A Study for Remote Monitoring of Water Points in Mauritania Based on IoT (LoRa) Technology

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ABSTRACT

Wetlands in Mauritania contain the most important water sources necessary for the survival of rural communities in the country. In these areas, the main rural activities such as animal husbandry, agriculture, and fishing take place. Lack of water or flooding must be monitored to plan solutions in advance. After a comparative study of IoT wireless technologies, we proposed that LoRa technology is the most suitable for our field of application. However, in certain areas where access to the cellular network is difficult, we propose the addition of satellite communication in the LoRamonitoring system to achieve information collected at any point in the world via the cloud and the Internet. We carried out a practical case for the areas covered by the UMTS (3G) cellular network using devices integrating LoRaWAN to evaluate the performance of this technology. The results show the success of the communication over a distance of 14 km.

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1. INTRODUCTION

Mauritania has more than 300 wet areas mainly located in the country's western, southern, and south-eastern parts. Water point areas provide many services to the population in various sectors (agriculture, animal husbandry, etc.).

To enhance this potential and integrate it into the country's development, Mauritania has set a goal of automating information for good management of this sector. Recently, Mauritania has participated in an international satellite monitoring project. The purpose of this project was to monitor lake filling, monitoring rainfall, weather conditions, and the detection of pastures and bush fires.

However, until now, this system was only in place to monitor weather conditions and rainfall at the country level. The implementation of this project is therefore complicated and very expensive. The aim of this study is to study the possibility of implementing an Internet of Things (IoT) based solution that is less complicated to set up and at a lower cost compared to the existing solution.

With technological developments, the digitization of work procedures and the minimization of human intervention have enabled good development and reduced costs in almost all areas of life. Technological innovations including M2M (Machine to Machine) [1] use computer and telecommunications technologies to enable the exchange of information between machines and the execution of operations. However, the development of the IoT, which is an extension of M2M, has gained popularity in professional sectors, particularly in the industry, retail, transportation,and medical.

The goal of IoT is to facilitate the communication of physical objects to the Internet-based on several wireless technologies such as short-range technologies including RFID, NFC, LoWpan, Bluetooth / BLE, WiFi, and Zigbee [2], large common technologies: cellular networks and LPWANs. These technologies have been widely used in urban areas where GSM, UMTS, LTE cellular coverage is available [3].

However, we seek to find among these technologies that meet the criteria of our field of application. Our study aims to propose and deploy a solution allowing the monitoring at the level of the water points of wet areas in Mauritania. In the following, we present the related work, IoT wireless technologies, the requirements of our scope, the comparison of IoT wireless technologies with our scope, the proposed IoT technology, the proposed architecture, a practical case, and a conclusion.

2. RELATED WORKS

A lot of research discussing the use of communication technologies to make smart urban cities have been carried out in various fields such as smart Lightning, Smart Grid, and smart parking.The technology of wireless sensor networks (WSNs) has been exploited in many research fields such as the military, agriculture, sport, medicine, and industry [4]. WSN technology with VSAT technology has been well adapted to applications of smart cities such as video surveillance, smart grids, and city lighting, however, the deployment of these technologies in rural areas is very complex and expensive.

Recently several other IoT technologies such as RFID, BLE, WIFI, Zigbee, LoRaWAN, Sigfox have been fully utilized in surveillance in urban areas [5-6].However, recent research has found the use of LoRa and Sigfox technology very adaptable for monitoring in rural areas [7-8].For example, article [9] uses the LoRaWAN network for fire monitoring in rural environments, article [10] presents agricultural and environmental monitoring using a sensor network based on Zigbee, GPRS, and VSAT technology to provide a system for monitoring different conditions in crops and animal environments.The sensors and the Zigbee gateway placed in the farm are linked to an online server via the general packet radio communication service (GPRS) to enable remote online data acquisition.

Furthermore, article [11] used Sigfox technology to collect environmental information (such as humidity, temperature, and light) that could allow optimal plant growth, and sensors from Pysense were interfaced with a Lopy development board. Then, article [12] proposed the actual implementation of a LoRaWAN-based IoT network for smart agriculture. The proposed system consists of four soil moisture sensors at different depths of the farm that are linked to a LoRaWAN node which transfers the sensor data to a LoRaWAN gateway. Thus a micro weather station equipped with a LoRaWAN module transfers its information to the LoRaWAN gateway.

The range of LoRa technology in rural areas is a very important criterion for our context, so according to the article [13], LoRa can reach 20 km in rural mode. However, article [14] presents a practical case study of the range of LoRa technology in rural areas with a TTGO ESP32 card that integrates a LoRa SX1276 module and shows a range of 500 meters of LoRa technology.

