A LoRaWAN Coverage Testbed and a Multi-optional Communication Architecture for Smart City Feasibility in Developing Countries

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Abstract. Connectivity is key for IoT and smart cities. Unfortunately, a stable Internet connection is scarce in developing countries. LoRaWAN standalone base station solutions can be used to fill the gaps. But since these difficulties may not affect everyone, then, affordable wireless communication, such as Wi-Fi, with direct access to Internet from the collection node, may be useful for data transmission. This article, first, discusses a coverage study based on LoRaWAN autonomous base stations and, then, extends the architectural model proposed in [3] to take into account the Wi-Fi protocol, thus diversifying the implementation choices. A gateway (Wi-IoT) capable of providing Wi-Fi access, on the one hand, and collecting, processing and monitoring data as a mini-server, on the other hand, will be proposed as proof of concept. From the node to the gateway, data will be compressed and sent securely. A user who connects to Wi-IoT will, then, be able to access his data.

Keywords: Sustainability · Smart and future city feasibility · IoT/ICT for development · Edge/Fog computing · Wireless and community network · LoRaWAN · Wi-Fi

1 Introduction

In recent years, LoRaWAN has become the most important sensor network protocol in both research and industrial worlds. This advantage comes from its wide coverage (ranging from 1 to 10 km in urban areas and more than 15 km in rural areas), its low energy consumption and the fact that it is open source, uses the industrial, scientific and medical (ISM) radio bands and also allows a

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low-cost deployment. LoRaWAN is a communication and architecture protocol that uses LoRa modulation which is a physical layer technology. In LoRaWAN, the data rate is between 0.3 to 5.5 kbps with two high-speed channels at 11 kbps and 50 kbps in FSK modulation and supports secure two-way communication, mobility and location; Spreading factors (SF) ranging from SF7 to SF12 are used to specifically define the data transfer rate with respect to the range. Depending on the environmental conditions between the node and the base station, the network will determine the proper spreading factor to work with. Using an adaptive data rate (ADR), the network is able to manage the data rate and output power of each node individually, in order to optimize battery life, signal range, and overall network capacity. Thanks to their CSS (Chirp Spread Spectrum) modulation and the different phase shifted frequencies used for chirps, the LoRaWAN network is insensitive to interference, multi-path propagation and fading phenomena. Chirps are used to encode the (Tx) side data, while the reverse chirps are used on the (Rx) side to decode the signal.

A first study [2] was conducted on stand-alone LoRaWAN base stations that can operate even when Internet is intermittent or non-existent and, that can communicate with one another [3], form a city size extensive network. In this paper, we will first discuss a coverage study based on LoRaWAN and, then, propose a testbed for this purpose. Noted that [2] and [3] are steps of [1] that aims to study the feasibility of the smart city in developing countries, especially in Africa.

Although Internet can generally be inaccessible or intermittent, acceptable connectivity [3] (with a round-trip time less than 100 ms (see Fig. 1)) can be present at some places. Therefore, it is fair to consider proposing an architectural model offering several options of communication on demand and which will remain flexible for future evolutions. Wi-Fi protocol (which is part of the broad family of radio technologies implementing IEEE 802.11x) is, then, added to the proposed model in [3] to meet the defined objectives. Indeed, it belongs to the Wi-Fi Alliance organization [7] and operates in the frequency band 2.4 GHz (for 802.11b, 802.11g or 802.11n) or 5 GHz for the 802.11a. We also see continuous improvement of its technologies (see Table 1).

Sending bare data over Internet is useless. Ensuring end-to-end integrity is essential. Moreover, in IoT, the data size must not be too large in order to minimize the volume of flux that it can absorb, and remain as close as possible to the real-time. It then becomes, necessary to set up a compression method.

