A LoRaWAN coverage testBed and a multi-optional communication architecture for smart city feasibility in developing countries*

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Abstract. Despite the inaccessibility or intermittency of Internet in developing countries, it remains one of the key elements in the field of IoT and the smart city. Most cities experiencing these difficulties can, therefore, use stand-alone LoRaWAN base station solutions and provide good coverage of the area. Leftovers can claim to have access to acceptable connectivity, and therefore cheaper wireless communication, giving direct access to Internet from the collection node, will be required for data transmission: Wi-Fi can attain these objectives. In this article, we first examine the existing tools to ensure a good coverage study of the LoRaWAN network and, thus, perform a testBed. After, we offer a multi-optional architectural model that supports LoRaWAN and Wi-Fi protocols and that is flexible for other options. A gateway (Wi-IoT) capable of both providing Wi-Fi access and at the same time the ability to collect, process and monitor data as a mini-server will be proposed as proof of concept. From the node to the gateway, the data is compressed and sent securely and a user who connects to the gateway can, then, have access to the 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 the research and the industrial worlds. This advantage is granted thanks to 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

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source, uses the ISM band and also allows a 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. This means that the lower the coverage, the better the SF. 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 have the ability to communicate with each other [3], in order to form a city size extensive network. In this paper, we will first look at the indexes as well as at the practitioners, to find the existing tools or to make one, in order to ensure a good coverage study based on this concept and, then, to 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.

However, saying that Internet is not accessible or is intermittent is only a general observation, so some people can claim to have acceptable connectivity [3] (with a round-trip time less than 100 ms (see Fig.1)) and therefore, will want to go in this direction. This is why it should be wise and judicious to propose an architectural model offering several options of communication on demand and which will remain flexible to future evolutions. This is how we thought to add the Wi-Fi protocol (which is part of the broad family of radio technologies and used for equipment implementing the IEEE 802.11x standard family) to the proposed model in [3] as it is able to achieve these goals. Indeed, it belongs to the Wi-Fi Alliance organization [7] and operates in the frequency band 2.5 GHz (for 802.11b, 802.11g or 802.11n) or 5 GHz for the 802.11a. We are also seeing continuous improvement of its technologies (see Table 1).

Strictly speaking, we all know that sending naked data over Internet is not a good option. It would, then, be important to ensure end-to-end integrity as well as the authenticity of the equipment. Moreover, as in IoT, the size of the data to be sent must not be very large (in order to minimize the volume of flux that it can absorb on the network and remain as close as possible to the real-time), it will be, then, necessary to set up a compression method adapted for this purpose.

The rest of this paper will be organized as follows: Section 3 will do the coverage study on LoRaWAN Autonomous Base Stations and will propose a

Fig. 1. Internet latency in Africa

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	1X1 SISO
b	1999	11 Mb/s	2.4 GHz	20 MHz	1X1 SISO
g	2003	54 Mb/s	2.4 GHz	20 MHz	1X1 SISO
n	2009	600 Mb/s	2.4/5 GHz	20/40 MHz	up to 4X4*
ac	2012	3.2 Gb/s	5 GHz	20 to 160 MHz	up to 8X8*, MU
ad	2014	6.76 Gb/s	60 GHz	2160 MHz	1X1 SISO
af	2014	426 Mb/s	54 to 790 MHz	6-8 MHz	up to 4X4*
ah	2016	@	below 1 GHz	1-2 MHz	1X1 SISO

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

testBeb for this purpose. Section 3 will propose an extension of the architectural model to take into account the Wi-Fi protocol and which will also remain flexible to future developments. Section 4 will present a proof of concept and give test results. The conclusion and some perspectives will complete this document.

2 Coverage study

In LoRaWAN, the nodes are able to measure, on the reception of the packet, the received signal strength indicator (RSSI) and the signal to noise ratio (SNR). Since it is possible to calculate the sensitivity (S) of the radio receiver, which is the minimum of the detectable signal that can be decoded, it will be possible to evaluate the quality of the signal by monitoring the RSSI. Provided that the RSSI is not less than sensitivity and its limit value is practically not less than -120 dBm, in order to get 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 equation (1)).

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

The test results in [4] show that, as LoRa chooses narrowband transmission, it covers 1 km in deep coverage scenarios and about 5 km in outdoor scenarios. The practical approach using the RSSI in [5] shows that LoRaWAN gateway can cover up to 10km 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 observed at a distance of about 4.4 km from the gateway. We can, then, hope to have a good coverage between 1 and 3km in dense urban areas, between 3 and 6km in moderately dense urban areas, between 6 and 10km in low-dense urban areas and up to 15km or more in rural areas.

