A LoRa enabled sustainable messaging system for isolated communities

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ABSTRACT

More that one billion people worldwide cannot take advantage of even the most basic connectivity services, most of them living in isolated communities. Even simple messaging services would be of great help for example to farmers wishing to know the price of a certain good they are interested to sell or buy before deciding whether a possibly long, expensive and exhausting trip is undertaken.

In this paper we describe a low-cost and low-power system based on the LoRa protocol to provide a messaging system without being subject to recurring costs. LoRa networks allow for very long wireless links that can connect villages and towns. In addition to the simple messaging application, LoRa can be used to distribute sensor information to communities or to provide disaster alerts. This system falls in the category of community networks, where users build their own network as no infrastructure is available.

CCS CONCEPTS

• **Networks → Network architectures**; **Middle boxes / network appliances**; *Network experimentation*; *Metropolitan area networks*; • **Human-centered computing → Ubiquitous and mobile computing systems and tools**;

KEYWORDS

LoRa; Messaging; ICT4D; Community Networks

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1 INTRODUCTION

Even the simplest messaging services are hardly available in rural areas in developing countries. The possibility to communicate between villages and between villages and main cities is a highly demanded service either for purely personal use or for commercial purposes. For example, farmers could know the price of a certain good they are interested to sell or buy before deciding whether a possibly long, expensive and exhausting trip is undertaken.

The ITU 2017 statistics report that mobile-broadband subscriptions have grown more than 20% annually in the last five years and have reached 56.4% of the world population by the end of 2017 [6]. However, mobile broadband prices represent more than 5% of GNI (Gross National Income) per capita in many of the least developed countries and are therefore not affordable for the large majority of the population. Whilst most cities enjoy 3G and 4G connectivity, mobile coverage does not exist in many rural areas. Those who are not covered at all (coverage gap) are 1.2 billion according to [2]. The lack of coverage in rural areas is the consequence of a basic economic challenge: deploying infrastructure there can be twice as expensive, while revenue can be as much as ten times lower [10]. Where GSM is present, SMS has been the killer application for mobile services all over the world due to its ability to maintain communication between individuals and also interconnecting members of a community. Those who benefit from GSM coverage are likely to own a smartphone: penetration rate is 44% worldwide and is expected to reach 59% by 2022.

DakNet [1] is an example of a messaging system aimed at providing services beyond the coverage of GSM networks. It leverages existing transportation and communications infrastructure to provide digital connectivity, by combining a physical means of transportation with wireless data transfer to extend the internet connectivity that a cyber cafe or post office provides. DakNet employs a delay tolerant infrastructure to offer applications like voice mail, e-mail and electronic bulletin board system (BBS) at much lower cost than their real-time counterparts. It transmits data over short point to point links between kiosks and a portable device on board of a public transportation vehicle (for instance a bus) serving the area of interest. The bus contains a simple WiFi transceiver connected to a server and when in range of one of the outlying

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information kiosks it synchronises data for later processing. The end user access the updated information delivered to the kiosk by means of WiFi with their own phone or tablet. Pilot projects have shown that asynchronous communications can meet the needs of people in remote areas [5].

In this work we define the architecture for a messaging system that combines very cheap and flexible devices and the LoRa technology to establish a link that can span wide areas with an easy to use interface. Moreover we integrate e gateway device that, if Internet is available, can forward messages to Telegram users.

The solution we developed aims at offering messaging services to isolated areas, not covered by GSM signals. Providing low cost, low power messaging services to rural areas without affordable access to existing communications networks is certainly an important and relevant application, and the described system using IoT tools is a compelling approach to do so. We are treating messaging at a high level abstraction, taking advantage of the existing protocols and services in the IoT world. Furthermore, in case of disasters, the LoRa network can be used for exchanging emergency messages at long distances even in the case of disruption of the cellular infrastructure.

The paper is organised as follows. Section 2 describes the LoRa technology and its advantages, and Section 3 details the motivations for this proposal. Section 4 presents the architecture of the proposed solution. Section 5 analyses the sustainability of the solution, and Section 6 presents the conclusions.