The rest of this paper is as follows: Sect. 2 deals with the coverage study on LoRaWAN Autonomous Base Stations and presents a testbed for this purpose. Section 3 proposes an extension of the architectural model to take into account the Wi-Fi protocol and remains flexible to future developments. Section 4 illustrates the proof of concept and gives test results. The conclusion and some perspectives completes this document.

2 Coverage Study

In LoRaWAN, the gateways can measure, upon reception of the packet, the received signal strength indicator (RSSI) and the signal-to-noise ratio (SNR).

Fig. 1. Internet latency in Africa

The calculation of the radio receiver sensitivity (S), which is the minimum of the detectable signal that can be decoded, helps evaluate the signal quality by monitoring the RSSI, provided that the RSSI is not less than the sensitivity and its limit value, practically not less than −120 dBm, for good coverage. The sensitivity of the receiver (S) in dBm is expressed as a function of the bandwidth (BW) in Hz, the receiver noise factor (NF) in dB and the signal-to-noise ratio (SNR) in dB (see Eq. (1)).

$$S = -174 + 10\log_{10}(BW) + NF + SNR \tag{1}$$

Table 1. IEEE 802.11 amendments

Standard	Year approved	Max data	Frequency band	Channel width	RF chains width
a	1999	54 Mb/s	5 GHz	20 MHz	1 × 1 SISO
b	1999	11 Mb/s	2.4 GHz	20 MHz	1 × 1 SISO
g	2003	54 Mb/s	2.4 GHz	20 MHz	1 × 1 SISO
n	2009	600 Mb/s	2.4/5 GHz	20/40 MHz	Up to 4 × 4*
ac	2012	3.2 Gb/s	5 GHz	20 to 160 MHz	Up to 8 × 8*, MU
ad	2014	6.76 Gb/s	60 GHz	2160 MHz	1 × 1 SISO
af	2014	426 Mb/s	54 to 790 MHz	6–8 MHz	up to 4 × 4*
ah	2016	@	Below 1 GHz	1–2 MHz	1 × 1 SISO

*: MIMO
@: from 150 kb/s to 347 Mb/s

The test results in [4] show that, as LoRa chooses narrowband transmission, it covers 1 km in-detp coverage situations and about 5 km in outdoor situations. The practical approach using the RSSI in [5] shows that LoRaWAN gateway can cover up to 10 km with a packet loss ratio of less than 30%. It also shows that up to 4–6 km, we can have good coverage in urban areas. Outdoor coverage results in [6] show that, when trees and buildings obstruct line of sight, a 54.33% packet delivery rate was observed at a distance of 2.6 km from the gateway and for an almost unobstructed line of sight, an 84.5% packet delivery rate was seen at a distance of about 4.4 km from the gateway. We can, then, hope to have a good coverage between 1 and 3 km in dense urban areas, between 3 and 6 km in moderately dense urban areas, between 6 and 10 km in low-dense urban areas and up to 15 km or more in rural areas.

2.1 Tools for the Coverage Study

In this Section, we introduce the considered tools in an African context, where there is, most of the time, lack of simulation equipment. The simulation aims at assessing the signal quality, under the constraints imposed by the network and the landscape, for a better presentation and interpretation of the results. To achieve that, the tool must:

- Be able to reveal the current state and the profile of the given area (trees, buildings, watercourses, available materials, etc.) to better take into account the phenomena related to the disturbance of the signal;
- Be able to adjust signal parameters (bandwidth, frequency, spreading factor used, modulation, etc.);
- Propose a good representation of the signal quality in a map with specific collection positions;
- After the simulation, propose a portable recording file, which can be used as needed, without having to repeat the simulation;
- When simulating communications between the base stations, give the acceptable distances and heights to allow good 'line of sight'.

Some tools were covered in [8], but none of them have met our expectations. Finding an open-access tool that can meet our requirements has been a challenge. Radio Mobile [9] can approach the solution but remains limited when it comes to the area conditions. RF Bot [10] is also a good tool for 'Line-of-sight' simulation, but as it is based on SPLAT [11], it requires one goes to generate its scripts. Based on the Pietro Manzoni's scripts [12], we suggest the following testbed that can meet our needs.

