Exploration of the LoRa Technology Utilization Possibilities in Healthcare IoT Devices

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Abstract—**Older people who live home alone can fall and lose consciousness. They are unable to call for help, what can cost even their lives. They should be monitored and if specific events occur, emergency service should be automatically notified about event description and GPS coordinates for the person to be easily located. IoT is not only modern trend, but it is also an affordable solution that could be integrated into our everyday lives. In this paper, we analyze LoRa technology using our low-cost Arduino end nodes to discover whether LoRa is suitable for person monitoring in urban areas. We propose the required steps to optimize end devices and base stations for maximum range and packet delivery rate, in order to help older people.**

I. INTRODUCTION

Based on data collected in years 2010-2012, EuroSafe has announced that 29% of people above 60 died each year due to fall injuries [1]. As statistics shows, this is a serious problem. Older people tend to be less confident when moving after first fall, which also increases the risk of another fall. We cannot predict someone's fall. However, according to Semtech (i.e. a creator of LoRa), we can build wearable devices that would send an alert with GPS coordinates, which could not only help older people get help as soon as possible, but also make them more confident when moving. This does not cover only fall detection, but many other problems related with monitoring of patients' wellbeing could be realized using the LoRa technology.

LoRa is not a real-time tracking technology and is not sufficient for critical real-time applications that need immediate response [2]. We focus on examining the possibilities of using LoRa technology for monitoring of patients using wearable Arduino nodes. It may not be fall-detection scenario, but it can be the first step towards using LoRa in medicine. The idea of using LoRa in medicine comes from its low power consumption and long-distance data transmission.

In this paper, we try to build cheap and wearable end nodes (EN) that could establish a reliable and secure connection with a base station (BS). We focus mainly on LoRa signal propagation and EN power consumption. We use features that are supported by LoRa natively, such as AES-128 encryption, different frequency channel hoping, and use of different spreading factors for each channel [3]. We also register devices using the so-called Over the Air Activation (OTAA) to increase security [3]. Our goal is to minimize energy consumption. As described in Section 3, we have tested a solution based on Arduino Uno board, but it was not power efficient, which is a requirement for development of mobile nodes.

It is not recommended to use Arduino platform for critical applications, as described by Arduino Community [4]. However, it is sufficient for prototyping, since it is cheap, well-documented, open-source, and has a lot of libraries and extensions for testing purposes. Diversity of libraries can result in selection of a better solution for the described scenario. The good documentation can help in writing our own library or function when needed.

The rest of the paper is organized in the following way. Section 2 describes existing LoRa solutions in healthcare or monitoring in urban areas. Section 3 covers background information regarding the LoRa technology and analysis of LoRaWAN protocol coverage and actual range in urban areas, which are two of the key features. Finally, we introduce our proposed solution using Arduino EN and discuss its power efficiency. We also present results of our measurement, focusing on indoor signal propagation of the proposed end node. Section 4 concludes the paper.

II. RELATED WORKS

Semtech has written an application brief about fall detection [5]. However, to our best knowledge, there is no research paper properly describing utilization of LoRa in fall detection. The application brief does not include any technical details, nor does it mention any successful implementation in a real-world scenario. However, Semtech has announced its first utilization of LoRa in another health care area. The first paper [6] announces usage of LoRa technology to monitor people with dementia by sending GPS coordinates. The second one [7] describes monitoring people with Alzheimer to prevent getting lost in cities or larger towns. Unfortunately, documentation for both solutions is not publicly available.

There is a commercial solution for fall detection, called Angel4 [8]. According to its documentation, it uses Bluetooth Low Energy (BLE) and requires a smartphone to be nearby (10–20m) when the fall is detected. The solution uses 2 AAA batteries that cannot last for several years due to a discharging rate. This is a good starting point for a developer, but the solution lacks some LoRa features, such as long-distance communication and low power.

In [9], the researchers have investigated signal propagation and packet loss for person monitoring in healthcare at the University of Oulu. In the presented solution, industrial BS, Kerlink IoT LoRa gateway, was put 24m above the street level on top of the University of

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Oulu to measure LoRa coverage. The area of 240x320 m was covered and signal strength on different floors was measured. Semtech LoRa Mote, serving as EN, was attached to a volunteer. He was doing his daily routine, which includes moving between different rooms, eating lunch, washing hands, and so on. The nodes were using frequency channel hopping, as would be the case in real environment. More than 90% of packets have been successfully delivered. However, the location of BS was not optimal, because the placement of BS was based on the existing infrastructure. The next work [10] focused on a packet-error rate using different spreading factors. A signal coverage heatmap is presented in the conclusion. The researchers have proved that LoRa is suitable for indoor monitoring for loss-tolerant applications. The area of 300m could be covered with 19.5% packet loss.

