A Long-Range Low-Power Wireless Sensor Network Based on U-LoRa Technology for Tactical Troops Tracking Systems

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***Abstract*—this paper presents the deployment of a LoRaWAN implemented by Thai people called Universal and Ubiquitous (U-LoRa) for an application of Internet-of-Things in tactical troop tracking systems. The proposed long-range communication system comprises only the implemented gateway using Raspberry-Pi but also an end-device using microcontroller with GPS and other sensors for geological and physical tracking. 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 0.5 kilometers using a transmission power of 4dBi.**

Keywords—U-LoRa; LoRaWAN; Long-range communication.

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 edge nodes deployment cost and maintenance cost. 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. Fig.1 shows the place of LPWAN in IoT wireless connectivity ecosystem whilst Fig. 2 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 [2-4]. Typically, LoRaWAN has three classes of end-point devices to address different needs reflected in wide range of applications as follows;

	Local Area Network Short-Range Communications	Low Power Wide Area (LPWAN) Internet-of-Tings	Cellular Network Traditional 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, Cost	Emerging Standard	Autonomy, High Cost
Examples	4.0 Bluetooth Wi-Fi	LoRa	3G 4G

Fig. 1. The place of LPWAN in IoT wireless connectivity ecosystem.

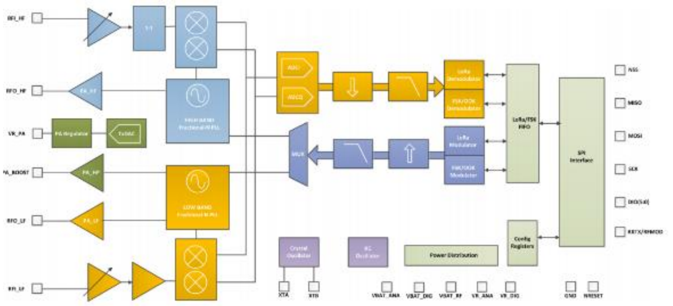

Fig. 2. The block diagram of a low-power long-range tranciever module SX1276/77/78/79, operating at 137 MHz to 1020 MHz [1].

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 [5].

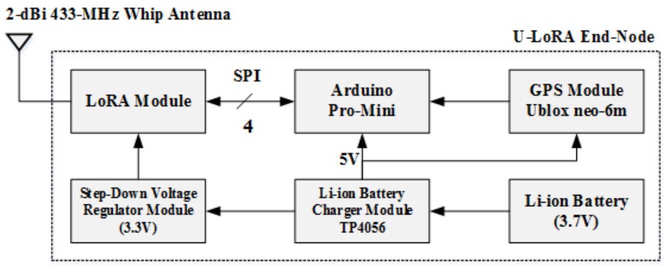

Fig. 3. Block diagram of the proposed Universal LoRA End-Node with GPS Module.

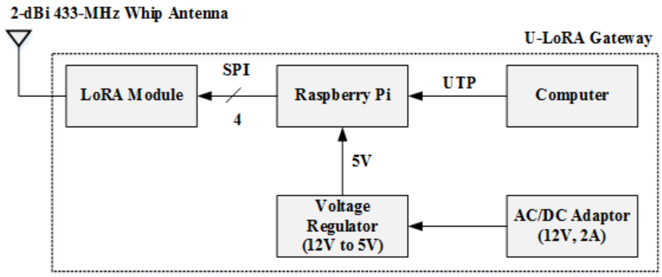

Fig. 4. Block diagram of the proposed Universal LoRA Gateway connecting to a computer.

Mohamed Aref and Axel Sikora [6] 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. *Juha Petäjäjärvi at al.,* [7] 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 ground and close to 30 km. on water.

Recently, *Thomas Wendt* et al., [8] employed EM Microelectronic developed a LoRa™–modulation chip called EM9101 for the 2.45 GHz frequency band, 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. 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. Proposed U-LoRA End-Nodes and Gateway

A. U-LoRa End-Node

The proposed Universal LoRa End Node so called "*U-LoRa*" has been designed as a stand lone device, which can be equipped with other microcontroller. Fig.3 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.

B. U-LoRa Gateway

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).

III. Proposed Tactical Troops Tracking Systems

Fig.4 shows the architecture of the proposed tactical troop tracking system. It is seen in Fig.5 that a single U-LoRa gateway is exploited in the center of an investigation area. The U-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 Layer2 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.6. 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. Implementations and Experimental Results

The proposed system has been implemented using commercially available devices. Fig. 7 (a) and (b) show the implemented end-node and gateway, respectively. Such devices are a very first implementation in Thailand.

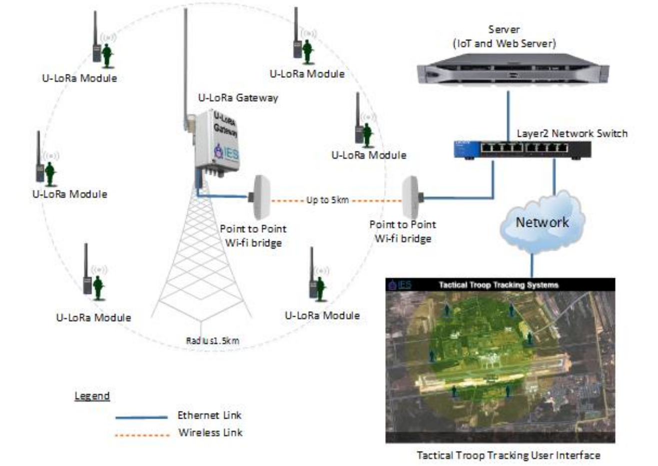

Fig. 5. The architecture of the proposed tactical troop tracking system with a single gateway with a point-to-point WI-FI bridge.

