harder due to clock drifts. Essentially the problem comes down to clock synchronization, where nodes need to be synchronized down to nanosecond scale in order to achieve a proper distance approximation. For a network such as Lora® WAN where the nodes are supposed to be low-cost and idle for a large amount of the time, the internal clock drift makes this a quite hard problem. There are techniques to go about this, such as two-way time of arrival (TW-TOA) or time difference of arrival (TDOA). The common denominator of these techniques is that they only demand the anchor nodes to be time synchronized, and there for the low cost of target nodes is not compromised. In TW-TOA the round-trip time between anchor and target node is measured, and if the target node has a well-defined processing time of the message this can give a good distance estimation. For TDOA the target node sends a broadcast message which is received by multiple anchor nodes. The anchor nodes, which are time synchronized, can then calculate the distance from the difference in time between signal receptions. This is a multiliterate problem which involves solving a set of hyperbolic functions, and therefore an additional anchor node is needed compared to the trilateration case.

2.1.2.4 Time of Flight (ToF) Technique

Time of Flight (ToF) exploits the signal propagation time to calculate the distance between the transmitter Tx and the receiver Rx. The ToF value multiplied by the speed of light c = 3 x 108 m/sec Provides the physical distance between Tx and Rx. In Figure 2.19, the ToF from three different reference nodes is used to estimate the distances between the reference nodes and the device. Basic geometry can be used to calculate the location of the device with respect to the access points. Similar to the RSS, the ToF values can be used in both the DBL and MBL scenarios. ToF requires strict synchronization between transmitters and receivers and, in many cases, timestamps to be transmitted with the signal (depending on the underlying communication protocol). The key factors that affect ToF estimation accuracy are the signal bandwidth and the sampling rate. Low sampling rate (in time) reduces the ToF resolution since the signal may arrive between the sampled intervals. Frequency domain superresolution techniques are commonly used to obtain the ToF with high resolution from the channel frequency response. In multipath indoor environments, the larger the bandwidth,

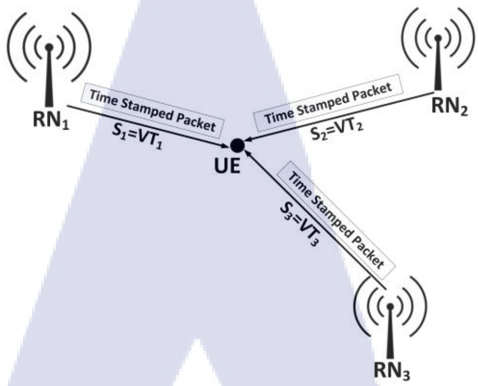

Figure 2.19 ToF based user equipment (UE) localization

The higher the resolution of ToF estimation. Although largeband width and super-resolution techniques can improve the performance of ToF, still they cannot eliminate significant localization errors when the direct line of sight path between the transmitter and receiver is not available. This is because the obstacles deflect the emitted signals, which then traverse through a longer path causing an increase in the time taken for the signal to propagate from Tx to Rx. Let t^1 be the time when Tx i sends a message to the Rx j that receives it at t^2 where $t^2 = t^1 + tp$ (tp is the time taken by the signal to traverse from Tx to Rx) . So, the distance between the i and j can be calculated using Equation (5) where v is the signal velocity.

$$D_{ij} = (t^2 - t^1) \times \mathrm{v} \tag{5}$$

2.1.2.5 Time Difference of Arrival (TDoA) Technique

Time Difference of Arrival (TDoA) exploits the difference in signals propagation times from different transmitters, measured at the receiver. This is different from the ToF technique, where the absolute signal propagation time is used. The TDoA measurements (TD(i;j) - from transmitters i and j) are converted into physical distance values LD(i;j) = c _ TD(i;j), where c is the speed of light. The receiver is now located on the hyperboloid given by Eq. (6).

$$L_{D(i,j)} = \sqrt{(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2} - \sqrt{(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2} \quad (6)$$

where (Xi; Yi; Zi) are the coordinates of the transmitter/reference node i and (x; y; z) are the coordinates of the receiver/user.

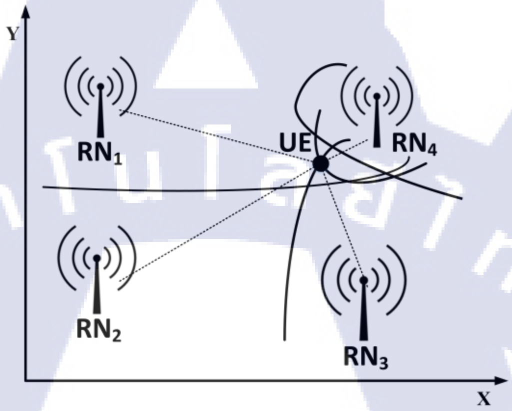

Figure 2.20 TDoA based localization and proximity detection

The TDoA from at least three transmitters is needed to calculate the exact location of the receiver as the intersection of the three (or more) hyperboloids. The system of hyperbola equations can be solved either through linear regression or by linearizing the equation using Taylorseries expansion. Figure 2.20 shows how four different RNs can be used to obtain the 2D location of any target. Figure shows the hyperbolas formed as a result of the measurements obtained from the RNs to obtain the user location (black dot). The TDoA estimation accuracy depends (similar to the ToF techniques) on the signal bandwidth, sampling rate at the receiver and the existence of direct line of sight between the transmitters and the receiver. Strict synchronization is also required, but unlike ToF techniques where synchronization is needed between the transmitter and the receiver, in the TDoA case only synchronization between the transmitters is required.

2.1.2.6 Angle of Arrival (AOA) Technique

Angle of Arrival (AoA) based approaches use antennae arrays (at the receiver side) to estimate the angle at which the transmitted signal impinges on the receiver by exploiting and calculating the time difference of arrival at individual elements of the antennae array. The main advantage of AoA is that the device/user location can be estimated with as low as two monitors in a 2D environment, or three monitors in a 3D environment respectively. Although AoA can provide accurate estimation when the transmitter-receiver distance is small, it requires more complex hardware and careful calibration compared to RSS techniques, while its accuracy deteriorates with increase in the transmitter-receiver distance where a slight error in the angle of arrival calculation is translated into a huge error in the actual location estimation. Moreover, due to multipath effects in indoor environments the AoA in terms of line of sight (LOS) is often hard to obtain. Figure 2.21 shows how AoA can be used to estimate the user location (as the angles at which the signals are received by the antenna array can help locate the user device.).

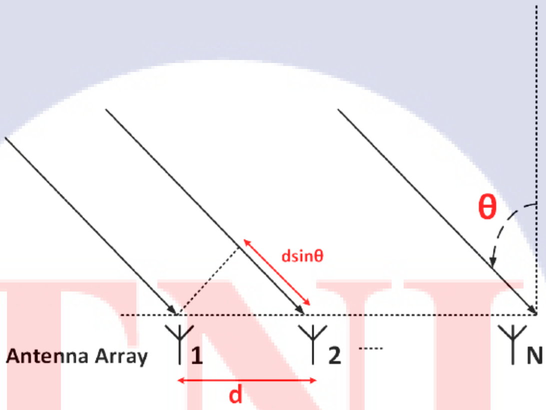

Figure 2.21 AoA based localization

In the AOA technique, the estimation of the signal reception angles, from at least two sources, is compared with either the signal amplitude or carrier phase across multiple antennas. The location can be found from the intersection of the angle line for each signal source, see Figure 2.22. AOA estimation algorithms are very sensitive to many factors, which may cause errors in their estimation of target position.

Furthermore, AOA estimation algorithms have a higher complexity compared to other methods. For instance, the antenna array geometry has a major role in the estimation algorithm. Increasing the distance between the sender and receiver may decrease the accuracy. The AOA technique can be used with other techniques to increase its accuracy.