It is not clear if LoRa technology is sufficiently usable for patients monitoring. To our best knowledge, there are no publicly available documents in field of monitoring patients' location, focusing on indoor signal propagation and energy consumption of ENs. However, there are indicators that LoRa could be a low-power replacement for GPS tracking solutions [11]. LoRa devices do not require additional equipment to locate someone's position. It has been tested in real scenarios and is well-documented. It requires receiving data from at least three gateways to get EN's coordinates which requires good infrastructure and reliable BSs. The average accuracy of LoRa localization is about 200m, which is not sufficient for monitoring of patients' location. The solution would be quite useless in crowded city areas, but it can still serve as an indicator that a patient has left the area where he/she should be located.

III. Using LoRa for People Monitoring

Firstly, we try to clarify some of the basic terminology. LoRa is a physical layer modulation based on Chirp Spread Spectrum, also called LoRa MAC, which can send small amount of data on long distances with minimal power consumption [9]. Spreading factor (SF) is a ratio between symbol rate and chip rate. Lower spreading factor decreases the airtime per packet but has lower signal-to-noise ratio (SNR) and vice versa [12]. Selection of SF depends on the Network Server (NS) settings [3]. If the received signal strength (RSSI) is good enough for data to be read, the SF is lowered and vice versa. This ensures also the capability to reduce power consumption when the EN is close to the BS. However, it takes effect based on previous measurements (i.e. historical statistics); thus, it might not result in optimal strategy using mobile nodes. Frequency channel hopping is a technique to transmit data on randomly selected channel to avoid link congestion and enable many devices to communicate with each other. Bandwidth is a range of frequencies used for communication. A transceiver can send data using another channel, if the intended channel is congested. Higher bandwidth decreases airtime of the packet along with noise resistance and vice versa [13].

According to [2], a single LoRa module can be powered by 2000mAh battery for nine years. However, there is no information regarding the battery type; thus, this claim cannot be verified. Due to a discharging rate, there are only a few types of batteries that can last for so long. The information does not also include power consumption of EN and other technical parameters, such as data frequency or SF that could shorten its life. LoRa has very good resistance to interference and uses unlicensed industrial, scientific, and medical (ISM) bands, which diverse depending on the region [11]:

- 868.1MHz in Europe,
- 915MHz in the USA,
- 433MHz in Australia and Asia.

LoRa ENs use channel hoping to deliver network packets even when the channel is congested, which is very common especially in cities or larger towns [10]. Two ENs send data on the same channel using different SFs, which are orthogonal to each other [12]. It basically means that two nodes can simultaneously send data on the same frequency but using different SF [13]. These characteristics designate LoRa to be a reliable solution when multiple ENs communicate with BS at the same time. The maximum number of ENs communicating with a single gateway is to our best knowledge not known.

A. *LoRaWAN Procol Stack*

LoRaWAN is a protocol stack maintained by LoRa Alliance [12]. LoRaWAN networks use a star topology. A typical LoRaWAN architecture is illustrated in Figure 1. LoRaWAN networks consist of several components [3]:

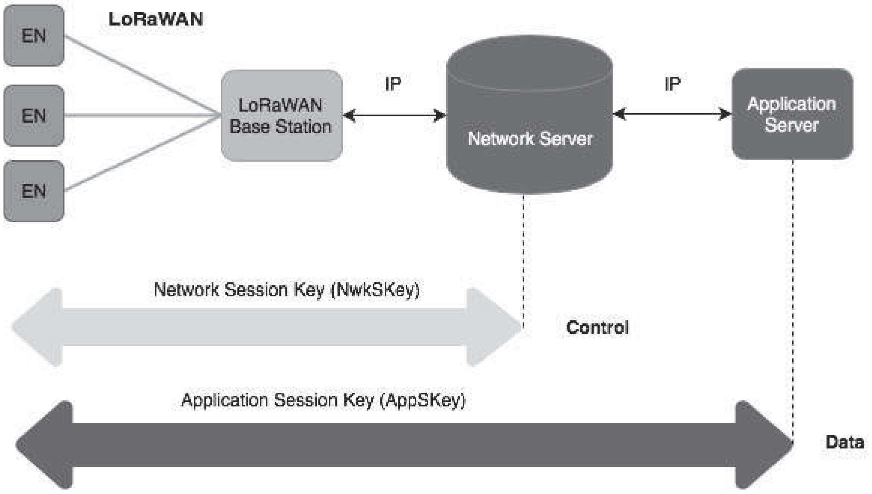

Figure 1. LoRaWAN network architecture scheme, based on [3].