2.2 Testbed

The testbed was conducted around the campus of the "Institute of Mathematics and Physical Sciences (IMSP)" and consisted of measuring the received Signal Strength from a node sending data. The purpose of this test is to assess the

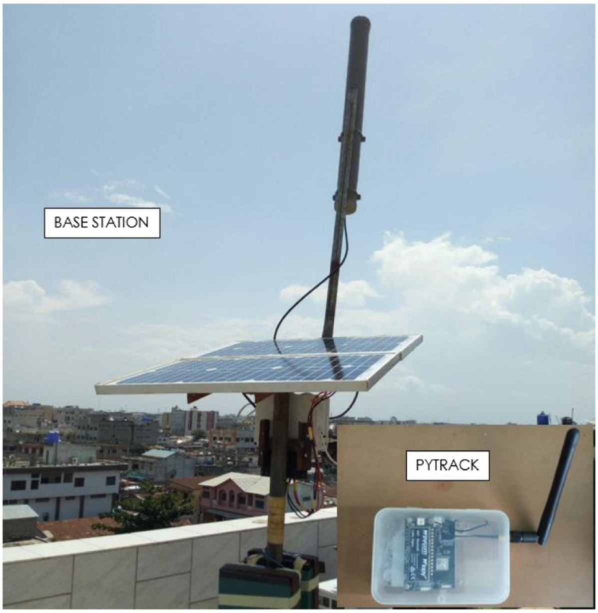

Fig. 2. Required types of equipment for the coverage study

coverage despite some obstacles. To expect a strong signal, the RSSI must be closer to zero (0) and the minimum acceptable must be −120 dBm.

To achieve that, we used an eight (8) channel gateway [13] placed at the Institute's computing center and a Pytrack [14], as a mobile node, whose role is to send GPS coordinates, to be able to measure signal strength (RSSI) at a given position. We also used a single channel gateway [15] (see Fig. 2) for the same purposes. The results on the map (see Fig. 3(a)) indicate, when in green that the signal is strong (RSSI higher than −90 dBm), when in yellow that the signal is quite good (RSSI between −90 and −110 dBm) and when in red that the signal is weak (RSSI below −110 dBm).

SPLAT has also been used to simulate the "line of sight" between two sites.

Considering a base station located at the "Ecole normale supérieure" (ENS) of the city of Porto-Novo as a slave, the one located at IMSP as the master, we manage to simulate a line of sight at a distance of 13,25 km (see Fig. 3(b)). The slave can be raised at about 30 m from the ground, while the master height is about 15 m from the ground.

3 Architectures

This vision of the smart city that wants to connect anything to the Internet is undeniably a waste of resources. This type of approach will not be accessible to people who cannot afford it, or even that, the infrastructure will not be stable in