2 THE LORA TECHNOLOGY

Modified WiFi has been used for very long distance links with very good performance [4]. However, in cities all over the world the proliferation of WiFi has resulted in serious issues of interference in the 2.4 GHz band and, although less severe, in the 5.8 GHz band, the two popular unlicensed bands. The unlicensed 868 MHz band in Europe and 900 MHz in the Americas opens new possibilities of communication, that can combat interference by leveraging the LoRa modulation [11], in which transmission speed is traded by range, in a classical application of Shannon's channel capacity formula:

$$C = B\log_2(1 + \frac{S}{N}) \tag{1}$$

were C is capacity or throughput in b/s, B is bandwidth in Hz, S is the signal power in W and N is the noise power in W.

It is intuitive that the same capacity can be achieved by using a narrow bandwidth and a high S/N or a wide bandwidth and low S/N. LoRa offers a versatile method for lowering the throughput in order to allow the data transfer to occur in very low S/N instances, even with signal power of 1 percent of the noise power. This is accomplished by controlling the data rate by means of modifications of a so called spreading factor (SF), which determines the degree of expansion of the information rate (bit rate) to the transmission data rate. The SF ranges between 7 and 12 in Europe, corresponding to bit rates from 10937 b/s to 292 b/s. When the receiver is close to the transmitter a low SF can be used, which requires a receiver sensitivity of -123 dBm, whereas when the distance is longer or there are obstacles that reduce the received signal a spreading factor of 12 will decode signals as low as -136 dBm, which are much lower than the thermal noise (that at room temperature over a bandwidth of 125 kHz corresponds also to -123 dBm).

In areas not covered by cellular service providers, which are very abundant in developing countries a few kilometres from towns and main roads, LoRa can provide a very low cost, community operated communication system that addresses many basic needs encompassing a variety of use cases. In mountainous regions one can leverage the terrain topography to accomplish line of sight transmissions at very long distances by fitting the nodes with external high gain antennas. A 316 km transmission using low-power nodes and small antennas is reported in [7] as an example of what can be achieved. The low cost of LoRa devices, the use of unlicensed bands, and the the wide availability of WiFi-enabled devices (smart phones, tablets and PCs) that provide the platform for user interface, constitute the ingredients for installing a community network, built and maintained by the direct beneficiaries, after they are properly trained.

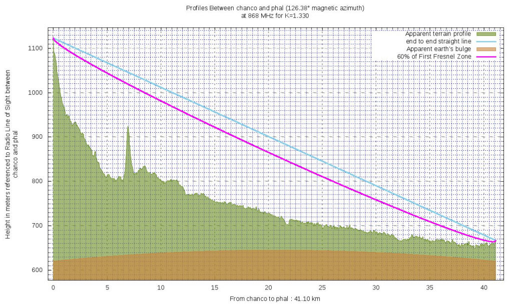


Figure 1: Profile of the terrain between Chancellor College of the University of Malawi and remote site.

For example, in 2013 a TV White Spaces network [9] was installed at the Chancellor College of the University of Malawi to provide broadband Internet access to several institutions surrounding it. One of the sites considered in the planning stage could not be reached with the power budget allowed by the TV White Spaces technology. By using LoRa, this site could be easily served since there is an unobstructed line of sight as shown in Figure 1 obtained with BotRf [13]. The power budget with 2 dBi antennas at both ends and 12 dBm transmitter power as calculated with BotRf shows a margin of 16 dB over the -123 dBm sensitivity of the LoRa receiver with a spreading factor of 7, as can be seen in Figure 2.

3 MOTIVATIONS

In [8] an analysis of communication needs in rural primary health care in developing countries is described, and although many interesting applications of telemedicine can be implemented with broadband solutions, one very simple application originally implemented over HF voice only radio communication proved quite successful: scheduling patient doctor's appointments. It was found that patients in isolated areas had to spend significant time and resources to reach the nearest hospital, and often they could not be treated immediately but given an appointment at a time that often implied a second trip from home. A simple messaging application like the one we are proposing, could serve to arrange for a specific

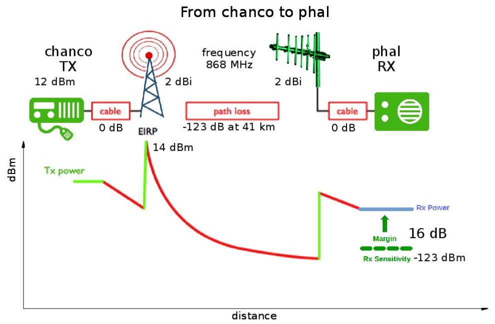


Figure 2: Power over distance between Chancellor College of the University of Malawi and remote site using LoRa.

date in which the patient is guaranteed treatment, thus saving time and resources.