AOA based algorithms have been used in a vast amount of literature. Xu et al., presented a new cooperative positioning method based on AOA that utilizes pairwise AOA information among all the sensor nodes rather than relying only on anchor nodes. Lee proposed the use of a signal model and weighted-average to estimate AOA parameters for low data rate UWB (LR-UWB). A Kalman filter based AOA estimation algorithm was introduced by Subramanian that relies on a new linear quadratic frequency domain invariant beam forming strategy. Furthermore, many studies have been conducted to evaluate the performance of AOA for different applications, environments, hardware, and configurations. Mok et al., studied the feasibility and performance of AOA for UWB in the Ubisense Real-Time Location System (RTLS) when integrated with GPS to facilitate resource management in underground railway construction sites. The influence of UWB directional antennas on the performance of AOA estimation was analyzed in detail by Gerok et al. who presented a corrected AOA estimation algorithm that mitigates the error resulting from the UWB directional antenna.

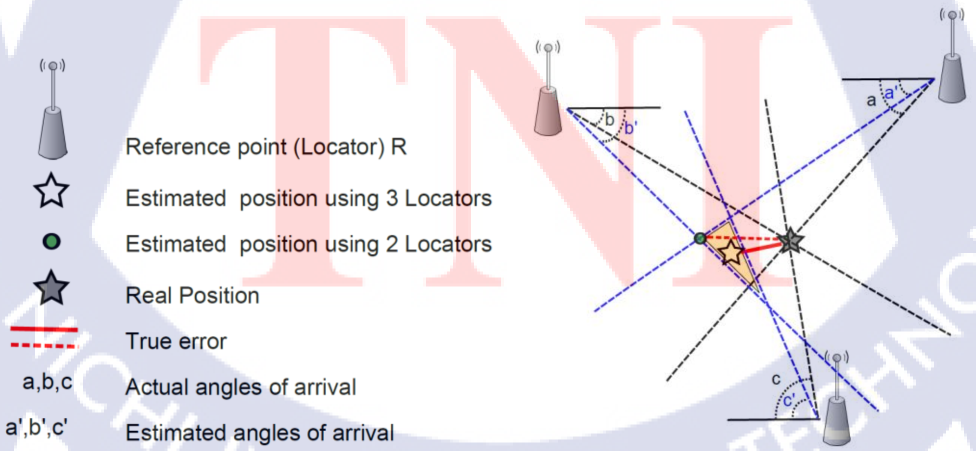

Figure 2.22 Angle of arrival (AOA)-based algorithms

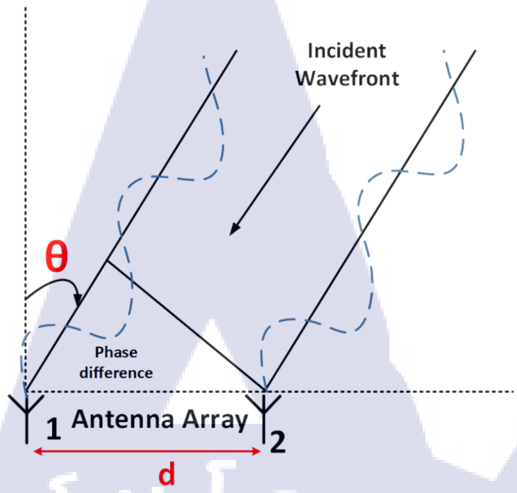

Figure 2.23 PoA based localization

2.1.2.7 Phase-of-Arrival (PoA)

PoA based approaches use the phase or phase difference of carrier signal to estimate the distance between the transmitter and the receiver. A common assumption for determining the phase of signal at receiver side is that the signals transmitted from the anchor nodes (in DBL), or user device (in MBL) are of pure sinusoidal form having same frequency and zero phase offset. There are a number of techniques available to estimate the range or distance between the Tx and Rx using PoA. One technique is to assume that there exists a finite transit delay Di between the Tx and Rx, which can be expressed as a fraction of the signal wavelength. As seen in Figure 2.23, the incident signals arrive with a phase difference at different antenna in the antenna array, which can be used to obtain the use location. A detailed discussion on PoA-based range estimation is beyond the scope of the paper. Therefore, interested readers are referred to [13], [14]. Following range estimation, algorithms used for ToF can be used to estimate user location. If the phase difference between two signals transmitted from different anchor points is used to estimate the distance, TDoA based algorithms can be used for localization. PoA can be used in conjunction with RSSI, ToF, TDoA to improve the localization accuracy and enhance the performance of the system. The problem with PoA based approach is that it requires line-of sight for high accuracy, which is rarely the case in indoor environments.

Table 2.3 provides a summary of the discussed techniques for indoor localization and discusses the advantages and disadvantages of these techniques. Interested readers are referred to [15] for detailed discussion on these localization techniques.

Table 2.4 Advantages and Disadvantages of Different Localization Techniques

Technique	Advantages	Disadvantages
RSSI	Easy to implement, cost efficient, can be used with a number of technologies	Prone to multipath fading and environmental noise, lower localization accuracy, can require fingerprinting
CSI	More robust to multipath and indoor noise.	It is not easily available on off-the-shelf NICs
AoA	Can provide high localization accuracy, does not require any fingerprinting	Might require directional antennas and complex hardware, requires comparatively complex algorithms and performance deteriorates with increase in distance between the transmitter and receiver
ToF	Provides high localization accuracy, does not require any fingerprinting	Requires time synchronization between the transmitters and receivers, might require time stamps and multiple antennas at the transmitter and receiver. Line of Sight is mandatory for accurate performance.
TDoA	Does not require any fingerprinting, does not require clock synchronization among the device and RN	Requires clock synchronization among the RNs, might require time stamps, requires larger bandwidth
RToF	Does not require any fingerprinting, can provide high localization accuracy	Requires clock synchronization, processing delay can affect performance in short ranger measurements
PoA	Can be used in conjunction with RSS, ToA, TDoA to improve the overall localization accuracy	Degraded performance in the absence of line of sight
Fingerprinting	Fairly easy to use	New fingerprints are required even when there is a minor variation in the space

2.1.2.8 Return Time of Flight (RToF) Technique

RToF measures the round-trip (i.e., transmitter-receiver transmitter) signal propagation time to estimate the distance between Tx and Rx [15]. The ranging mechanisms for both ToF and RToF are similar; upon receiving a signal from the transmitter, the receiver responds back to the transmitter, which then calculates the total round-trip ToF. The main benefit of RToF is that a relatively moderate clock synchronization between the Tx and the Rx is required, in comparison to ToF.

However, RToF estimation accuracy is affected by the same factors as ToF (i.e., sampling rate and signal bandwidth) which in this case is more severe since the signal is transmitted and received twice. Another significant problem with RToF based systems is the response delay at the receiver which highly depends on the receiver electronics and protocol overheads. The latter one can be neglected if the propagation time between the transmitter and receiver is large compared to the response time, however the delay cannot be ignored in short range systems such as those used for indoor localization. Let t1 be the time when Tx i sends a message to the Rx j that receives it at t2 where t2 = t1 + tp. j, at time t3, transmits a signal back to i that receives it at t4 So the distance between the i and j can be calculated using Equation (7) [15].

$$D_{ij} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2} \times v \tag{7}$$

2.2 Literature Reviews

As LoRaWAN has recently been developed as a promising technology comparing to those existing short-range and cellular evolutions, research on LoRaWAN is still in early stage.

Recently, M. Aref and A. Sikora [10] presented a short overview on the technologies to support Long Range (LoRaTM), and described the outdoor setup at the Laboratory Embedded Systems and Communication Electronics of Offenburg University of Applied Sciences. It was found that the range directly depends on the link budget, which can be increased by the choice of modulation and coding schemes. The SX127x family from Semtech Corp. is a member of this device class and promises significant benefits for range, robust performance, and battery lifetime compared to competing technologies.

J. Petäjäjärvi at al. [11] studied the coverage of the LoRa LPWAN technology through real measurements. The experiments were conducted in the city of Oulu, Finland, using commercially available equipment. The measurements were executed for cases when a node located on ground or on water reporting their data to a base station. The node operates in the frequency range of 868 MHz ISM band using 14 dBm transmitting power and the maximum spreading factor. The maximum communication range was found over 15 km. on ground and close to 30 km. on water.

