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Establish Connection Between Remote Areas and City to Improve Healthcare Services

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Abstract- **LoRa is a proprietary technology developed by Cycleo SAS and it was acquired by Semtech in 2012. LoRa utilizes the license-free ISM band and by leveraging on LoRa's low power and long-distance transmission platform, it connects healthcare personnel in remote areas with medical specialist in urban areas in real time. A medical personal or a traditional midwife can consult medical specialist in the city regarding on a specific symptom or disease. We developed a device that is capable to send out request for emergency service, an e-stock management system and there is a medical symptom database built into it. The device is comprised of 2 Raspberry Pi model B, 7-inch touch screen and 2 Dragino LoRa/GPS shields operating at 915Mhz. A Graphical User Interface (GUI) was designed as a platform to connect the two users. We also evaluated the feasibility and practicality of this long-range transmission platform.**

Keywords – LoRa, long-range data transmission, medical database, low-power, medical IoT

I. INTRODUCTION

The lack of medical facilities in remote areas is because of disproportional number of peoples it is servicing. As compared to urban areas where the population is bigger, it is logical to concentrate more medical facilities in those areas as compared to remote areas where small community live further apart from other small communities. Hence, it is much harder to provide universal healthcare to folks living in remote areas because of accessibility issues. For example, there are a lot of indigenous tribes or communities that are still living in places that are only accessible by 4x4 vehicles or strictly by boat. Besides that, most of these places have minimal mobile network coverage that makes any communication hard. Until today, 42.2% of the total population in Sarawak are still living in remote areas [1]. Many of these communities still rely on traditional medicine to cure common diseases.

In many cases, folks living in remote areas are neglected in healthcare aspect as medical facilities are not concentrated in rural areas. Hence, the response time for an emergency requested from these areas are often lengthy[2]. Besides that, because of the unreliability of telecommunication network in the remote areas, the network conditions are often unpredictable. Hence, there is a need for an innovation in communication protocol which does not rely on the mainstream GSM network to send messages. Besides that, it must consume little power and it also must be battery powered and cheap so that it can be deployed in remote areas which might have limited electricity source. Considering all these factor, LoRa communication protocol is chosen as the transmission protocol in this project.

LoRa is a communication technology that features ultra-long range spread spectrum communication and high interference immunity whilst keeping power consumption to the minimum. The only downside for LoRa technology is it has a slow data transfer rate and require a line-of-sight. Typical WAN network using 802.11 standard has a small operational radius and has a low tolerance towards noise. Hence, because of LoRa's low cost, long-range, low power consumption capability, many hobbyists use LoRa as a passive sensor that collect data from the node. Data is then pushed to the application server and processed. Currently, LoRa technology is divided into two types. LoRa, which contains only the link layer protocol and can be used as a point to point communication between nodes (Fig 1(b)& Fig 2(b)). While LoRaWAN includes the network layer (Fig 1(a) & Fig 2(a)). LoRaWAN can be utilised in a way where there are many nodes connected to one gateway and the gateway can push data received to the application server. LoRaWAN is more suitable to be deployed in a scenario where there are hundreds of end nodes sending data to the gateway simultaneously while LoRa is suitable for a simple point to point communication between 2 nodes with the benefits LoRa technology bring. Hence, the potential of LoRa technology is investigated in this paper since we only need a simple point to point communication. The system can be expanded to LoRaWAN in the future once

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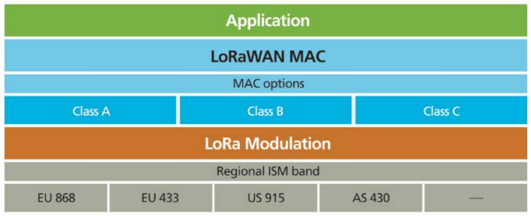
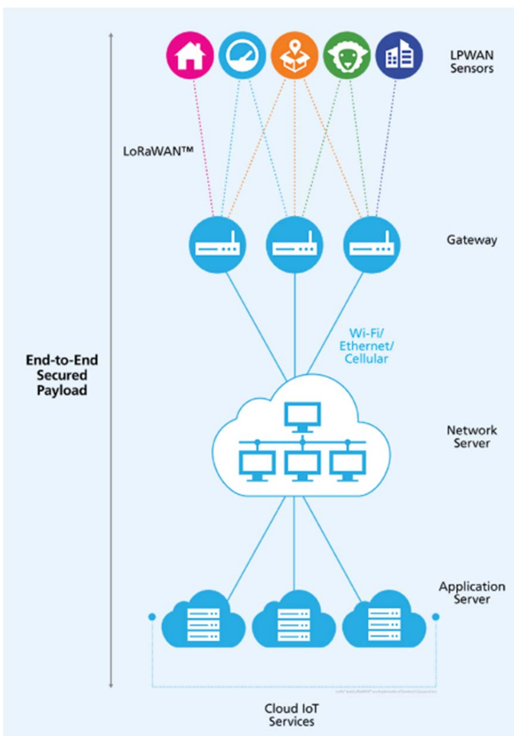
development in term of software and hardware matures.