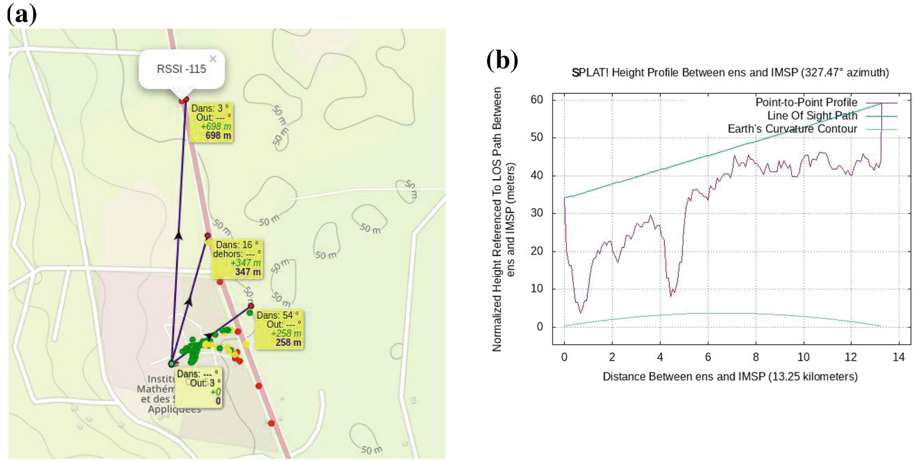

Fig. 3. (a) LoRaWAN network coverage study around the IMSP campus. (b) The line of sight simulation between Slave (ens) and Master (IMSP). (Color figure online)

case of intermittency [3]. However, for people who have access to good connectivity, they can, then, connect their end nodes to Internet using a Wi-Fi interface. The collected data can then be routed to a public Cloud. A local gateway will, then, be able to collect, process and monitor them. We will, therefore, orient our research in this direction and, thus, complete the model proposed in [3] to include this case and, consequently, to diversify the communication modes.

As an illustration, let us consider the scenarios described in [3], with Yao and Benin government. Yao is a businessman and owner of a taxi company and wants to be able to know at any time the position of his taxis. He can easily have access to Internet and capable of building his infrastructure on the latter. Similarly, the Beninese government can also connect its measuring stations to Internet and thus manage the collected data.

The requirements remain the same, and consist of choosing affordable and accessible equipment, implementing a system that uses fewer resources (5 V DC and at least 2.5 A sufficient), with a scalable storage system. The infrastructure must be based on open source and use the free ISM band (industrial, scientific and medical radio bands). The proposed architecture must then meet these requirements and at the same time be flexible for future additions.

We modified the general architecture proposed in [3] by adding the Wi-Fi option as follows (see Fig. 4):

- In "Local Access", we have, at the bottom, the "Measurement Layer", then, the "Messaging Layer" and, between them, the "PublisherInterf" interface.
- In "Remote Access", we first have the "Wi-IoT Services" block, then, the "Application Layer" and, between them, the "MlAppInterf" interface on the one hand and the "MonitorServ" interface on the other.

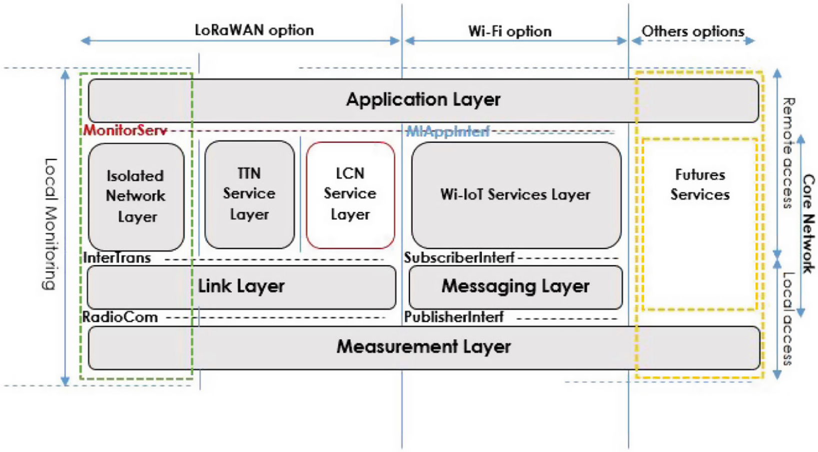

Fig. 4. General architecture

– Between "Local Access" and "Remote Access" we have the "SubscriberInterf" interface. The model is later left flexible to future additions.

When considering an architecture with several communication options, the interoperability problem is present. Also, with a city-sized infrastructure, the centralization of data is considered. The interoperability problem can be handled at the "backup layer" level (central database to which all other communication options converge their data). As a result, remote access to the proposed applications will be required and, each communication option should present data from its "middleware layer" (see Fig. 5).