- End nodes (EN) collect data from sensors and send it to BSs.
- Base station (BS) forwards packets from EN to NS and vice versa.
- Network Server (NS) is responsible for network and BSs management, choosing the right SF for end devices and storing Network Session Key (NwkSKey).
- Application Sever (AS) is used to store and display data in a human readable form. It also stores Application Session Key (AppSKey) derived when an EN is trying to join the network.

In LoRaWAN networks, a packet is usually received by several BSs and forwarded to a single NS via IP network [12]. NS picks a packet with the best signal and sends it to AS [3]. It also chooses the best spreading factor based on the previously received packet. NwkSKey is used to encrypt LoRaWAN control packets and AppSKey is used to encrypt data between AS and ENs. There are two activation methods used to connect ENs. A less secure one is Activation by Personalization, for which the AppSKey and NwkSKey are hardcoded into the device and remain unchanged for node's lifetime. It could be used with a single-channel gateway for testing purposes, because it does not require LoRa gateway downlink possibility. The more secure method is Over the Air Activation (OTAA). When a node is joining the network, it receives NwkSKey generated by NS and AppSKey generated by AS. EN rejoins the network each time the device is restarted.

The proposed test network uses The Things Network (TTN) cloud service [14]. We have chosen this solution to focus on ENs. However, it is not clear if TTN uses NS properly, because the SF does not change even if we are changing the distance from the BS after device registration.

B. *Requirements for Application of the LoRa Technology in Healthcare*

According to Semtech [2], the LoRa technology is scalable and able to cover wide area. It performs well on long distances sending few bytes periodically, as presented in [9]. Other key features are high resistance against Doppler Effect and low power consumption, which makes it useful for monitoring of mobile objects scenario [2]. The security is also important, as it is frequently being underestimated. We do not want someone to misuse location data or get personal medical information (e.g. heart rate). As a result, a developer should use a full-featured LoRaWAN gateway with downlink capability for OTAA to work.

We have created BS using Raspberry Pi (RP), running Raspbian Stretch Lite, and LoRa/GPS Hat from Dragino v1.4. After initial testing, we have found out that a single channel solution is not sufficient due to 50% CRC errors and no support for the OTAA activation, which increases risk of compromising payload data. During the testing, EN has been placed in an outdoor location, just 500m from the BS. Based on these tests, we have replaced Dragino Hat with the iC880a concentrator, which supports listening on eight channels and provides downlink capability. We have placed the concentrator (attached to RP board) on the 8th floor of the standard 8-level high building in Bratislava. The 7-dBi indoor generic antenna has been attached to the i880A concentrator. Due to high power consumption and requirement to be always listening, the BS has to be powered from the grid. The antenna and its location are shown in Figure 2. The gateway runs the standard TTN Linux gateway software, which is available on GitHub [15]. The software provides a possibility to collect data and display them using the TTN Console tool in a web browser [14].

Figure 2. Placement of an indoor antenna on the 8th floor.

C. *End Nodes*

The Arduino Uno board has been created for a rapid prototyping and not for low-power scenarios. Due to its voltage regulator, it is not possible to save enough power to use it as a battery-powered EN, as we have discovered in our early research. However, it could still serve as a static sensor plugged in an electrical outlet. We have discovered that even in the sleep mode, the Uno board uses 34mA, compared to the initial 46.5mA. This saves 27% of power. The current in the sleep mode should be several μA to run on a single battery for several years.

We have proposed using Arduino 101. It has the same pins and supports the same shields as Arduino Uno. In contrast, it uses the Intel Curie 32-bit processor, which is not compatible with the Uno's 8-bit microcontroller ATMega328P-PU and cannot run the same code. Different libraries must be used for both solutions. Arduino 101 has also a built-in accelerometer, which could be used for fall detection, and can be equipped with a pulse meter. The whole board is powered by 3.3V, which makes it a better candidate for low-power scenarios than the Arduino Uno Rev 3 board. To add the LoRa transceiver capability to the 101 and Uno boards, we have used LoRa Dragino Shield with a 2dBi antenna. The shield uses a RFM95W LoRa compatible module that uses the RF96 LoRa transceiver.

We have not found this solution reliable in the fall-detection use case. During our test measurements, the TTN BSs were not able to receive data that were sent by a node placed on the floor or under the table, which is critical for utilization in fall detection. This issue could rise due to board shielding. We recommend further investigation in this scenario for a conclusion to be made.

