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GPS-BASED LOCALIZATION SYSTEM USING LORA TECHNOLOGY

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ABSTRACT: *LoRa is a Low Power Wide Area Network (LPWAN) technology which has been used widely in recent years. LoRa transmits data with low bitrate, however, it supports a long-range transmission and has a low power consumption. Therefore, this technology is suitable for Internet of Things' applications such as smart cities, precision agriculture, localizing and tracking, etc.*

In this paper, we build a GPS-based localization system using LoRa technology to transmit the coordinations of the objects to LoRa gateway. The gateway then forwards the data to the network server. We also build a mobile application that can access the data from the network server and display the locations of the tracked object on a map. The system can be used to track humans or properties.

Keywords: *Internet of Things, GPS localization, LoRa, Low-Power WAN.*

I. INTRODUCTION

The Internet of Things (IoT) is a communication paradigm which is a network of inter-connected things and connects to the Internet. Thanks to the wired and wireless communication links and protocol stacks, things which are the sensors or actuators send or receive the data to the gateway or other objects [1]. The IoT data can be stored, accessed and analysed via cloud. There are many IoT applications in variety fields such as home automation, industrial automation, medical aids, intelligent energy management and many others [2]. It is predicted that there will be 50 billion connected devices by 2020 [3].

Different IoT applications requires different wireless technologies, from the short range to long range. Most of them are low-power communications. Low-Power Wide Area Networks (LPWAN) technologies can support long-range communication (in kilometers) and low-power consumption. In LPWAN, each node connects directly to the gateways to form a star topology [5]. We can customize the transmission rate, power, duty cycle, *etc.* LoRa which is designed by Semtech Corporation is the newest LPWAN technology. LoRa supports low energy, low bitrate, long range communication with low cost hardwares. Hence, LoRa is suitable for the IoT applications, *e.g.*, environment monitoring, precision agriculture, smart cities, *etc.*

In this research, we monitor humans and properties such as pets, animals, cars, children, elders, *etc.* using LoRa technology. The coordinations of the tracked object is read by Global Positioning System (GPS) receiver attached to the object and sent to LoRa gateways. GPS is a space-based satellite navigation system that provides location and time information to GPS receivers in any weather conditions and anywhere on the Earth with error in meters. Compare to localizing using cellular system, using LoRa is cheap and less power consumption. The structure of the paper is organized as follows. LoRa and LoRaWAN is described in Section II. Section III presents our localization system and Section IV concludes the work.

II. LORA AND LORAWAN

A. LoRa

LoRa is a physical layer specification of LPWAN. LoRa frequencies are 169 Mhz, 433 Mhz, 868 Mhz and 915 Mhz. For example, 868 Mhz frequency band is popular in Europe. It also can work on ten different license bands from 868.1 Mhz to 869 Mhz. Today, the other regions are still defining LoRa band.

Thanks to chirp spread spectrum (CSS), LoRa not only consumes the power as low as frequency shifting keying (FSK) modulation, but also supports a long range communication [4]. CSS modulation encodes the data by using continuous-varying frequency chirps which assures the continuous phase between adjacent chirp symbols in the preamble part of physical layer frame format [4]. Therefore, LoRa can provides accurate timing and synchronization for end-devices.

Three parameters, *i.e.*, bandwidth (BW), spreading factor (SF=7,..,12) and code rate (CR=1,..,4), affect the bit rate of a LoRa link in following equation [4]:

$$R_b = SF \times \frac{4/(4+CR)}{\frac{2^{SF}}{BW}} (bits/sec).$$

For example, a LoRa link with $BW = 175$ kHz, $SF = 8$, and $CR = 1$ yields bit rate $R_b = 4.38$ kbps.