(a)

(b)

Fig 1. (a) Protocol stack of LoRaWAN (b) Protocol stack of LoRa



(a)

(b)

Fig 2. (a) Network diagram of LoRaWAN (b) Network diagram of LoRa

LoRa chips can be integrated across multiple platform namely Raspberry Pi, Arduino and many more. Semtech produced different kind of chips for different frequency requirement and usage. For LoRaWAN case, a gateway consists of 2 transmit/receive radios made from SX 1257 chips. Besides that, there is a built-in processor (SX 1301) used to demodulate the signal. Where else for LoRa, we can use 2 nodes to communicate with each other. Usually end node uses either a SX 1276/SX 1278 chip and they can be programmed to allow one-way communication between two nodes.

This paper will contribute to LoRa communication including but not limited to healthcare services. By studying the characteristic of data rate and distance between the transmitter and receiver, both characteristic can be further explored in future research project.

II. METHODOLOGY

A. Dragino LoRa/GPS shield

Different countries utilise different frequency for the Industrial, Scientific and Medical (ISM) band. Malaysia's ISM band for LoRa devices is 915Mhz[3].The key component for LoRa communication is the LoRa chip and they are pre-configured to respective frequencies out-of-the-box. Dragino offers a compact LoRa shield solution that can be plugged and play onto any Raspberry Pi 2/3. It has a Sentech's SX 1276 chip and a L80 GPS chip for GPS application. GPS functionality will not be utilised as this paper will only focus on studying LoRa application. GPS functionality can be activated in the future if needed.

The shield is secured on top of the Raspberry Pi and it utilises Pi's GPIO pin to communicate. Two Raspberry Pi with Dragino's LoRa/GPS shields (Fig. 3) are used as the transmitter and the receiver. The receiver is placed in an elevated place preferably in a multi-storey building and the transmitter is mobilised. The shield can only operate on one channel and the frequency of the channel can be configured using software. Both the transmitter and the receiver need to be configured to the same channel to allow them to communicate. In this case, they are configured to channel 922.0- 923.2MHz for uplink and downlink.

Fig 3. Two Dragino LoRa/GPS shield installed on top of two Raspberry Pi 3

Besides that, LoRa transmission requires a line-of-sight between the transmitter and the receiver. LoRa has poor resistance toward solid object penetration and the signal performance drop dramatically when there is a solid object in between the transmitter and the receiver. To overcome this problem, a line-of-sight between the transmitter and the receiver must be establish prior the deployment of the devices. By using Google Earth Pro, a theoretical line-of-sight can be established via inputting the locations. To increase the chance of successful data transmission, the receiver is placed in elevated position. This allow the signal to clear past the height of vegetation or small buildings.

B. *Establish a theoretical line-of-sight using Google Earth Pro*

Technological advancement in geographical topography technology allows a theoretical line-of-sight to be plotted and they were shown in an interactive way in Google Earth Pro. This helps to save time and resources by determining whether a theoretical line-of-sight can be established between the transmitter and the receiver in the first place.

The location of the receiver is fixed at 9th floor, G block, Swinburne University of Technology, Kuching. The height of the elevated receiver position is estimated to be 40m above sea level whilst the elevation for the transmitting end is estimated to be 1m. Information pertaining the location of the transmitter and the receiver was inputted into the program. Once a line-of sight is established between the transmitter and receiver, theoretical set of distances to test the capability of LoRa were established and marked in the map. A set point of 5km, 10km, 15km, 20km are plotted in the map as a point of reference to measure signal performance.

Two points which are Buntal village and Mount Serapi were selected as the end point. The estimated line-of-sight distance measured from transmitter to Buntal village is (estimated) 20.03 km whilst the distance to Mount Serapi is (estimated) 20.12 km (Fig 4). Different geographical topography was used to mimic real life situation. Transmitter was brought to the peak of a mountain (see Fig.4) to mimic elevated remote areas while another set of experiment was done in flat area to mimic remote places that are rather flat. However, both end points were selected in a way that both end points have a line-of-sight to the receiver. Google Earth Pro has elevation profile functionality to determine whether line of sight can be established.