Recently, T. M. Wendt et al., [5] employed EM Microelectronic developed a LoRa™–modulation chip called EM9101 for the 2.45 GHz, which is based on the Semtech technology. This transceiver-modem-design offers an ultra-long range spread spectrum communication and high interference robustness. The spread-spectrum technology is not new but implemented into a 2.45 GHz frequency-based chip which can be taken as add on modem to a standard transceiver chip. The gain for the air-link budget which is more than 20 dBm can be utilized to obtain a huge communication distance. This paper therefore presents the long-range communication system that comprises not only the implemented gateway using Raspberry-Pi but also an end-device using microcontroller with GPS and other sensors for geological and physical tracking. Consequently, the proposed system employs four gateways with bridge-to-bridge WIFI connection for communication to the server. The end node can be integrated more than ten types of sensors such as GPS, temperature, humidity, and water sensors. All data can be visualized real-time via monitor station. The proposed system provides not only an emerging long-range communication but also low-power operation in a military campsite within 1.5 kilometers.

Chapter 3
Methodology

3.1 Experiment Process and Design

The proposed Universal LoRa End Node has been designed as a stand lone device, which can be equipped with other microcontroller. Fig. 3.1 shows the block diagram of the proposed Universal LoRa End-Node with GPS Module. It can be seen from Fig.2 that the end-node comprises a LoRa Module with an antenna operating at 2-dBi and 433 MHz Whip Antenna. The LoRa module is connected to the Arduino Pro-Mini that processes all signal both inputs and outputs. The GPS Module is Ublox neo-6m. The power supply system is a Lithium-Ion Batter (3.7V) that supplies Lithium-Ion Battery Charger Module TP4056. Such a module TP4056 supplies 5V for Arduino Pro-Mini as well as a step-down voltage regulator module of 3.3V for LoRa module. Fig. 3.2 shows the block diagram of the proposed Universal LoRa Gateway connecting to a computer. The computer is connected to the Raspberry Pi controller as a main microprocessor, which connects to the LoRa Module via SPI. As a main station, the AC/DC Adaptor (12V, 2A) has been exploited for a voltage regulator (12V to 5V).

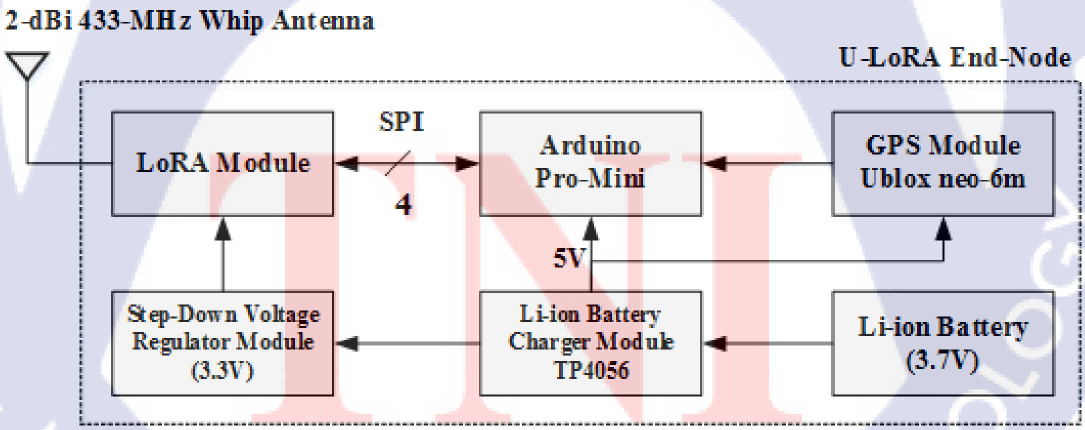

Figure 3.1 Block diagram of the proposed Universal LoRa End-Node with GPS Module.

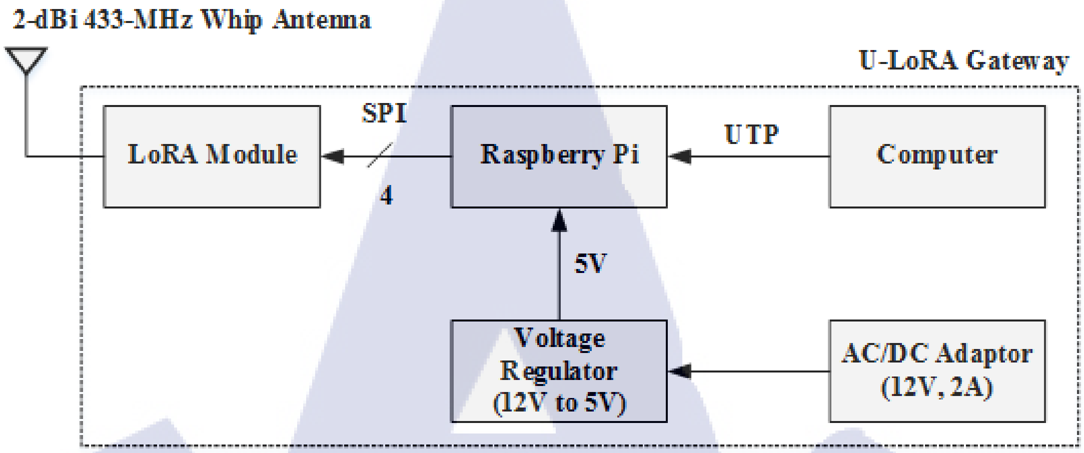

Figure 3.2 Block diagram of the proposed Universal LoRa Gateway connecting to a computer.

Fig. 3.3 shows the architecture of the proposed tactical troop tracking system. It is seen in Fig.4 that a single LoRa gateway is exploited in the centre of an investigation area. The LoRA End-Nodes can be as much as preferred, but there are six nodes demonstrating in this system. All the end-nodes are connected to the LoRa gateway before transmitting to the Layer 2 network switch under IoT and web server. All the data will be transferred to the network before visualizing on the graphic user interface. The system can be extended to a wider range area within 5×5 Kilometers as shown in Fig. 3.4. The systems can be expanded to the tactical troop tracking system with a four gateway with four point-to-point Wi-Fi bridges. Such a system could provide wider coverage. It should be noted that the gateway should be in an appropriate height in order to be capable of receiving signals from each end-nodes, and the electrical surge system should be considered and integrated in order to protect from any possible failures.

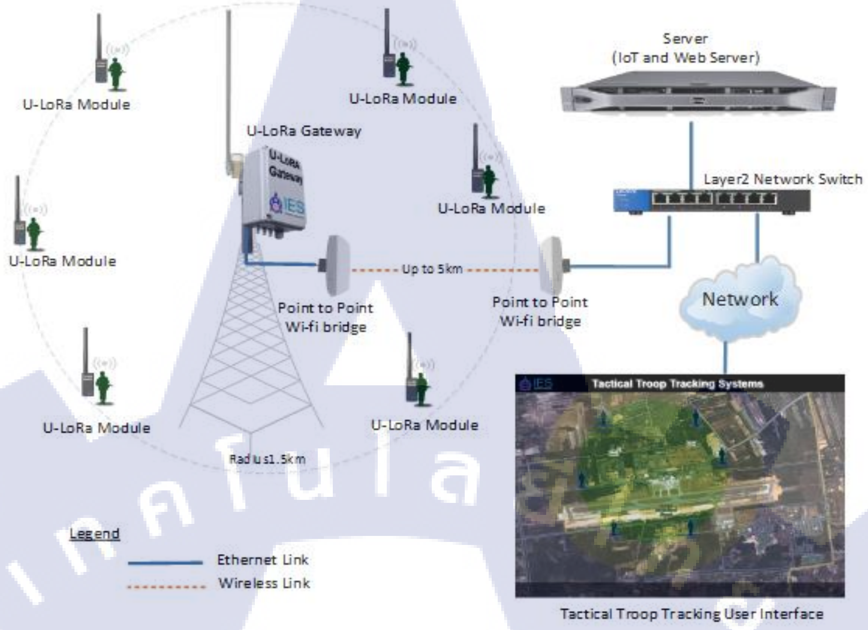

Figure 3.3 The architecture of the proposed tactical troop tracking system with a single gateway and a point-to-point WI-FI bridge.