LoRa transmission is also constrained by duty cycle, which is the percentage of time a node occupies the channel. Low duty cycle reduces the congestion when many nodes transmit on the same band and power consumption of the node [7] [8]. For instance, duty cycle is 1% in 868 Mhz band [12]. Each region has different regulations in setting duty cycle for end-devices. For example, 868MHz band in Europe allows maximum duty cycle 1% for any LoRaWAN end-devices. It means that if a node transmits a packet taking 1 second, the node can send data after 99 seconds. If a node having duty cycle 1% send a packet per minute then its time on air is no longer than 0.6s per transmission. If a LoRa link uses a higher SF, the time on air needs to be longer to transmit the same amount of data per transmission (see Table 1).

Table 1. Relationship between SF and ToA, BW = 125kHz, CR = 4/5, 25-bytes payload [16]

SF	Time on Air (ms)
7	46
9	164.86
12	1155.07

B. LoRaWAN

LoRaWAN defines the network architecture and MAC protocol used by LoRa's nodes and gateway. LoRaWAN can provide adaptive data rate by changing SF to trade-off between the link robustness and power efficiency. Strong security is also an advantage of LoRaWAN. Correct keys must be assigned to the node to be able to join to the network.

1. Network architecture

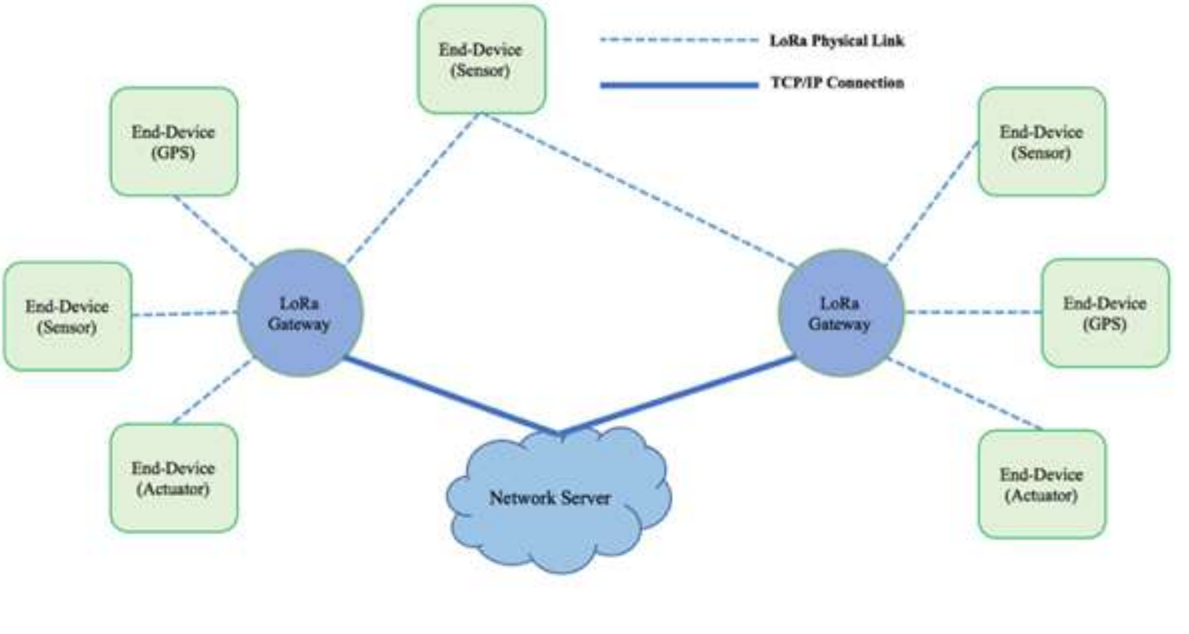

Figure 1. LoRaWAN's network architecture

LoRa network has star-of-stars topology in which the end-devices connect to one or several gateways via single-hop LoRa links [5]. Main components in the LoRa network includes end-devices (nodes), gateways, and network server (see Figure 1).

- *End-device* can be sensors or actuators connecting to one or more gateways via LoRa links.
- *LoRa gateway* forwards the data sent by the nodes to the network server over a TCP/IP connection. Multiple gateways can receive the data messages from one node.
- *Network server* receives and decodes the messages sent from the gateways or send the control messages back to the end-devices via the gateways.