In this work we focus on a basic application of the LoRa system which is a SMS-like, one-to-one messaging. Although this is very useful when there are no other systems in place, more applications can be developed using the same solution. For example, a Bulletin Board System (BBS) like functionality can be provided to inhabitants of isolated areas. It can be used to offer weather forecasting data, health-care information, market prices of crops, and so on. In this case the communication is one-to-many as everyone is able to read the messages.

Finally, our proposed solution can also be leveraged to support ordinary LoRa applications, like environmental sensors, weather forecasting and so on. If these sensors are equipped with LoRa transceivers, they can be located beyond the reach of cellular towers and send data to the LoRa hub which can forward the data to the interested parties. In particular, for disaster mitigation text only communications using the LoRa device can be very valuable when the cellular service is disrupted and also to extend connectivity beyond the range of cellular towers.

4 THE PROPOSED ARCHITECTURE

At the core of the proposed architecture are dedicated devices, called *hubs*, that create the connectivity spot inside an area. The hubs must have both a WiFi (IEEE 802.1b/g/n) and a LoRa transceiver. Figure 3 presents the overall architecture.

The hubs work as standard WiFi access point to provide connectivity to close by devices. The interface with the messaging application is a web based page (see Figure 4). The user can decide whether to send a text a message to a specific destination or to check for incoming messages stored in the hub. Every user need to "register" before interchanging any message. Registration is required to allow the system to localise end-point that can possibly move to different locations in time.

The hubs receives POST commands from the connected devices to either send a message or return previously received and locally stored ones.

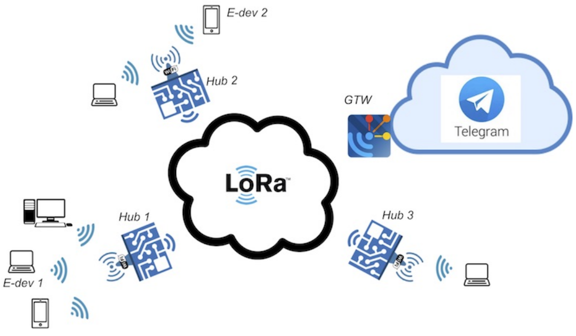
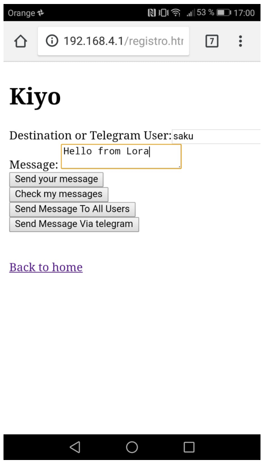


Figure 3: Overall structure of the messaging platform.



Kiyo

Destination or Telegram User: saku

Message: Hello from Lora

Figure 4: Screen capture of the web based interface

When a user sends a message, the local hub "learns" that that user is connected through it and creates an entry in a table. The first step is to discover where the destination user is located. To this end the hub sends a broadcast message using the physical layer LoRa protocol to all the surrounding devices. The device which has that end user as a registered one, replies to the requesting hub. The packet structure used by this protocol is very simple with two bits for control and a 32 bytes field to store the name to be searched. A *broadcast* user was included for messages that are to be delivered to all the registered users.

Figure 5 show the ordered set of outcomes of the user discovery process. The median value for the whole process is 2.077 msec. Once the user location is know, this process is not repeated.

Then, using a unicast reliable protocol, the message is transferred and stored in the destination hub. Once the user to whom the message is addressed checks for available message he or she will receive the one stored in the local hub. The unicast protocol is based on a classical stop-and-wait ARQ approach with a dynamic and adaptive value for the retransmission delay. The protocol ensures that information is not lost due to dropped packets and that packets are received in the correct order. The packet structure is shown in

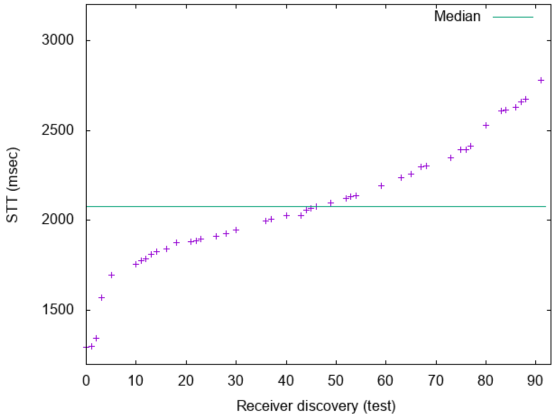


Figure 5: User discovery process; ordered set of outcomes ("tests").