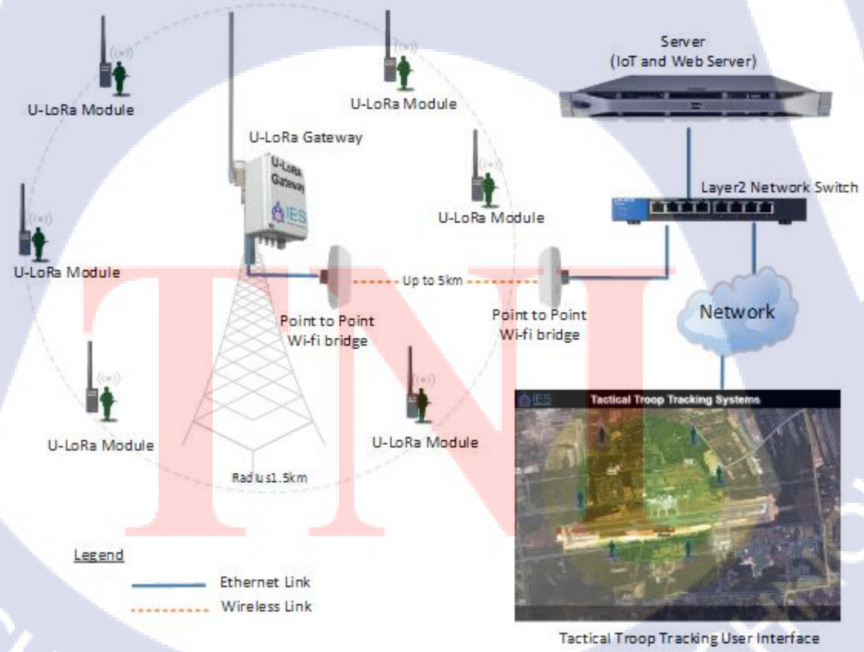

Figure 3.4 The architecture of the proposed tactical troop tracking system with a four gateway with four point-to-point WI-FI bridge.

3.2 Main Tools used within the Experiment

3.2.1 Hardware List

3.2.1.1 LoRa-based transmitter module – 1 sets

The overall modules of the senders are identical in configuration and are essentially used as fixed at each position of the coverage area transmitters to emit the RSSI to the targeted receiver that move around the field.

3.2.1.2 LoRa-based receiver module – 1 set

The receiver designed to move around the coverage area of localization system as for receiving the RSSI data from all transmitters at each coordinate of the grid. The receiver is manually moved along the entire area to gain the information.

3.2.1.3 Portable PC laptop – 1 set

The PC laptop is to manage the system and collect the received data while performing and testing the experiment. Moreover, all the records are kept in form of CSV file and used to train the ANN model within the software here as well.

Figure 3.5 LoRa-based transmitter module

Figure 3.6 LoRa-based receiver module

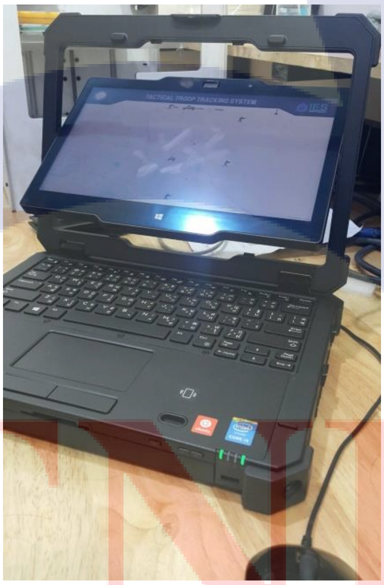

Figure 3.7 Portable PC laptop

3.2.2 Software List

3.2.2.1 Arduino IDE software

Arduino IDE software is for programming the script to communicate with both the LoRa-based transmitters and the sole receiver.

3.2.2.2 Math work MATLAB software

The ANN toolbox from MATLAB has been utilized to model the feedforward neural network from training data gathering by the PC laptop. The parameter of the ANN model can be configured, and the training process is also performed here on ward.

Chapter 4

Result and Discussion

4.1 End Device Design

<u>A Circuit and System Designs</u>

The proposed LoRa module has been designed as a stand-alone device, which can be equipped with another microcontroller. Fig.46 shows the block diagram of the proposed LoRa End-Node. It can be seen from Fig.46 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 is connected to a battery charger module TP4056. The TP4056 module become the power supply in order to step-down the 3.3V voltage regulate module.

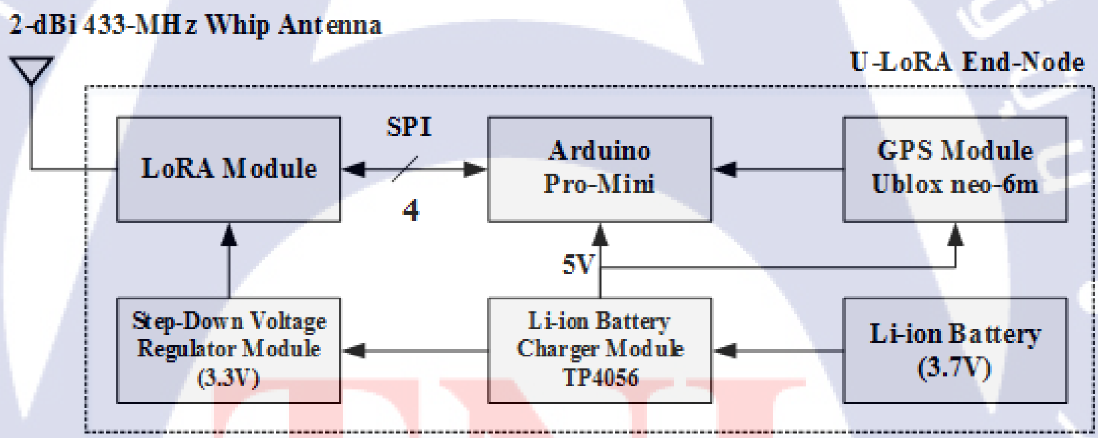

Figure 4.1 End device design

Table 4.1 Technical Specification of Circuit Modules

Circuit Modules	Specifications
LoRa Chip	168 dB maximum link budget +20 dBm - 100 mW constant
SX1276/77/78	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

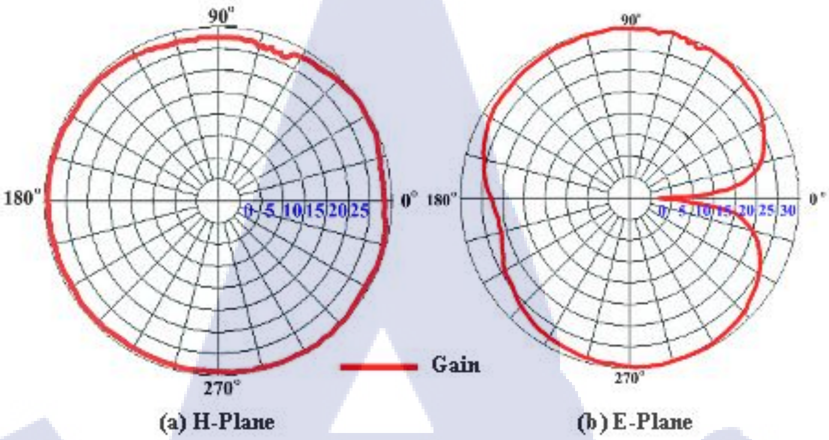

Figure 4.2 The radiation pattern of an antenna; (a) H-Plane, (b) E-Plane

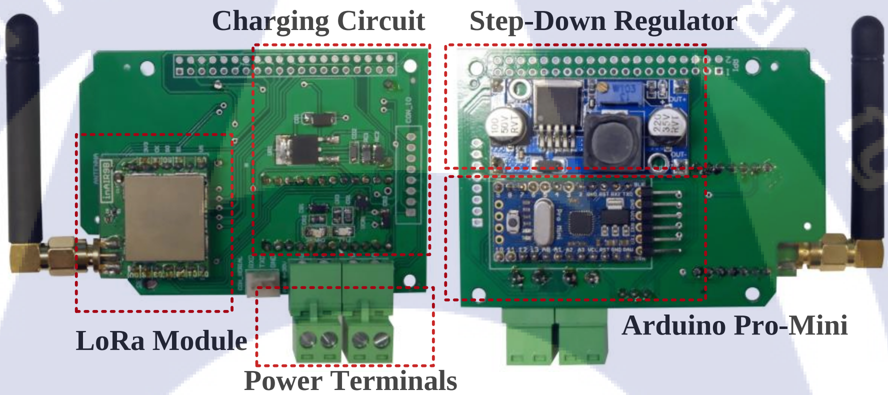

Figure 4.3 The assembled two-layer circuit prototype of the LoRa-based communication module with built-in monopole antenna