There are three classes of end-devices for various requirements of IoT applications (see Figure 2) [6].

- *Bi-directional end-devices (Class A)*: The uplink window is followed by two consecutive downlink windows. The access method for uplink transmission is Aloha-type protocol. Class A end-devices has the lowest power consumption. The end-devices built in our system is class A end-devices.
- *Bi-directional end-devices with scheduled receive slots (Class B)*: In addition to the class A receive windows, class B end-devices open an additional receive window at scheduled time. Beacons are broadcasted from the gateway to synchronize the schedule between gateway and end-devices.
- *Bi-directional end-devices with maximal receive slots (Class C)*: a class C end-device of Class C keeps receive windows always open and only closes the receive windows when transmitting. Hence, a class-C end-device consumes more power than class A or B end-device. This class is suitable for the IoT application which requires high downlink transmission and low downlink latency.

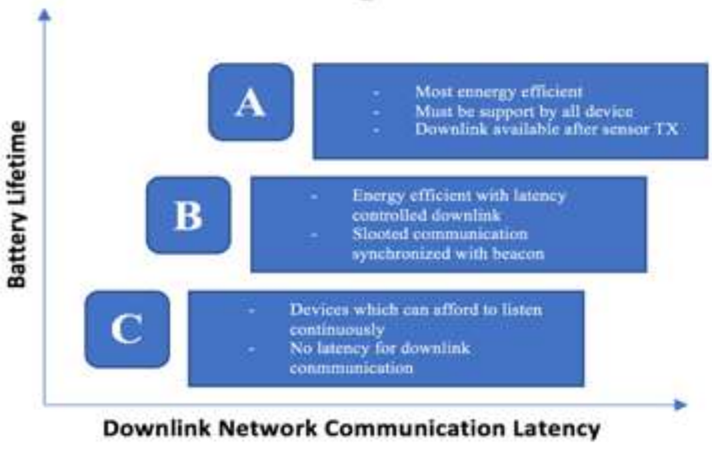

Figure 2. End-device classes

2. Keys Activation and Security

If an end-device wants to join to the LoRaWAN network, it must be configured with required information. There are two ways to active an end-device: Over the Air Activation (OTAA) and Activation by Personalization (ABP) [4]. Theses information should be configured for the end-devices in activation process.

- *End-device Address (DevAddr)*: a 4-byte unique identifier for the end-device. The network identifier is first seven bits and the address of end-device is last twenty-five bits.
- *Application Identifier (AppEUI)*: a 8-byte hexadecimal number the IEEE EUI64 address format assigned by the network server. It uniquely identifies the owner of end-device or the type of devices.
- *Network session key (NwkSKey)*: a 16-byte hexadecimal key configured by the network server and the end-device to ensure data integrity by calculating and verifying the data integrity code.
- *Application session key (AppSKey)*: a 16-byte hexadecimal key configured by the network server and end-device to encrypt and decrypt the payload field of data messages in application.

In OTAA, each new session requires a join procedure (a join-request and a join-accept message exchange). The new session keys (NwkSKey and AppSKey) are obtained by the end-device via a join-accept message. In contrast to ABP, two session keys are directly configured in the end-device.

There are two layers of security: network and application. The network layer security uses NwkSKey to check the validity of the messages sent from the node. The application layer security uses AppSKey to prevent the network operator read or access to the contents of the messages. Two keys NwkSKey and AppSkey are unique per device and re-created on each activation in OTAA. However, they keep the same unless be changed in ABP.

III. GPS-BASED LOCALIZATION SYSTEM USING LORA

A. System architecture

Our system architecture is closely based on LoRaWAN architecture. Figure 4 describes the architecture of our localization system. Our system has four components: end-devices, gateway and network sever and mobile application. LoRa nodes equipped with GPS sensor send its coordination to the gateway via LoRa connection. The gateway sends the data to The Thing Network (TTN) server via an Internet connection. After receiving the messages from the gateway, TTN server push them to Firebase database. Mobile devices can monitor the location of the nodes via a mobile app. The node in our system can be attached to the animals, children and properties to tracking them.