2.1 What simulation tool ?

This is the question we often ask ourselves when it's time for simulation. Research in most African countries is not always easy because of lack of tools (equipment) within our laboratories. To be able to simulate the quality of the signal with the constraints imposed by the network, the conditions of the area, with a better interpretation and presentation, are what we are looking for. To do this, the chosen tool or put in place must:

- To be able to propose the current state of 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;
- Being able to adjust the signal parameters (bandwidth, frequency, spreading factor used, modulation, etc ...);

- Propose a good representation of the quality and the strength of the signal in a map with specific collection positions;
- After simulation, to propose a portable recording file, which can be used as needed, without having to repeat the simulation;
- When simulating communications between base stations, to give the profile of the obstacles, the distances between the two base stations in communication as well as their acceptable heights to allow a good 'line of sight'.

Some tools were covered on [8], but none of them met our expectations. A simulator that is free and that can allow us to concretize our ideas is rare. Radio Mobile [9] can approach the solution but remains limited when it's question to take into account 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 is better to go to the source and, thus, generate our own scripts. We will, then, based on the Pietro Manzoni's scripts [12], suggest a testBed that can meet our needs.

2.2 TestBeb

The testBed was conducted around the campus of the "Institut de Mathmatique et de Sciences Physiques, Dangbo" and consisted of measuring the received Signal Strength from a node sending data. The purpose of this test is to show how to know if the coverage is good or not, depending on the data sent by the sensors, despite some obstacles. To expect a good signal, the RSSI must be closer to zero (0) and the minimum acceptable must be -120 dBm.

To meet our needs, we used an eight (8) channel gateway [15] placed at the Institute's computing center and a Pytrack [16], as a mobile node, whose role is to send GPS coordinates at a given moment of measurement. We also used a single channel gateway [17] (see Fig.2) for the same purposes. The results on the map (see Fig.3) indicate to us in green that the signal is strong (RSSI higher than -90 dBm), in yellow that the signal is quite good (RSSI between -90 and -110 dBm) and in red the signal is weak (RSSI below -110 dBm).

SPLAT also allowed us to simulate, on the other hand, the "line of sight" between two base stations (Master/Slaves).

Considering a base station located at the "cole normale suprieure" (ens) of Porto-Novo as a slave, that located at the institute as master, we manage to simulate a line of sight at a distance of 13, 25 km (see Fig.4). The slave can be placed about 30 m from the ground (35 m from the earth's curvature contour), while the master can be about 10 m from the ground (60 m from the earth's curvature contour).