Table 4.1 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 8 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. 47 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 0O. The experiment shall be carefully considering a vertical polarization in order to receive a RSS properly. Finally, Table 8 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. 48 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.

4.2 Experimental results

The proposed system has been implemented using commercially available devices. Fig. 4.4 show the implemented end-node and gateway, respectively. Such devices are a very first implementation in Thailand. Performance analysis has been tested at Thai-Nichi Institute of Technology where the gateway was installed at the 6th floor of C-building with a height of 500 meters. The coverage range has been incremented by 100 meters with actual obstacles as depicted. The performances were investigated by received signal strength indicator (RSSI), which is a measurement of the power present in a received radio signal. It should be noted that RSSI is usually expressed in dBm from 0 to approximately lowest at -120 dBm. Typically, a higher value of SNR guarantees the clear acquisitions with low distortions and artifacts caused by noises. The better value of SNR causes the better signal strength, resulting in the better quality of transmitted signals. In this work, the received signals are the Latitude and Longitude obtained from the GPS module.

Fig. 4.5 also plots the measured RSSI in dBm versus a distance in meter. It can be seen in Fig.9 that the RSSI decreases from 0 to -90 dBm within 100 meters. The values are in the region of -90 dBm to approximately -100 dBm within the distance of 100 meters to 500 meters before the signal was lost and plots the measured SNR in dB versus_a distance in meter. It is apparent that the SNR is positive till the distance of around 160 meters.

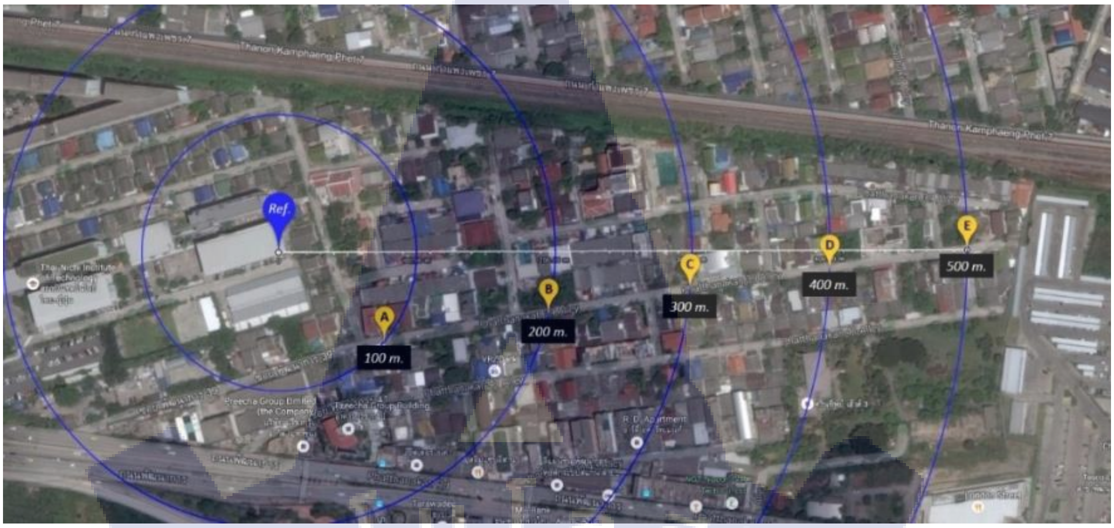

Figure 4.4 Test for signal strength coverage area at C-Building of Thai-Nichi Institute of Technology

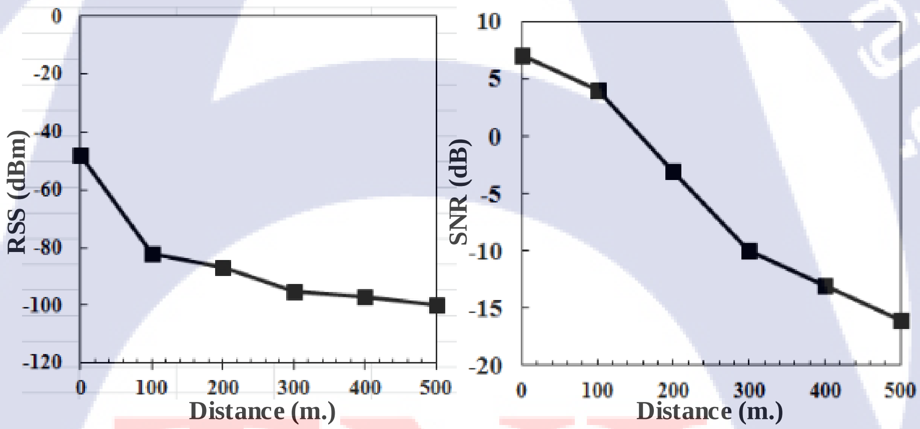

Figure 4.5 The measured RSSI in dBm and SNR in dB versus a distance.

4.3 Positioning Algorithm

In RSS-based algorithms, the tracked target measures the signal strength for received signals from multiple transmitters in order to use signal strength as an estimator of the distance between the transmitters and receivers. This way, the receiver will be able to estimate its position relative to the transmitter nodes. Although RSS is sensitive to multipath interference and a small-scale channel effect that causes a random deviation from mean received signal strength, it is used frequently with unrealistic assumptions. For example, the transmitted power and path loss exponent are already known, and the transmitter antennas are isotropic. According to Pittet et al., the accuracy of RSS for non-line-of-sight (NLOS) and multipath environment is low, which shows clearly that RSS is not the right estimation method for indoor positioning systems. Gigl et al., explored the performance of RSS algorithms for positioning using UWB technology. They also studied the effect of small-scale fading on the system accuracy; however, a simulator based on the UWB channel model 802.15.4a was used to evaluate the algorithms rather than relying on real scenarios for indoor environments. Leininger et al., used maximum likelihood estimator as well as floor plan information to improve positioning in the existence of diffuse multi path for the NLOS environment.

This thesis 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 are Arduino Pro-Mini that processes all signals with Lithium-Ion Battery.

4.5 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, the Free-Space Path Loss (FSPL) can be modeled as

$$P_{\mathrm{R}} = P_{\mathrm{T}}\left(\frac{\sqrt{G_{\mathrm{R}}}G_{\mathrm{T}}\lambda}{4\pi d}\right)^{2} \tag{7}$$

where P_R is a received power, P_T is a transmitted power, G_R is a transmitting antenna gain, G_R is a receiving antenna gain, λ is a signal wavelength, and d is the distance between the two antennas. Eq. (7) can also be described in Decibel (dB) as follows.

$$P_{\mathrm{R}}[\mathrm{dBm}] = P_{\mathrm{T}}[\mathrm{dBm}] - 20\log_{10}(d) - 20\log_{10}\left(\frac{4\pi}{\lambda}\right) \tag{8}$$

It should be noted that real model of (8) 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.