Figure 6. We must point out that the maximum application payload depends on the selected data rate. For example, assuming the European 863-870MHz band, in worst propagation conditions, one should assume the lowest data rate, provided by SF12, where the node cannot send more than about 51 bytes per packet; with SF7, the payload might be 222 bytes. These values consider LoRaWAN protocol which adds at least 13 bytes to the application payload. The maximum packet size used was set according to the spreading factor used, i.e. 25 bytes for SF12 and 200 bytes for SF7, with a fixed 24 bytes header.

<table>
<tr><td>1</td><td colspan="4">Source addr (8 bytes)</td></tr>
<tr><td>2</td><td colspan="4">Dest. Addr. (8 bytes)</td></tr>
<tr><td>3</td><td>Seqnum (2B)</td><td>Acknum (2B)</td><td>flags</td><td>Checksum (3B)</td></tr>
<tr><td>4</td><td colspan="4">...data...</td></tr>
<tr><td></td><td colspan="4">⋮</td></tr>
<tr><td>16</td><td colspan="4">...data...</td></tr>
</table>

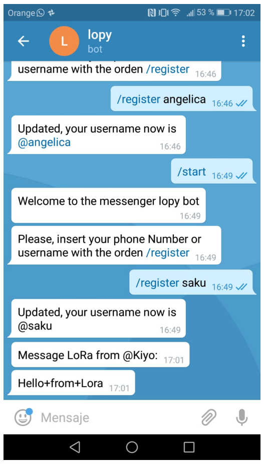
Figure 6: Structure of the packet used by the stop-and-wait ARQ.

4.1 Integration with Telegram

To better integrate our architecture with standard Internet application we designed a gateway hub to link it with Telegram[1], a widely used messaging application (see Fig. 7). We selected Telegram since if offers so called Bots. Bots are third-party applications that run inside Telegram. Users can interact with bots by sending them messages, commands and inline requests.

The gateway receives via LoRa messages directed to a Telegram user, registered through the Bot, and forwards that to the user's phone via the Internet link.

The gateway of our prototype is based on a Raspberry Pi board provided with a Lora adaptor and a stable connection to the Internet. The processes required by the Bot are running on the Raspberry Pi.



username with the orden /register 16:46

/register angelica 16:46

Updated, your username now is @angelica 16:46

/start 16:49

Welcome to the messenger lopy bot 16:49

Please, insert your phone Number or username with the orden /register 16:49

/register saku 16:49

Updated, your username now is @saku 16:49

Message LoRa from @Kiyo: 17:01

Hello+from+Lora 17:01

Figure 7: An example of interaction with the Telegram Bot.

4.2 Some preliminary results

In our experiments we used devices called LoPy[2], a MicroPython enabled microcontroller, based on the latest Espressif ESP32 chipset. It has a dual processor and three transceivers (LoRa, WiFi, Bluetooth) and two antenna connectors: one for the 868 MHz band used by LoRA and another for the 2.4 GHz band used by WiFi and Bluetooth. This allows for fitting the antenna best suited for the application. For instance, high gain directional antennas can be used to connect a rural village to a city that could be at a very long distance, using very small power by leveraging the spread spectrum features of LoRa modulation. The network processor handles the WiFi connectivity and the IP stack while the main processor is entirely free to run the user application. It has a 512KB RAM memory and allows for an external flash of 4MB. It has hardware floating point acceleration and can be programmed in Python multi-threading.

The complete hub is shown in Figure 8: a LoPy node with an omnidirectional antenna, an external battery and a 5 W solar panel.

The plots below were all based on a parameter called "successful transfer time (STT)" which measures the transfer time of a message from the point of view of the sender. It is computed from the moment the first fragment of the message is sent, to the moment the last ACK of the last fragment of the message is received.