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

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

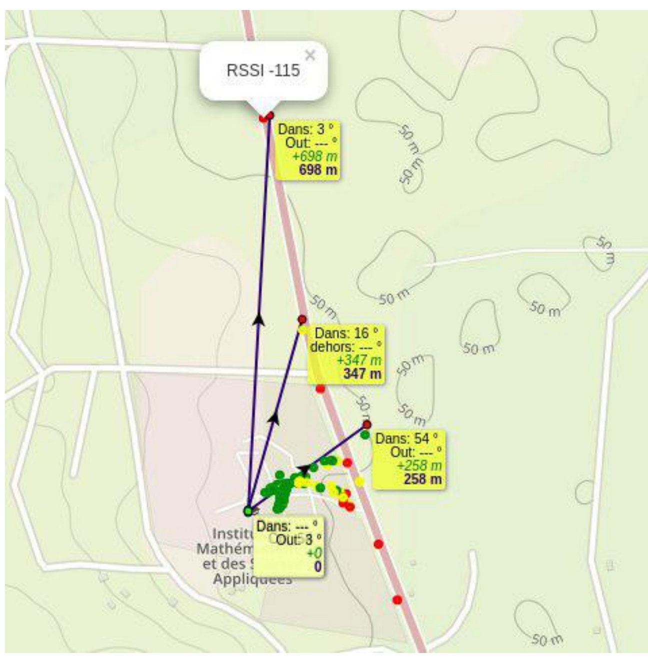

Fig. 3. LoRaWAN network coverage study around the IMSP campus

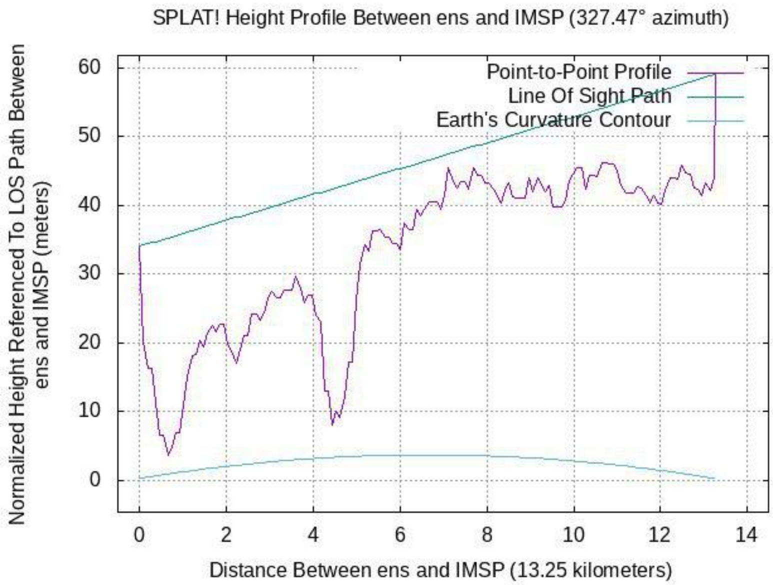

Fig. 4. the line of sight simulation between Slave (ens) and Master (IMSP).

in case of intermittency [3]. However, if this type of constraint does not bother some people, they can then connect their end nodes to the 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] in order to include this case and, consequently, to diversify the communication modes.

To illustrate, we can consider the scenarios, Yao and the Beninese government, described in [3]. Yao is a businessman and owner of a taxi company and wants to be able to know at any time the position of its taxis. He can easily have access to Internet and able to build its infrastructure on the latter. Similarly, the Beninese government can also connect its measuring stations to Internet and thus manage the collected data.

The requirements have not changed. This implies choosing affordable and accessible equipment and implementing a system that uses fewer resources (5 V DC and at least 2.5 A sufficient) and the storage system must remain scalable. 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 had to modify the general architecture proposed in [3] by adding the Wi-Fi option as follows (see Fig.5):

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

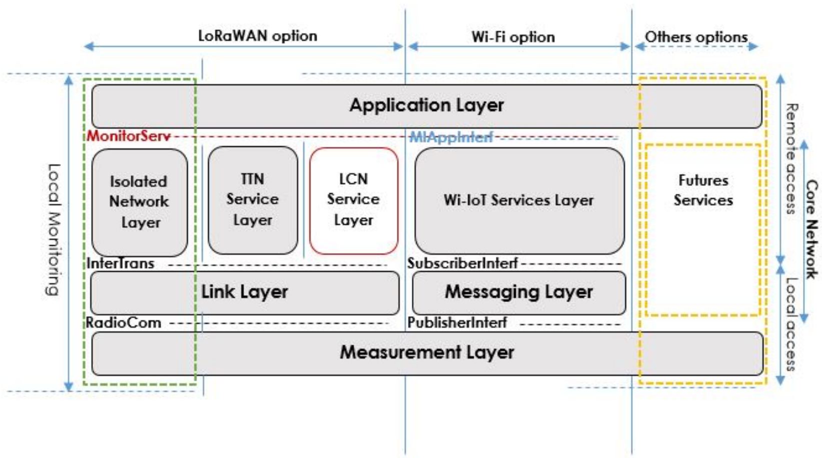

Fig. 5. General architecture

When we talk about architecture with several communication options, an interoperability problem arises. Since it is a city-sized infrastructure, centralization of data is then considered. In this case, the 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 is also able to present data from its "middleware layer" (see Fig.6).

4 Proof of concept

In this section we will discuss the methodology adopted to implement the Wi-Fi option. LoRaWAN options descriptions are available on [3].

To carry out this task, a choice of equipment (see Fig.7) must be done first before thinking about programming. So, we chose, on the node side, a Pycom expansion board 3.0 [18] on which we put LoPy 4 [19] and as a sensor, we used a DHT11 [20]. The gateway (Wi-IoT) is developed on a Raspberry pi 3 [21].