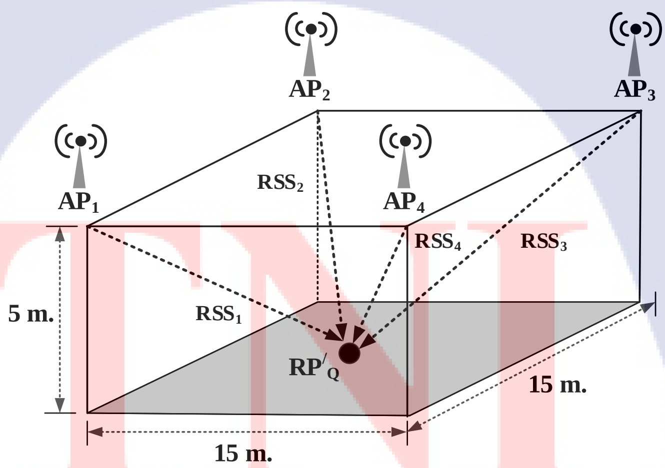

Figure 4.6 System model geometry and area coverage, involving four APs and a single target in a reference point RP/Q

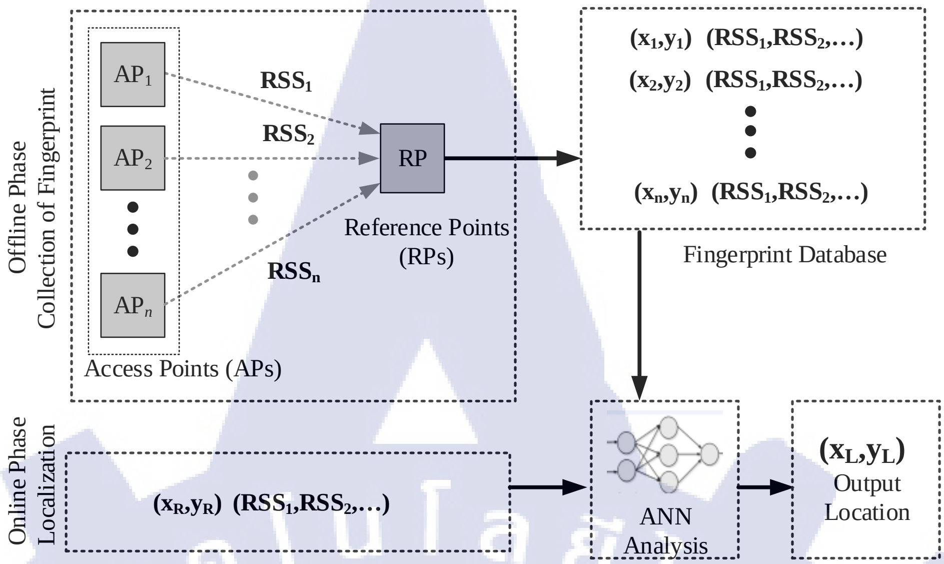

Figure 4.7 The overall architecture of the proposed RSSI-based indoor localization using LoRa technology with fingerprinting database

Chapter 5
Conclusion

5.1 Conclusion

Low–Power, Wide-Area Networks (LPWAN) are projected to support a major portion of the billions of devices forecasted for the Internet of Things (IoT). LoRaWAN™ is designed from the bottom up to optimize LPWANs for battery lifetime, capacity, range, and cost. A summary of the LoRaWAN™ specification for the different regions will be given as well as high level comparison of the different technologies competing in the LPWAN space. Indoor Positioning Systems uses sensors and communication technologies to locate objects in indoor environments. IPS are attracting scientific and enterprise interest because there is a big market opportunity for applying these technologies. There have been various previous surveys on indoor positioning systems. However, most of them lack a solid classification scheme that would structurally map a wide field such as IPS, or omit several key technologies or have a limited perspective; finally, surveys rapidly become obsolete in an area as dynamic as IPS. The goal of this thesis is to provide a technological perspective of indoor positioning systems, comprising a LoRa® technology classify the existing approaches in a structure in order to guide the review and discussion of the different approaches.

This thesis has presented the deployment of a LoRaWAN implemented by Thai people called Universal and Ubiquitous for an application of Internet-of-Things in tactical troop tracking systems. The proposed long-range communication system has been implemented based on a commercially available Raspberry-Pi, GPS and other sensors for geological and physical tracking. Bridge-to-bridge Wifi connection for communication to the server was exploited. The end node can be integrated more than ten types of sensors such as GPS, temperature, humidity, and water sensors. All data can be visualized real-time via monitor station. The proposed system provides not only an emerging long-range communication but also low-power operation in a military campsite within 0.5 kilometers using a transmission power of 4dBi at 433MHz.

As a result, this thesis 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 modules 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 and low-power operation as for an alternative.

5.2 Suggestions and Recommendations

During the experimental process of this research, found that the Received Signal Strength is changed which might be coming from the voltage drop. After checking this root cause, there is occurred from the small battery that used to provide the energy. As a result, the recording of the signal strength decreases and the transmission device stops working. Thus, the antenna should be turned into the experimental area and consider the appropriate energy providing to eliminating this problem.

5.3 Future works

This thesis propose to DTI and awaiting government approval. The next propose for this research methodology has applied for tactical troops tracking systems in military, including prototype and mass production with military grade ; i.e. IP68 in which industrial grade.

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Appendixes

Appendix A

Tactical Troops Tracking Systems Topology through LoRaWAN Communications

Relevant Academic Work

Tactical Troops Tracking Systems Topology through LoRaWAN Communications: In the proceeding of ICAITI 2018 The 2018 International Conference on Applied Information Technology and Innovation, Padang, Indonesia

Tactical Troops Tracking Systems Topology through LoRaWAN Communications

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***Abstract*—This paper presents the deployment of a LoRaWAN communication system as an Internet-of-Things (IoT) for military applications. Such a LoRaWAN system is a relatively new wireless IoT connectivity, and is well suitable for supporting services and applications that require long-range communication to reach end devices. In addition, the LoRaWAN system consumes low power supply and can be operated several years remotely using only on single battery storage. In contrast to short-range or cellular connections, the LoRaWAN system is a promising technology for military applications in terms of highly-secured location-based tracking, and this paper consequently applies to intelligent tactical troop tracking systems. The proposed system comprises the cost-effective gateway using Raspberry-Pi, a microcontroller as a central processing unit with Global Positioning System (GPS) and other sensors for and physical tracking. The proposed system employs four gateways with bridge-to-bridge WiFi connection for communication to the server. The end devices can be integrated more than ten types of sensors such as GPS, temperature, humidity, and water sensors. Knowledge on the exact location of troops and any coalition troops in an area of operational interest can be visualized real-time at base station. The proposed system offers not only essential information for effective tactical decisions but also potentially leads victory in a battle filed.**

Keywords*—*LoRaWAN, Long-Range Communication, Security, tactical troop tracking system, tactical decision, Raspberry-Pi

I. Introduction

Internet of Things (IoT) has been initiated from enabling connectivity on edge devices, and providing new services which have not been available with reasonable cost. Key challenges in the realization of IoT systems and applications are to minimize both edge nodes deployment and maintenance costs. It is because the number of required edge nodes is much higher than that of hand-held devices. Wireless communication protocols, which are specially designed for IoT applications, can minimize the hardware complexity and power consumption of edge nodes. Furthermore, cloud technology providing the common service frameworks can reduce maintenance cost of IoT systems. Table.1 shows the place of LoRaWAN in IoT wireless connectivity ecosystem whilst Fig.1 demonstrates the block diagram of a low-power long-range transceiver module SX1276/77/78/79, operating at 137 MHz to 1020 MHz [1]. In accordance to possible communication ranges, two wireless communication protocols can be classified into two categories, i.e. (i) short-range and (ii) long-range communication protocols. On the one hand, WiFi, Zigbee, and Bluetooth represent the short-range communication protocols, which are suitable for indoor environments. On the other hand, long-range communication protocols can be deployed using LoRa communications [2]. Typically, LoRaWAN has three classes of end-point devices to address different needs reflected in wide range of applications as follows; First, class A or a bi-directional end-device in which end-devices allow for bi-directional communications whereby each end-device uplink transmission is followed by two-short downlink receives windows. This class A operation is the lowest power end-device system for applications that require downlink communication from the server shortly after the end-device has sent an uplink transmission. Second, class B or a bi-directional end-device with scheduled receive slots. Such a class B device opens extra receive windows at scheduled times. In order for the end-device to open receive window at the scheduled time it receives a time synchronized Beacon from the gateway. This allows the server to know when the end-device is listening. Last, class C or a bi-directional end-device with maximal receive slots in which end-devices have nearly continuously open receive windows, only closed when transmitting [3].