Figure 9 shows the behaviour of the STT when varying the distance between two nodes. The median values are shown. Plots are obtained using a spreading factor (SF) of 7 and message size of 1, 256, and 512 bytes. As can be seen, there is a stable behaviour in the results although clearly the STT grows as the message size grows; at SF7 the maximum size for the payload was 200 bytes.

It seems that the system is quite stable to the increase in distance and very few retransmissions were necessary during the experiment. Overall we had a retransmission rate of 9% but we must

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[1] https://telegram.org/

[2] https://pycom.io/

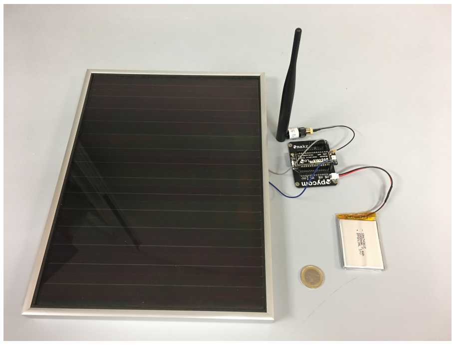

Figure 8: Overall system: LoPy, battery and solar panel.

point out that the distribution of retransmissions was practically independent from the distance.

The absolute values of the STT highlight that the set-up time required by the two devices to sync the transmitter has the highest overhead, followed by the actual data sending.

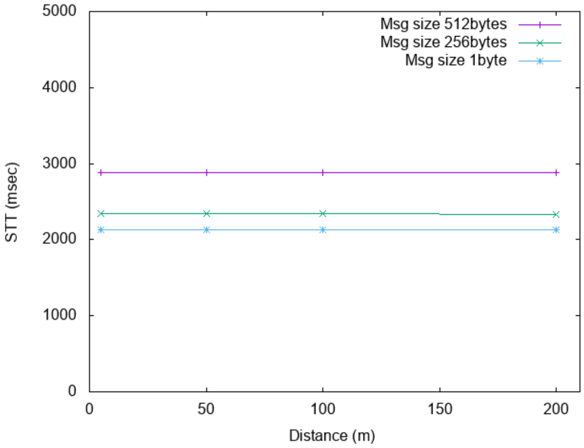

Figure 9: The behaviour of the STT when varying the distance between two nodes (median values).

Figure 10 allows to better view the evolution of the STT as a function of the message size. As we can see, the STT clearly grows as the message size increases, but it is evidenced that the impact of distance is negligible.

Finally, Figure 11 shows the behaviour of the STT when varying the frequency of the generated messages, more exactly, when the number of generated simultaneous messages increased. Plots are obtained using a spreading factor 7 and message size of 256bytes. As can be seen the STT grows linearly as the number of simultaneous messages increases giving the extreme case where 14 simultaneous users were trying to send a message; a maximum delay of 80 seconds was obtained in a few cases. The median value, for the 14 simultaneous users was 35.892 sec. With more than 14 simultaneous users the system showed a very unreliable behaviour and we considered it as basically unusable.

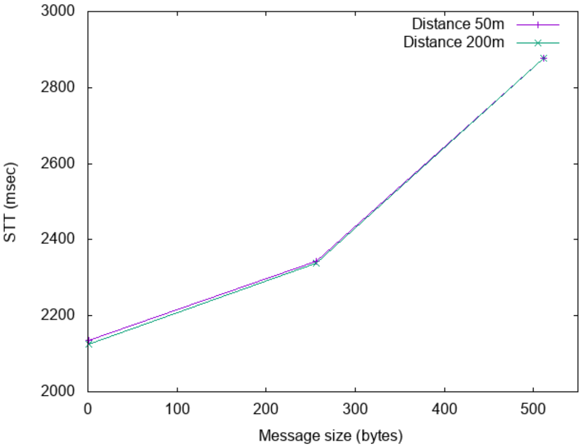

Figure 10: The behaviour of the STT when varying the message size (median values).