As presented in Figure 3, we have also tested Arduino Pro Mini due to its low power consumption. It uses the 3.3V power supply and has 8MHz Atmel microprocessor. The board is small enough to be wearable and it has enough pins to attach the RFM95W module. There are

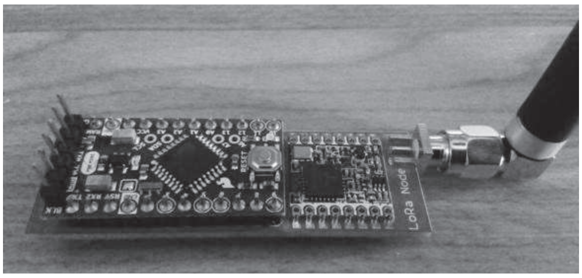

Figure 3. The Pro Mini node with the LoRa module.

some pins left for some sensors to be attached (an accelerometer or a pulse sensor). The RFM95W module has been selected, because it does not have any implementation of the LoRaWAN stack, thus a developer can load a desired LoRaWAN library [16]. There is also a wide range of libraries for this purpose. After early testing, we have chosen the Arduino-LMIC library [17]. Other libraries were not well-documented or did not implement LoRaWAN features. The selected library is also recommended by TTN users. The library is a slightly modified version of LoRaWAN in C, created by IBM in Switzerland. It implements the AES-128 encryption standard and basic transceiver functions. It has an up-to-date documentation and repository, so it is a good starting point for new LoRaWAN developers.

Another used library is a lightweight Low-Power [18] Arduino library for Atmega328P processors (i.e. suitable for both, Arduino Uno and Pro Mini). The reason why we have used this library and not the built-in sleep function is that the Low-Power library saves more energy in the sleep mode [19].

Very critical is the attachment of an antenna. It should not touch any object while being worn, in order the signal could propagate clearly, increasing the chance for transferred data to be received by a BS.

D. Optimization of LoRa Coverage

We have formed some recommendations for implementation of BSs, based on the results of our research and we have taken into account results from a similar research in Prague [20].

Place a BS on the top of a high building in your surrounding [9]. We have placed a single-channel gateway at an altitude of 200m above sea level and it was not able to transmit through the nearby hill located just 300m away from the BS. After we have placed it about 50m higher, the connection between EN and BS has been established.

A developer should prefer an outdoor omnidirectional antenna to an indoor antenna and use a short and reliable cable between the antenna and BS to avoid signal loss and interference on the wire before transmitting data through antenna [9].

As mentioned in Subsection B, we have succeeded in creating LoRaWAN BS that listens on eight channels. It is based on Raspberry Pi 3 model B and the iC880a concentrator with the SX1257 transceiver.

E. Power Efficiency

We were not able to measure exact current of proposed node, but we can still calculate it approximately.

According to Sparkfun [19] (creator of our Arduino Pro Mini board), their 8MHz 3.3V Pro Mini board current is 6.48mA during an awake period. If we use the Low-Power library, we can minimize the current in the sleep mode to 4.3µA, which is sufficient for a low-power scenario. To minimize power consumption to such a low level, it is expected from a developer to mechanically remove a voltage regulator, along with a built-in power LED. The regulator could shorten node's life, when battery voltage goes under a certain level. The LED is always turned on, consuming a significant amount of current. In addition, the RFM95W module has current 29mA while transmitting with output of +14dBm. The current could also be 120mA if we decide to transmit with output +20dBm. The sleep current is maximally 1µA [16].

Based on the facts above, we have developed a LoRa node with very low power consumption. Notice, that we have not attached any sensors (just simulated them), which have also their own current draw.

A battery has to be selected carefully. There are only a few kinds of batteries, which can last for several years due to a discharging rate. The LiSOCI2 batteries have a discharging rate about 1%, and thus they are to our best knowledge suitable candidates for powering a low power EN. In our test scenario, we have used a 3.6V LiSOCI2 battery.

F. Measurements

In this section, we present the results of our measurement, which has taken place at the campus in Bratislava. The campus consists of four blocks of buildings (marked A – D). Each block contains four 8-level high buildings (marked 1 – 4). Our BS has been placed on the 8th floor of the B1 block.

The measurement was focused on LoRa indoor signal propagation using the proposed Pro Mini node. The Pro Mini node was sending packets with a 6B payload, consisting of a current battery voltage measurement value in mV. The radio frequency output has been set to +14dBm and a data rate of SF9BW125 has been used. Approximately 79% of all packets have been successfully delivered to the BS. This includes the fact that the D block has almost no LoRa coverage. Thus, actual packet delivery rate should be higher. The blocks A1 and A2 have been under reconstructions, so it was not possible to enter them.