SodaqOne equipped with GPS sensor [10] is used as the end-device development board. It has RN2483 Microchip [11]. The gateway is built from OrangePi and RFM95W transceiver LoRa module made by HopeRF (see Figure 4). The antenna gains is 5dBi. The gateway and end-devices are set to operate Class A which is a typical class in most of IoT applications. Currently, the gateway is built as the single channel gateway operating on 867.9 Mhz frequency. The main role of the gateway is “listen” the cooditations sent from end-devices and forward them to the TTN server.

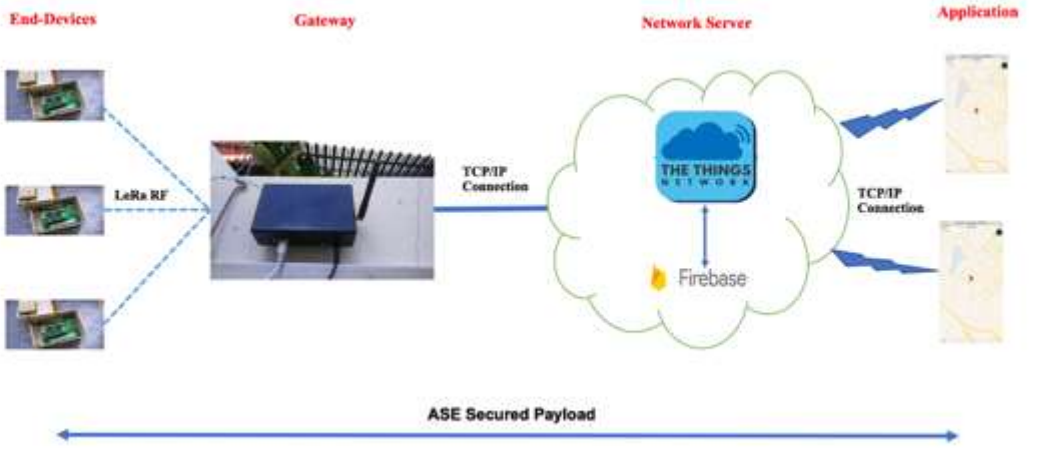

Figure 3. GPS-based localization using LoRa communication

a) LoRa gateway b) End-device

Figure 4. LoRa gateway and LoRa nodes in the localization system

The parameters of the end-devices in our system is set as follows:

- Fix Interval = 1 minute/packet - suitable for tracking moving object.
- Minimum satellite = 4 satellites - more accurate GPS
- ADR (Adaptive Data Rate) = False - ADR is suitable for static nodes [15]
- BW = 125 kHz - compatible with almost cases and not cross the regulation of 866 MHz band.
- CR = 4/5 - decrease time on air.
- Duty Cycle = 1% - prevent packet lost happen when using small interval.
- SF = SF7 - better data rate, shorter time on air for testing.

The total length of messages are 25-bytes include: 13-bytes for LoRaWAN header and 12-bytes for application payload. The transmit power of GPS node is set 14dBm and Spreading Factor is 7. If SF increases, the time for sending a packet (time on air) also increases.

End-device needs to be configured to join to our system. First, we set the Device EUI to distinguish the devices. We then set up the end-device with DevAddr, AppSKey and NwkSKey, provided by TTN network server for joining Activation by Personalization mode.

The gateway needs to register to the network server with its MAC address. We use TTN as a LoRaWAN network server [12]. When an end-device joints to the network, TTN server assigns the address and authenticated keys (DevAddr, NwkSKey and AppSKey in ABP) for the node. The gateway receives messages sent from the nodes in its coverage and uploads the messages to TTN server via Internet connection. TTN server analyses the fields in the receive messages to extract the required data, *e.g.*, coordinations, RSSI, SNR, … The keys and addresses in the message headers sent from end-devices must be match before the received data is stored in TTN's temporary storage. The data is transformed to JSON objects in which the format is customized by developer (see Figure 5).