4 Proof of Concept

In this Section we will discuss the Wi-Fi option implementation methodology. LoRaWAN options descriptions are available in [3].

A choice of equipment (see Fig. 6) must be made first before thinking about programming. So, we chose, on the node side, a Pycom expansion board 3.0 [16] on which we put LoPy 4 [17] and as a sensor, we used a DHT11 [18]. The gateway (Wi-IoT) is developed on a Raspberry pi 3 [19].

In development, the node (embedded system) collects the data, encrypts it, compresses it and publishes it on a broker via Wi-Fi.

– Encryption is based on 128-bit Advanced Encryption Standard (AES),
– The compression is done in 2 steps:
  - First, since the data is transformed into a bitstream, we used a grouping of 4 bits and for each group, a representation character is associated with it. The number of bits must be a multiple of 4, otherwise, the string is filled with zeros at the beginning.

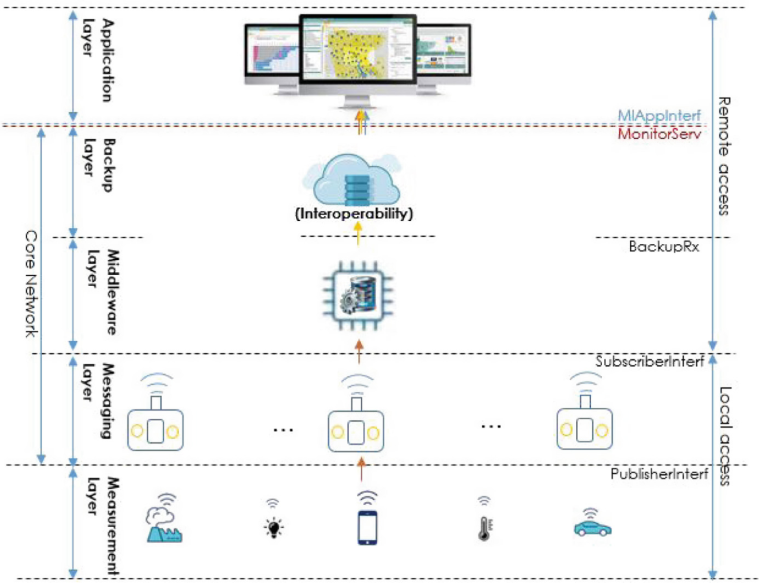

Fig. 5. Infrastructure in each layer

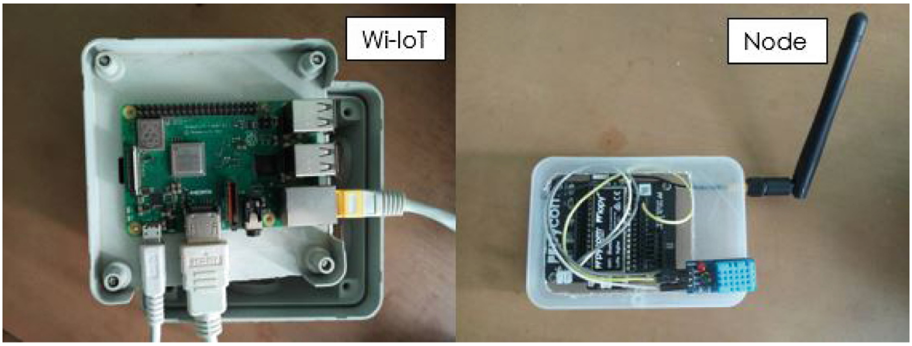

Fig. 6. Required types of equipment to implement the Wi-Fi option

- In a second step, the successive duplicates are identified and listed to be added later to the compression chain by taking the character followed by the number of successive repetitions (like the logic of RLE (Run Length Encoding)).

– Eclipse mosquitto "iot.eclipse.org" is used as a Broker but we could have chosen "test.mosquitto.org", "www.cloudmqtt.com", "mqtt.swifitch.cz" or others ...