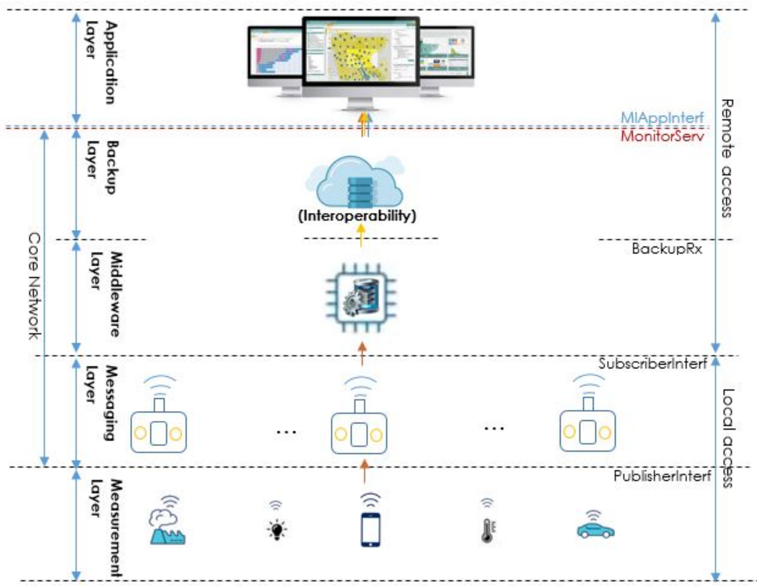

Fig. 6. Infrastructure in each layer

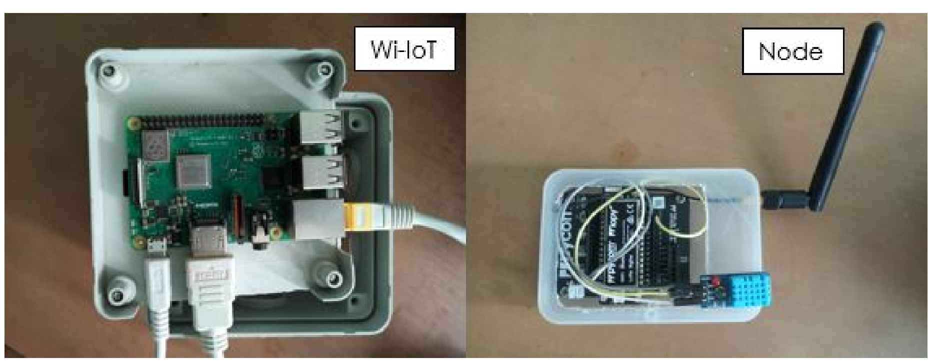

Fig. 7. Required types of equipment to implement the Wi-Fi option

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:
  - At 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, then, be a multiple of 4, otherwise, the string is initially completed.
  - 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 data is collected by the Wi-IoT gateway (which subscribes to the subjects of their choice in connected mode), then decompressed, decrypted and stored in InfluxDB (open-source time-series database). A backup in the central database for interoperability and other processing is then possible.

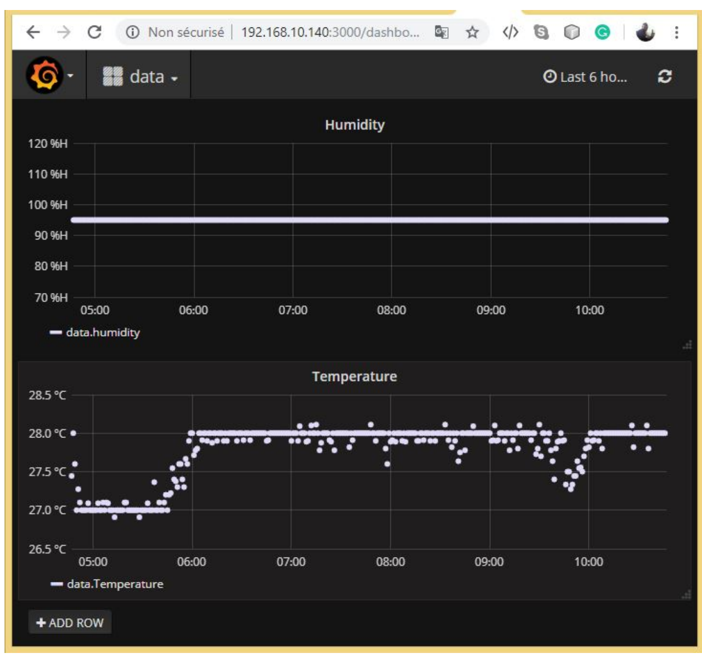

Fig. 8. Display of measurement of temperature and humidity collected

Grafana (open platform for analysis and monitoring) is, then, accessible on (IP: 3000) by any client connecting to the Wi-IoT gateway (see Fig.8). The applicability of machine learning is also possible with respect to self-correction, prediction, or decision-making.

5 Conclusion

In developing countries, Internet access is often a serious 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. "traditional third-generation cellular architecture" techniques in cellular mobile networks could well apply to this type of network when it comes to optimizing coverage. These techniques will be able to intervene when it is a question to talk about a city-size coverage problem based on the autonomous base stations LoRaWAN. In this case, it will be interesting to consider the addition of another radio protocol, such as Zigbee [22], to expand the sensor network while ensuring interoperability with the existing.

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