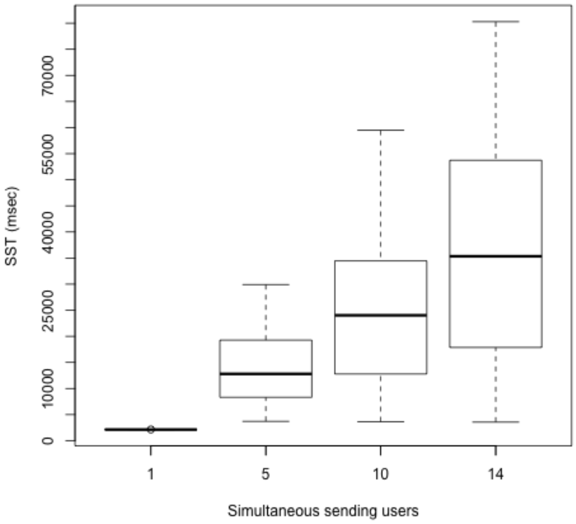

Figure 11: Scalability evaluation of the system by increasing the number of concurrent sending users.

5 SUSTAINABILITY OF THE SOLUTION

In order for any networking solution to be sustainable, several aspects have to be taken into account. Following is the sustainability analysis of the proposed solution.

5.1 Power grid independent solution

We measured the power consumption of the proposed solution in two conditions: WiFi-only communication and WiFi+LoRa communication. In the first case (while compiling the message on the web interface) we measured 0.476 W, in the second case (when sending a message via LoRa) we measured 0.587 W with an increase of 23% in power consumption. We then compared our solution based on LoPy devices to an alternative platform based on Raspberry Pi and Uputronics LoRa board, and measured a power consumption of 1.454 W, an increase of consumption of 248% compared to our solution. Since the WiFi must always be on to serve incoming user requests, the hub cannot take advantage of deep sleep mode, but other power saving features will be investigated in future work.

With a maximum power consumption of 0.587 W, the device can easily be powered via renewable sources such as solar. A 3.7 V, 2000 mAh battery can power the hub for 17 hours and a 5 W peak solar panel is enough to replenish the battery in most climates.

5.2 Economic sustainability

Traditional network architectures are based on the assumption that a fixed infrastructure is in place, and that final users make use of this infrastructure by paying a fee (this is the case of GSM, satellite and WiFi networks). While this model works well in industrialised countries (where corporations or the government takes care of the initial investment), it constitutes a huge barrier in many developing countries, especially in rural and remote areas. The proposed solution requires a limited initial investment that can be shared among community members and does not require any recurring costs. This is the same model as community networks, where WiFi link are setup in a community and are not necessarily connected to the Internet. Another example is community cellular telephony, where communities in rural areas install their own GSM network [3]. The proposed network architecture is based on low-cost LoRa devices which cost about 30 euro. The total cost of the device, including the solar panel, the battery and the enclosure, is about 70 euro.

5.3 Regulation

LoRa devices operate in frequencies of 868 MHz in Europe with 14 dBm maximum output power, and 915 MHz in North and South America, Australia and New Zealand with 20 dBm maximum power. These frequencies are part of the ISM bands which do not require any license to operate on. While the frequencies are usable, regulation is in place to allow for the fair use of the spectrum by dictating the duty cycle of the devices. A 1% Duty Cycle means that the transmitter can only transmit 1% of the time. Most European countries follow CEPT/ERC Recommendation 70-03 relating to the use of short range devices (SRD), while a dozen African countries follow Communications Regulators' Association of Southern Africa (CRASA) Harmonised Frequency Bands For SRD Applications.

6 CONCLUSION

We have presented the design of a low-cost, low-power solution to provide messaging to isolated communities. We consider solution like ours necessary since there is still a significant population out of its reach that can benefit from the proposed solution in rural areas of developing countries. Once in place, the LoRa hub can also be used for sensor and other kinds of data of interest.

Our platform integrates a gateway to Telegram, a widely adopted messaging application. This device allows extending the reach of the messaging system to the standard Internet.

We developed a prototype to obtain some first results of its performance. The results obtained show that this solution can offer a low cost and efficient solution for the context we aimed to. Moreover, as indicated in the text, this architecture can be extended and used for other applications like to offer weather forecasting data, health-care information, market prices of crops, and so on.

A lot of improvements are planned for this platform which shows plenty of possibilities. We are currently working on voice messages to ease the use of the platform to users who are not comfortable with reading and writing. We will also explore the possibility of fitting a bus or other public transportation vehicle that traverses areas not served by the cellular operator with a LoRa hub. This will allow it to gather LoRa text messages that can later be forwarded to the intended destination once the vehicle reaches the coverage of the cellular service. Another important evolution is oriented to include a gateway to SMS with possibly the integration of payment platforms like M-PESA [12]. In this latter case, security issue will be considered.

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