Subsequently, the Wi-IoT gateway (which subscribes to the topics of their choice in connected mode) collects data, decompresses, decrypts and stores in

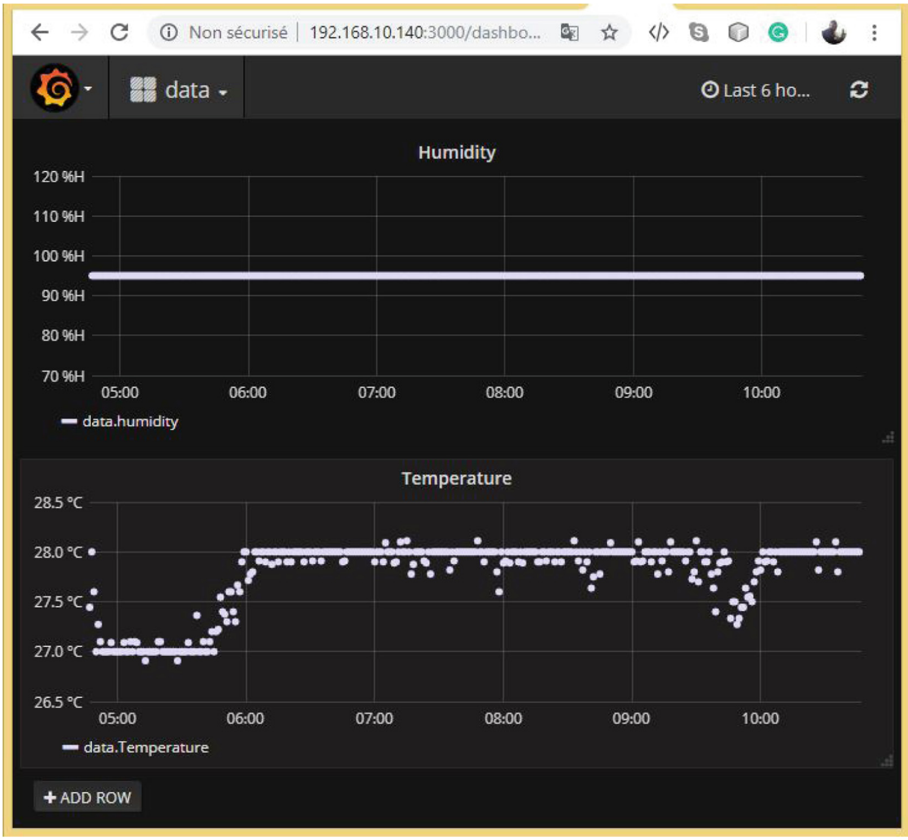

Fig. 7. Display of measurement of temperature and humidity collected

InfluxDB (open-source time-series database). A backup, in the central database for interoperability, and other processing are, then, possible. Grafana (open platform for analysis and monitoring) is, then, accessible on (IP: 3000) by any client connecting to the Wi-IoT gateway (see Fig. 7). The applicability of machine learning is also possible with respect to self-correction, prediction, or decision-making.

5 Conclusion

In developing countries, access to Internet is often a severe problem. Accessibility would be relative, since some of them may claim to have access to acceptable connectivity and will, therefore, prefer to go in that direction. The rest will be satisfied with a good coverage of the LoRaWAN network based on autonomous base stations.

This step consists of completing [2] and [3], which are part of the project described in [1], and extending the architecture by adding the Wi-Fi protocol to diversify radio communication options. The model must always remain flexible to future developments while ensuring the interoperability of the protocols taken into account.

In the future, it will be interesting to propose a complete web application integrating all the constraints for a better LoRa network coverage study. In terms of diversity, it will be interesting to consider the addition of another radio protocol, such as Zigbee [20]. It would also be interesting to discuss the performance of the proposed architecture, given the complexity of the time required to deliver the data.

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