Figure 5. Define the data format on TTN

TTN does not support a permanent database. The data is only stored temporarily at TTN server. We build a simple backend written in Node.js to track and push the data to Firebase supported by Google after being processed by TTN server (see Figure 6). Firebase is a database that stores data in JSON format and easily to access in real-time [13].

An IOS mobile application is developed using Swift language to access the coordination of the tracked node from mobile device (Figure 7).

Figure 6. Back-end command prompt running on Windows

Our system passes all the test successfully. The GPS location have the error in 5-10 meters. Figure 7 shows the positions of the tracked node on the screen of the mobile app and Figure 8 describes the received signal strength measured in area around the gateway.

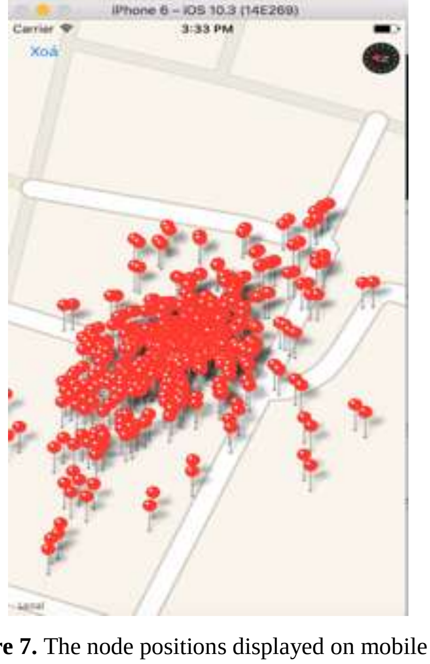

Figure 7. The node positions displayed on mobile app

The concentration of points shows the node's location. The system receives signal every minute from 7AM to 9AM at the same point, there is no lost packet phenomenon. There are up to eight satellites at most precise point and only three at points having high error.

Figure 8. LoRa signal strength

To test signal strength, one node is programmed to transmit 25-bytes signal every 20 seconds. We move the node far away from gateway until completely lost the signal. We collect position and signal's time on air, and RSSI at every transmit time events. The results are shown in Figure 8.

Our system can be configured to be suitable for different environment. For instance, in urban we can reduce Spreading Factor for better transmit time. Battery or solar panel can be used for the power supplies of the LoRa nodes and gateways. Our proposed system satisfies the important requirements of IoT such as security, precision, energy saving, synchronization, *etc.*

IV. CONCLUSIONS

LoRa is the new technology in Low-Power Wide Area Network which offers a long-range communication and low-power consumption and is very suitable for IoT applications. We have presented our system which is built to localize the objects using GPS sensor and LoRa technology. Our system is closely based on LoRaWAN network architecture. Our system can be used to monitor humans or properties in kilometers away from the gateway.

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HỆ THỐNG ĐỊNH VỊ DỰA TRÊN GPS DÙNG CÔNG NGHỆ LORA

Ngọc Thiện Nguyễn, Tấn Tài Lê Minh, Hùng Thuận Nguyễn Phan, Lưu Phương Võ,
Minh Đức Đặng Ngọc, Tuấn Anh Lê

TÓM TẮT: *LoRa là một công nghệ truyền mạng diện rộng công suất thấp đang được sử dụng rộng rãi trong những năm gần đây. LoRa truyền dữ liệu với tốc độ thấp, tuy nhiên, LoRa cho phép truyền với khoảng cách xa và rất tiết kiệm năng lượng. Chính vì vậy, công nghệ này phù hợp với những ứng dụng Internet vạn vật như thành phố thông minh, nông nghiệp chính xác, định vị và theo dõi vị trí,...*

Trong nghiên cứu này, chúng tôi xây dựng một hệ thống định vị sử dụng công nghệ LoRa để truyền tọa độ GPS đến các trạm gateway, và từ đó được truyền đến cơ sở dữ liệu để lưu trữ và xử lý. Một ứng dụng di động cũng đã được phát triển để có thể theo dõi vị trí của vật thể. Hệ thống này có thể được áp dụng để định vị con người và đồ vật..