The results show values of RSSI and SNR and displays device location on the map using the TTN Mapper tool [21]. In Figure 4, values for RSSI and SNR for each successfully delivered packet are presented. Notice that most of the time, the RSSI value is near -120dBm, which

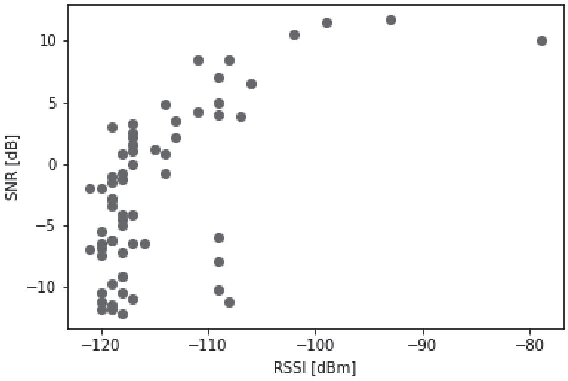

Figure 4. RSSI and SNR for successfully delivered packets.

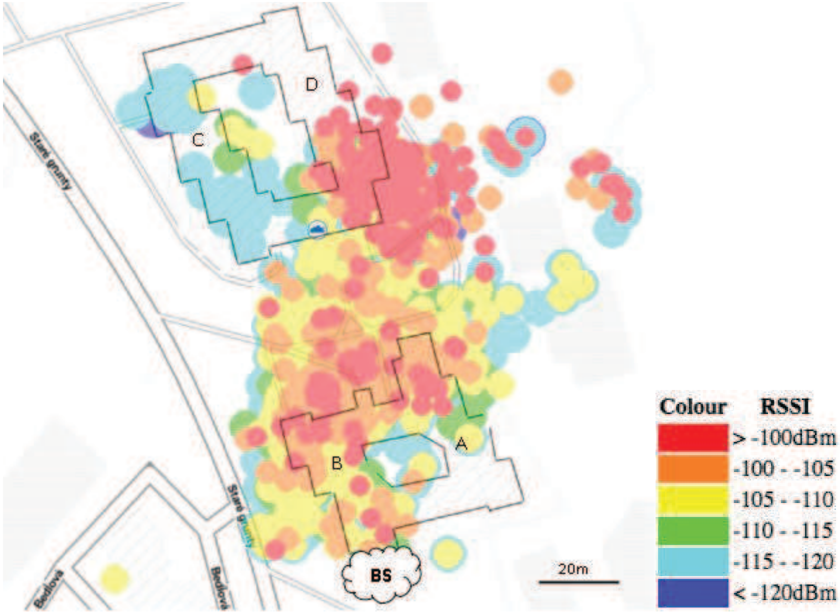

Figure 5. Heatmap of LoRa coverage.

is poor, and a lot of packets had been delivered with signal close to noise threshold (SNR value around 0). However, the signal is still readable and CRC checksum is valid, so it could be processed by AS.

Figure 5 presents a position of an EN in comparison to the gateway. The location of BS is marked with a cloud symbol. The best results, marked by red color on the heatmap, can be found closer to BS and also outdoor or in environment with clear sight to the BS location. Coverage in the C block is rather limited; however, LoRa was capable of reading those packets. The D block has good coverage in the front due to clear view of BS, but none for the buildings in the back.

IV. CONCLUSION

In this paper, we have discussed a potential utilization of the LoRa technology in healthcare IoT devices, focusing on battery-powered end nodes with low power consumption. Based on our testing, we do not recommend using LoRa for a fall-detection scenario before further investigation (the LoRa connection was unreliable when the end node was on the floor during the testing). However, the LoRa can still be used for less critical applications in healtcare (e.g. patients' location, heart rate or temperature measurements). We propose using the Arduino Pro Mini as an end node, because it is affordable and has very low power consumption. Moreover, this device is small enough to become wearable.

In further research, we plan to focus on BS and thus replacing the TTN network infrastructure with a custom solution for easier control and management of BSs, ENs and the collected data. We plan to test a pulse sensor with Arduino 101 and save measured data to the device memory or to a person's smartphone, since it is usually located nearby. If we succeed in lowering Arduino 101 power consumption to a minimum, we plan to develop an Android application to pair the device with a smartphone and use Bluetooth Low Energy when there is no LoRa coverage at all in the measured area.

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