Fig 4. Estimated line-of-sight distance between the location of transmitter and Mount Serapi (white line)

C. *Spreading factor & Bandwidth & Duty Cycle*

LoRa communication protocol uses LoRa modulation to transfer signal across long distances. LoRa modulation is based on chirp spread spectrum modulation and each LoRa symbol is denoted by a 2^{SF} chirp. Free-space path loss is the biggest consumer in link budget as signal propagation thru reflection or diffraction weakens the signal strength in logarithmic relationship. Free-space path loss model can be represented using Eq. (1)[4]

$$PL_{fs} = 20 * \log_{10}(f) + 20 * \log_{10}(d) + 32.45 \quad (1)$$

The further the distance between the transmitter and receiver, the bigger the Fresnel Zone and this result in bigger signal propagation ratio. SF or spreading factor is used to represent the six-orthogonal spreading factor ranging from 7 to 12. Different spreading factor also reflects different data rate where a higher spreading factor results in a lower spectral efficiency and a smaller network capacity. Besides that, bandwidth of the signal correlates closely with the spreading factor and data rate. The bigger the signal bandwidth, the faster the data rate irrespective of SF. However, bandwidth allocation is dictated by the respective regulatory bodies in each country, For example, the allowable bandwidth for LoRa in Malaysia is 125kHz [3]. Hence, the data rate is somewhat solely determined by the SF because of fixed bandwidth frequency. In layman term, as we increase the number of spreading factor, the distance between the transmitter and the receiver can be increased with the cost of lower data rate. This relationship can be expressed using Eq. (2):

$$Data\ Rate\ = SF * \frac{BW}{2^{SF}} * \frac{4}{(4 + coding\ rate)} \quad (2)$$

Duty cycle is defined by the maximum percentage of time during which an end-device can occupy a channel[5]. Each country has regulation on the maximum time a device can broadcast using the ISM band and usually the duty cycle for these devices limited to <1%. Meaning the device must remain dormant 99% of the Time-On-Air (TOA) before the next data transmission. This is to prevent congestion and abuse of the unlicensed ISM band by limiting each device to broadcast on a short period of time. Duty cycle can also be program to the shield using software, but we don't have to manipulate the duty cycle since it is fixed by its regulatory body.

SF value can be configured using software and they are manipulated at each set point. A fixed 2MB dummy file is created and it is used as a test file to determine the data rate. Experimental data rate is calculated using Eq. 3:

$$Experimental\ data\ rate = \frac{2MB}{file\ transfer\ time} \quad (3)$$

Table 1: Parameter of the experiments

Frequency	922.0- 923.2MHz subdivided into 9 channels
Bandwidth	125kHz
Duty Cycle	1%
Spreading Factor (SF)	7-12
Size of dummy file	2 MB
Data set point	5km, 10km, 15km, 20km
Receiver elevation (from sea level)	40m
Transmitter elevation (from sea level)	1.5m

D. Hardware Programming & GUI

There is a need for an interface to allow both user interact with each other seamlessly. A GUI or Graphic User Interface is designed using Microsoft Visual Studio and it was programmed using C# language. Besides that, we are programming the GUI using window console for the application. Noticed that we used a fixed size dummy file to test the data rate instead of using the GUI to send data to make the process of calculating data rate easier. The GUI is not part of the testing setup because it cannot serve as an accurate tool to measure the performance of the system. The GUI is designed to allow the hardware to boot and it also allow user operation such as requesting emergency service. But it was not used as a tool to measure the performance of the device such as RSSI testing, SNR testing and data rate testing. These performance testing was conducted using command prompt inside Raspbian.

The Raspberry Pi was installed with Raspbian operating system which can be obtained for free from the Raspberry Pi foundation. The medical interface is programmed and designed in Microsoft Visual Studio in Window 10 and it was compile as an execution (.exe) file. The exe. file is then exported to Raspbian. There is a need to download a Mono repository in Raspbian and Mono was used to create an ECMA standard-compliant .NET Framework-compatible software framework. Mono is then run as an emulator for the .exe file as Raspbian does not run native Window's exe files because of the difference in processor architecture.

Fig. 5 The Window Console application that was designed and programmed in Microsoft Visual Studio

Moreover, the code to initialise the Dragino/GPS shield can be cloned on Github authored by Dragino. The code to initialise the hardware is sideloaded with the GUI as shown in Fig 5. Hence, the shield is only active when the GUI is initialised. There is no performance testing tools built into the GUI and they are initialised using command prompt in Raspbian. RSSI or Received Signal Strength Indication and SNR or Signal to Noise Ratio are the two-main indicator to measure the performance of the system. RSSI measures the received signal power in dBm and this value refers to how well a receiver can hear a signal from the sender. The closer the value to 0, the better the signal is. Meanwhile, SNR ratio is used to measure the ratio between the received power signal and the noise floor power level. Typical LoRa SNR value are between -20db and +10dB. The bigger the value, the less corrupted the signal is. These tools can be found on Github titled: "Simple LoRa Transmit/ Receive library in RPi for LoRa GPS HAT" authored by goodcheney