Table 2 compares LoRaWAN specifications on different regional spectrum allocations and regulatory requirements. It is apparent that the specification for Europe and North America are well-defined. However, other regions, involving China, Korea, Japan, India, and Thailand, are still being defined by the technical committee. Particularly, Thailand allows a frequency of 433 MHz as a licensed frequency, but the National Broadcasting and Telecommunication Commission (NBTC) is now considering an approval for a frequency band of 920-925MHz. in order to avoid an overlap with GSM band.

As LoRaWAN has recently been developed as a promising technology comparing to those existing short-range and cellular evolutions, research on LoRaWAN is still in early stage. Recently, M. Aref and A. Sikora (2014) presented a short overview on the technologies to support Long Range (LoRaTM), and described the outdoor setup at the Laboratory Embedded Systems and Communication Electronics of Offenburg University of Applied Sciences. It was found that the range directly depends on the link budget, which can be increased by the choice of modulation and coding schemes. The SX127x family from Semtech Corp. is a member of this device class and promises significant benefits for range, robust performance, and battery lifetime compared to competing technologies. J. Petäjäjärvi at al. (2017) studied the coverage of the LoRa LPWAN technology through real measurements. The experiments were conducted in the city of Oulu, Finland, using commercially available equipment. The measurements were executed for cases when a node located on ground or on water reporting their data to a base station. The node operate in the frequency range of 868 MHz ISM band using 14 dBm transmitting power and the maximum spreading factor. The maximum communication range was found over 15 km. on

TABLE I. THE PLACE OF LORAWAN IN IOT WIRELESS CONNECTIVITY ECOSYSTEM.

	(ii) Local Area Network for Short-Range Communications	(ii) Low Power Wide Area (LPWAN) for Internet-of-Tings	(iii) Cellular Network for Machine-to-Machine
Ratio Use	40%	45%	15%
Advantages	Well Established Standard	Low Power Consumption Low Cost	Existing Coverage High Data Rate
Disadvantages	Battery Live Time, High Cost	Emerging Standard	Autonomy, High Cost
Examples	Bluetooth Wi-Fi	LoRa	3G 4G

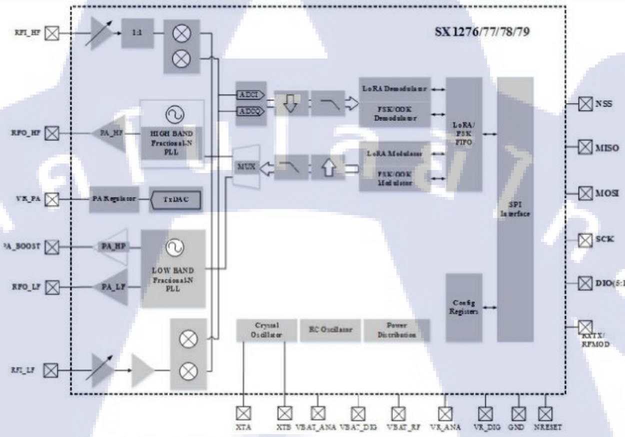

Fig. 1. The block diagram of a low-power long-range tranciever module SX1276/77/78/79, operating at 137 to 1020 MHz.

TABLE II. DIFFERENT REGIONAL SPECTRUM ALLOCATIONS AND REGULATORY REQUIREMENTS.

	Europe	North America	China	Korea	Japan	India	Thailand
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz	433MHz, 920-925MHz
Channels	10	64+8+8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by National Broadcasting and Telecommunication Commission
Channel BW Up	125/250kHz	125/500kHz					
Channel BW Dn	125kHz	500kHz					
TX Power Up	+14dBm	+20dBm type (+30dBm allowed)					
TX Power Dn	+14dBm	+27dBm					
SF Up	7-12	7-10					
Data rate	250bps-50kbps	980bps-21.9kpbs					
Link Budget Up	155dB	154dB					
Link Budget Dn	155dB	157dB					

ground and close to 30 km. on water. Recently, Thomas Wendt et al., (2015) [8] employed EM Microelectronic developed a LoRa™–modulation chip called EM9101 for the 2.45 GHz, which is based on the Semtech technology. This transceiver-modem-design offers an ultra-long range spread spectrum communication and high interference robustness. The spread-spectrum technology is not new, but implemented into a 2.45 GHz frequency based chip which can be taken as add on modem to a standard transceiver chip. The gain for the air-link budget which is more than 20 dBm can be utilized to obtain a huge communication distance. This paper therefore presents the long-range communication system that comprises not only the implemented gateway using Raspberry-Pi but also an end-device using microcontroller with GPS and other sensors for geological and physical tracking. Consequently, the proposed system employs four gateways with bridge-to-bridge WIFI connection for communication to the server. The end node can be integrated more than ten types of sensors such as GPS, Temperature, Humidity, and water sensors. All data can be visualized real-time via monitor station. The proposed system provides not only an emerging long-range communication but also low-power operation in a military campsite within 1.5 Kilometers.

II. LoRa Spread Spectrum Principles

On the one hand, a Traditional Direct Sequence Spread Spectrum (DSSS) system (R.C. Dixon, 1994) [9] has been existed as for an alternative to those of existing modulation techniques. In DSSS system, a carrier phase of a transmitter changes correspondingly to a code sequence. This process can typically be achieved through a multiplication of an original data with a chip sequence. The chip sequence rate is much faster than the data signal, and consequently such a chip sequence spreads a signal bandwidth beyond the original bandwidth occupied by the original data. In order to effectively recover an original data at a receiver, the regaining process is performed by re-multiplying with a locally generated replica of the spreading sequence. In other words, this multiplication process in the receiver compresses the spreading signal back to its original un-spread bandwidth. Typically, the amount of spreading is dependent upon "Chips per Bit", which is a ratio of the chip sequence to the preferred data rate referred to as the processing gain (G_p) in dB, which can be described as

$$G_p = 10\log\left(\frac{R_c}{R_b}\right) \tag{1}$$

where R_c and R_b are a chip rate (chips/s) and a bit rate (bits/s), respectively. Although DSSS has been extensively utilized in data communications, low-cost or power-constrained devices and networks are main concerns in such a DSSS since a highly accurate and expensive reference clock source is required. Moreover, a long spreading code essentially requires time in order to perform a correlation over the entire length of the code sequence, and hence repeatedly and rapidly synchronization is necdceesary, leading to high power consumption [11].

On the other hand, Chirp Spread Spectrum (CSS) system was also developed in parallel particularly for secure communications. The CSS system provides not only low transmission power requirements but also inherent robustness from channel degradation mechanisms, including as multipath, fading, Doppler, and in-band jamming interferers. Therefore, IEEE has alleviated CSS PHY for Low Range Wireless Personal Area Networks (LR-WPANs) through the standard 802.15.4 with the OQPSK DSSS PHY mode [12]. Of particular interest in LoRa Spread Spectrums (LoRa SS), a LoRa modulation addresses all difficulties associated with DSSS systems in order to afford a low-cost, low-power, and robust modulation technique comparing to that of the DSSS communications techniques [13] In LoRa modulation, the spectrum is spread through a generation of a chirp signal that continuously varies in frequency. Consequently, the frequency bandwidth of the chirp signal is equivalent to the spectral bandwidth, leading to equivalence in timing and frequency offsets between transmitter and receiver and significantly reducing the complexity of

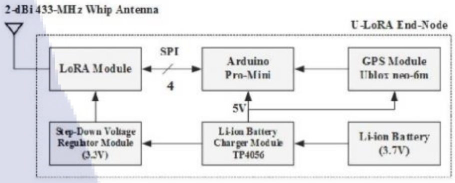

Fig. 2. Block diagram of the proposed Universal LoRa End-Node with GPS Module.