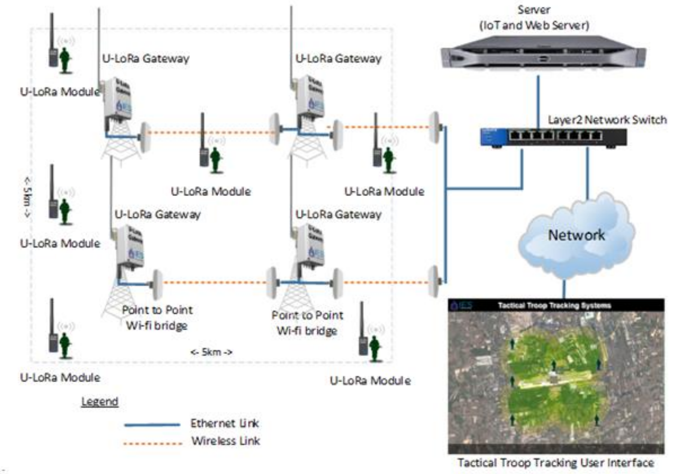

Fig. 6. The architecture of the proposed tactical troop tracking system with a four gateway with four point-to-point WI-FI bridge.

(a) (b)

Fig. 7. Implementations of devices : (a) U-LoRa end-node, (b) Gateway.

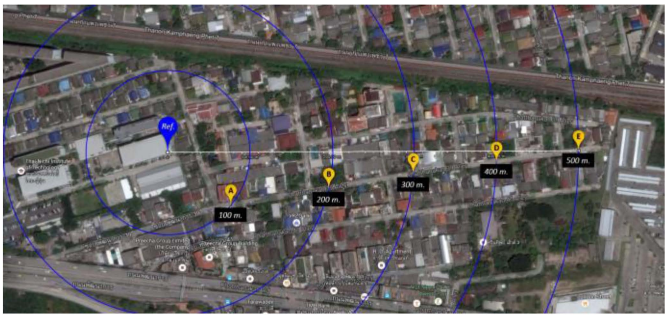

Fig. 8. Test for signal strength coverage area.

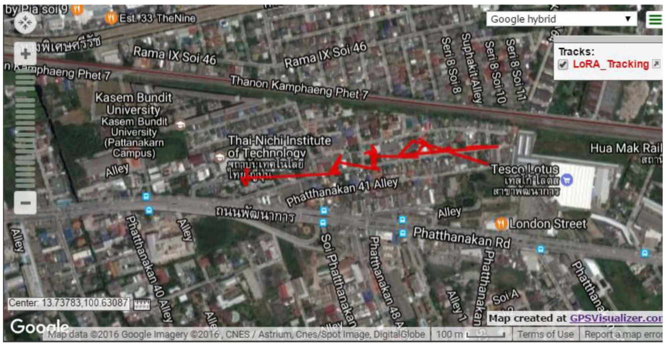

Fig. 9. The trajectory of LoRa test

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. In addition, Signal-to-Noise Ratio (SNR) has also been investigated and is defined as the ratio of signal power to the noise power expressed as

$$SNR = \frac{P_S}{P_N} \tag{1}$$

where P_S is a signal power while P_N is a noise power. Such SNR is a defining factor in order to measure the quality of signal in communication channels. 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. Fig. 9 also shows he trajectory of LoRa test.

In this work, the received signals are the Latitude and Longitude obtained from the GPS module. Fig. 10 plots the measured RSSI in dBm versus a distance in meter. It can be seen in Fig.10 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.

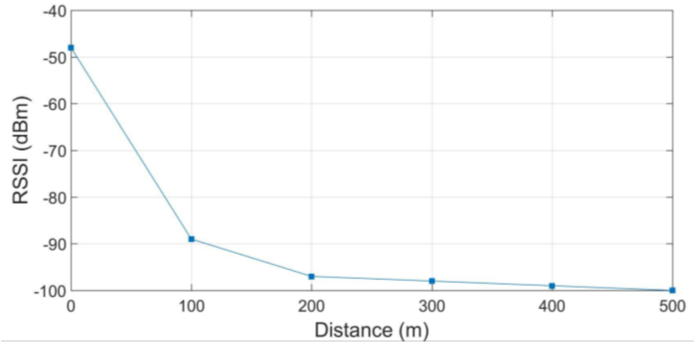

Fig. 10. The measured RSSI in dBm versus a distance in meter.

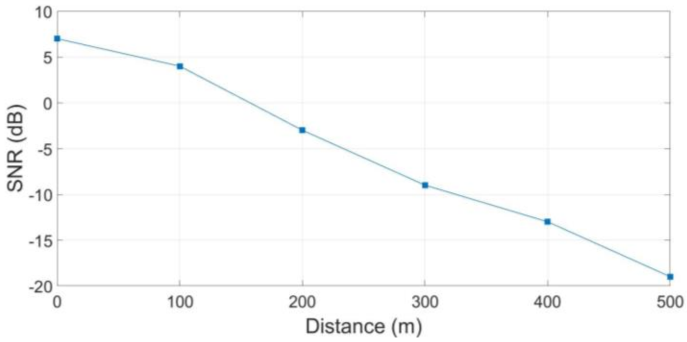

Fig. 11. The measured SNR in dB versus a distance in meter.

The SNR was then decreases to -18 dB at 500 meters. It can be considered from Figs. 9 and 10 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 (U-LoRa) 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.

VI. ACKNOWLEDEMENTS

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