Transmitter location & elevation	Approximate distance between transmitter and receiver, km	Receiver location & elevation	Spreading Factor (SF)	Transferred data size, MB	Data rate, bps	Signal to Noise Ratio (SNR), dB	RSSI, dBm
9th floor, G block, Swinburne University of Technology Sarawak, Kuching, 40m (1°31'57.41"N, 110°21'25.55"E)	5	SMK Sungai Maong, 14.5m (1°32'44.75"N, 110°18'54.47"E)	7	2	32300	+8	-79
			8		17230	+9	-64
			9		8769	+9	-52
			10		4432	+9	-49
			11		2432	+9	-42
			12		1130	+9	-37
	10	Taman Heng Guan, 26.5m (1°33'33.66"N, 110°16'21.74"E	7	2	27163	+6	-110
			8		14320	+7	-98
			9		6853	+7	-92
			10		3123	+7	-87
			11		1533	+8	-82
			12		848	+8	-79
	15	Taman Sri Harmony Batu 8, 38.6m (1°34'22.42"N, 110°13'49.00"E)	7	2	733	-18	-118
			8		432	-17	-116
			9		230	-17	-111
			10		116	-15	-110
			11		62	-10	-102
			12		30	-2	-91
	20	Gunung Serapi Upper Peak, 853.6m (1°35'7.54"N, 110°11'39.25"E)	7	2	853	+2	-115
			8		412	+2	-110
			9		178	+3	-107
			10		96	+4	-98
			11		65	+4	-92
			12		43	+5	-89

Table II. Experimental result between Swinburne University and Kubah National Park

Transmitter location & elevation	Approximate distance between transmitter and receiver, km	Receiver location & elevation	Spreading Factor (SF)	Transferred data size, MB	Data rate, bps	Signal to Noise Ratio (SNR), dB	RSSI, dBm
9th floor, G block, Swinburne University of Technology Sarawak, Kuching, 40m (1°31'57.41"N, 110°21'25.55"E)	5	Kolej DPAH Abdillah, 18.0m (1°34'42.94"N 110°21'23.38"E)	7	2	34327	+8	-74
			8		19326	+8	-66
			9		7986	+9	-57
			10		4397	+9	-44
			11		2612	+9	-42
			12		1233	+9	-34
	10	MRSM Kuching, 8.0 m (1°37'22.35"N 110°21'21.23"E)	7	2	26983	+4	-64
			8		14656	+4	-60
			9		7201	+6	-53
			10		3423	+7	-49
			11		1653	+8	-46
			12		953	+8	-42
	15	Jalan Sultan Tengah, 10.0 m (1°37'22.35"N 110°21'21.23"E)	7	2	823	-2	-115
			8		431	+1	-110
			9		275	+1	-107
			10		133	+3	-98
			11		177	+3	-92
			12		89	+4	-89
	20	Buntal Village, 8m (1°42'48.85"N 110°21'16.86"E)	7	2	-	-	-
			8		-	-	-
			9		87	-17	-118
			10		40	-15	-112
			11		26	-10	-107
			12		17	-2	-102

Table III. Experimental result between Swinburne University and Buntal Village

IV. RESULT AND ANALYSIS

From table II and III, we compare the performances of the system in two different geographical topography. Table II simulates a hilly area and Table III simulates a flat area. The peak of Kubah National Park has an elevation of approximately 853.6m from sea level. If we compare the performance of the system for 20 km, the performance at the peak of Mount Serapi is much better compared to Buntal Village. It agrees with our early prediction as there is a proper line-of-sight established between the transmitter and receiver. Since the line-of-sight is elevated far from ground, it does not interfere with any building or vegetation. Hence, it explained significant improvement in performance as compared to 20 km in Buntal Village. Besides that, the performance of the data rates is also within our expectation. As we increase the value of spreading factor, the data rate is restricted by half because of smaller network capacity. Moreover, as we increase the spreading factor, the SNR value and the RSSI value will improves as increase in spreading factor results in better spectral efficiency.

In table III, performance result for 20km for SF 7 and SF8 cannot be retrieved as the device cannot detect any incoming signal. The signal is too weak to be sensed by the receiver and therefore, no connection can be made. Moreover, in table II, the performance of signals for 15km is worse than 20km. We suspect the cause for the dip in signal performance is the interference from a small hill located before the 15km set point. Signal reflection propagation has a big influence in signal performance as LoRa signals cannot penetrate through big solid object or heavy vegetation. High accuracy is not reliably expected given the components used.

IV. CONCLUSION AND FUTURE WORK

In this work, we tested the signal performance for LoRa on 5km, 10km, 15km and 20km sets points. Two geographical topography scenarios were tested to reflect the signal performance in real life situation. The system shows promising results when the price of the devices was taken into account. Not many devices in the market can perform as well as LoRa system at the given price bracket. We demonstrated that the device is suitable for medical application in remote areas as the device is affordable and data rates are at satisfactory level. Signal performance can be further improved in future work by adding external amplifier and utilising directional antenna.

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