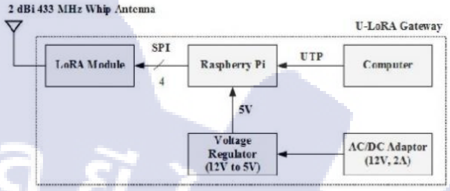

Fig. 3. Block diagram of the proposed Universal LoRa Gateway connecting to a computer.

receiver designs. Subsequently, the original data is chipped at a higher data rate and modulated onto the chirp signal. In particular for LoRa modulation, a variable error correction scheme that enhances the robustness of the transmitted signal at the expense of redundancy is also included, and therefore the nominal bit rate of the data can be re-defined as follows;

$$R_b = SF \times \frac{RC}{\left[\frac{2^{SF}}{BW}\right]} \tag{2}$$

where RC is a rate code, and generally equal to RC=4/(4+CR) where CR is a code rate, generally in a range of 1-4 (Semtech Application Note AN1200.13, 2013).

III. Proposed Tactical Troop Tracking System Topology

The proposed Universal LoRa End Node has been designed as a stand lone device, which can be equipped with other microcontroller. Fig.2 shows the block diagram of the proposed Universal LoRa End-Node with GPS Module. It can be seen from Fig.2 that the end-node comprises a LoRa Module with an antenna operating at 2-dBi and 433 MHz Whip Antenna. The LoRa module is connected to the Arduino Pro-Mini that processes all signals both inputs and outputs. The GPS Module is Ublox neo-6m. The power supply system is a Lithium-Ion Batter (3.7V) that supplies Lithium-Ion Battery Charger Module TP4056. Such a module TP4056 supplies 5V for Arduino Pro-Mini as well as a step-down voltage regulator module of 3.3V for LoRa module. Fig. 4 shows the block diagram of the proposed Universal LoRa Gateway connecting to a computer. The computer is connected to the Raspberry Pi controller as a main microprocessor, which connects to the LoRa Module via SPI. As a main station, the AC/DC Adaptor (12V, 2A) has been exploited for a voltage regulator (12V to 5V). Fig.4 shows the architecture of the proposed tactical troop tracking system. It is seen in Fig.4 that a single LoRa gateway is

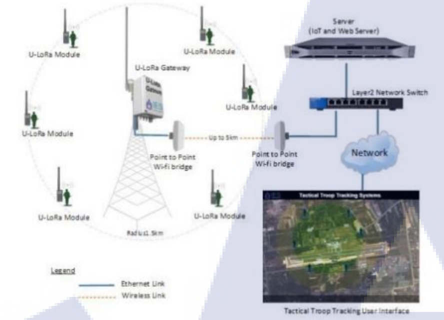

Fig. 4. The architecture of the proposed tactical troop tracking system with a single gateway and a point-to-point WI-FI bridge.

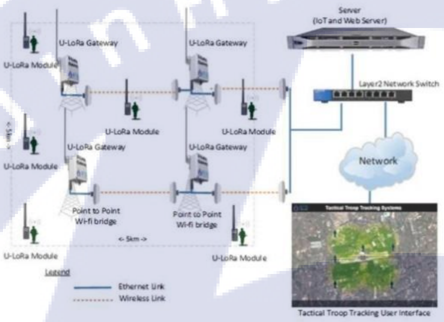

Fig. 5. The architecture of the proposed tactical troop tracking system with a four gateway with four point-to-point WI-FI bridge.

exploited in the centre of an investigation area. The LoRA End-Nodes can be as much as preferred, but there are six nodes demonstrating in this system. All the end-nodes are connected to the LoRa gateway before transmitting to the Layer 2 network switch under IoT and web server. All the data will be transferred to the network before visualizing on the graphic user interface. The system can be extended to a wider range area within 5×5 Kilometers as shown in Fig.5. The systems can be expanded to the tactical troop tracking system with a four gateway with four point-to-point Wi-Fi bridges. Such a system could provide wider coverage. It should be noted that the gateway should be in an appropriate height in order to be capable of receiving signals from each end-nodes, and the electrical surge system should be considered and integrated in order to protect from any possible failures.

IV. Experimental Results

The proposed system has been implemented using commercially available devices. Fig. 6 show the implemented end-node and gateway, respectively. Such devices are a very first implementation in Thailand.

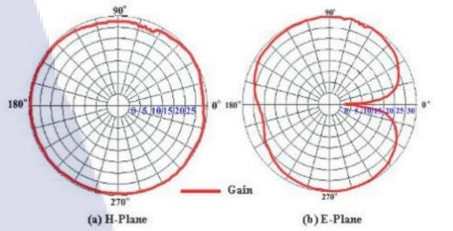

Fig. 6. The radiation pattern of an antenna; (a) H-Plane, (b) E-Plane.

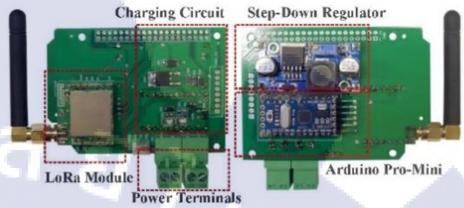

Fig. 7. The assembled two-layer circuit prototype of the LoRa-based communication module with built-in monopole antenna.

Fig. 8. Test for signal strength coverage area at Thai-Nichi Institute of Technology

Performance analysis has been tested at Thai-Nichi Institute of Technology where the gateway was installed at the 6th floor of C-building with a height of 500 meters. The coverage range has been incremented by 100 meters with actual obstacles as depicted in Fig.8. The performances were investigated by received signal strength indicator (RSSI), which is a measurement of the power present in a received radio signal. It should be noted that RSSI is usually expressed in dBm from 0 to approximately lowest at -120 dBm. Typically, a higher value of SNR guarantees the clear acquisitions with low distortions and artifacts caused by noises. The better value of SNR causes the better signal strength, resulting in the better quality of transmitted signals. In this work, the received signals are the Latitude and Longitude obtained from the GPS module. Fig. 9 also plots the measured RSSI in dBm versus a distance in meter. It can be seen in Fig.9 that the RSSI decreases from 0 to -90 dBm within 100 meters. The values are in the region of -90 dBm to approximately -100 dBm within the distance of 100 meters to 500 meters before the signal was lost. Fig.11 plots the measured SNR in dB versus a distance in meter. It is apparent that the SNR is positive till the distance of around 160 meters.

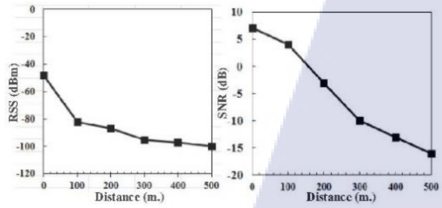

Fig. 9. The measured RSSI in dBm and SNR in dB versus a distance.

The SNR was then decreases to -18 dB at 500 meters. It can be considered from Figs. 9 that the implemented U-LoRa devices both end-node and gateway have been operating very effectively with long distance of 500 meters using only an antenna power of 4 dBi at 433MHz. For an applications in longer distance, the antenna power can be increased depends upon the application requirements. Moreover, military application can exploit other possible frequency channels with a closed wireless network through extranet.

V. Conclusions

This paper has presented the deployment of a LoRaWAN implemented by Thai people called Universal and Ubiquitous for an application of Internet-of-Things in tactical troop tracking systems. The proposed long-range communication system has been implemented based on a commercially available Raspberry-Pi, GPS and other sensors for geological and physical tracking. Bridge-to-bridge Wifi connection for communication to the server was exploited. The end node can be integrated more than ten types of sensors such as GPS, temperature, humidity, and water sensors. All data can be visualized real-time via monitor station. The proposed system provides not only an emerging long-range communication but also low-power operation in a military campsite within 0.5 kilometers using a transmission power of 4dBi at 433MHz.

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