Thus article [15] uses LoRa technology for smart agriculture and wildlife monitoring and proves a range of LoRa technology over a distance of 2050 meters using a device board that integrates a LoRa module RN2483A supported by the LoRaWAN. Also, article [16] proves a range of LoRa technology over a distance of 12 km using ESP32 modules LoRa technology and WIFI. However, within the framework of our research, we seek to propose an architecture of IoT technologies adaptable to our context.

3. STUDY OF THE FIELD OF APPLICATION

In Mauritania, water point's areas include both forms of expanses of ponds and swamps, fens, peat bogs, permanent or temporary, where the water is stagnant or running, soft, brackish, or saline, where the main factor influence of the biotope and its biocenosis is water. The literature distinguishes several types of water points areas having in common their endorheic characteristics, dependent on annual precipitation, and sharing the status of incomparable natural heritage.

However, nowadays, these areas are under great pressure that threatens the sustainability of the ecosystem services they harbor and provide, which need urgent action from public authorities. In fact, the eco-floristic, hydrological, climatic, and anthropogenic characteristics of these areas make them an environment that is both fragile and sensitive to all forms of risk, in particular climatic. Figure 1 and Table 1 summarize the situation of the water point areas in Mauritania.

Risks and threats

There are two main risks/threats with regards to water quality in water points areas, i.e.:

Pressure on water and plant resources

The various uses of water leading to the drying up of certain ponds and lakes in the area:the use for road works, fatting animals (transhumant workforce increasing strongly, particularly with the long drought:

thousands of heads), for the irrigation of palm, for the construction of houses and the creation of protected areas against animal wandering.

Change of water quality

Some carried out studies show that there is a risk of deterioration in the quality of water surfaces.

Pollution risk

Several activities are potential sources of pollution. This concerns particularly pollution due to the use of fertilizers, pesticides, fungicides to fight against pests in agriculture, market gardening and breeding, etc.

Table 1. The most important water points

Name of water point	GPS coordinates of the water point		Water duration in months
Mahmouda	N 16° 18’	W 7° 31’	12
TamourtNaaj	N 17° 51’	W 12° 07’	12
ChattTboul	N16° 06’	W 16° 42’	12
Mal	N 16° 55’	W 13° 26’	12
Aleg	N 16° 55’	W 13° 26’	12
Rkiz	N 16° 45’	W 15° 10’	12
Boughari	N 16°32'02"	W 10°47'09"	12
GaatSawana	N 16°29'40"	W 9°24'20"	8
OumAzvavail	N 15°86'30"	W 9°01'70"	8
Agueila	N 15°50'80"	W 9°81'70"	8
Sambou	N 16°15'40"	W 10°36'10"	9
Douerera	N 16°50'10"	W 9°93'00"	8
Eyer	N 16°90'90"	W 10°14'30"	10
Koubeir	N 15°98'70"	W 9°06'70"	10
Kervi	N 15°98'70"	W 9°06'70"	10

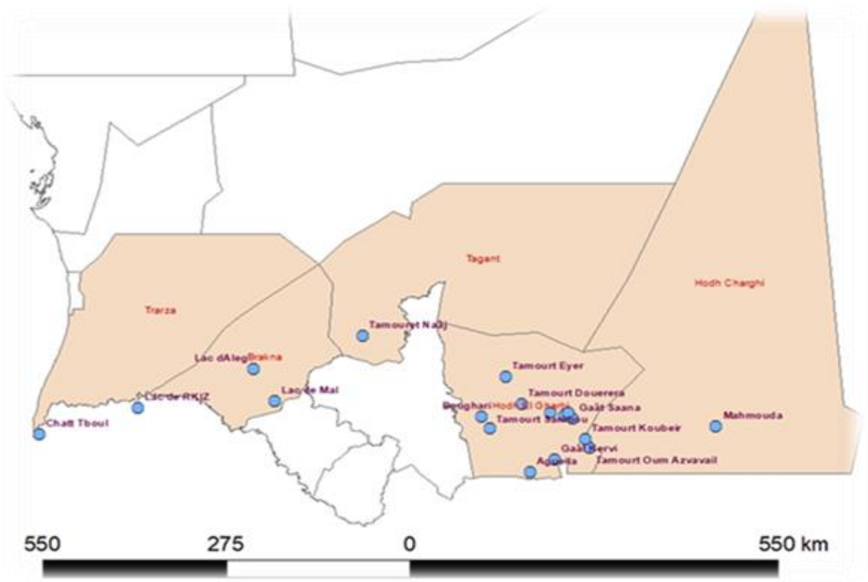

Figure 1. Map of the most important water points in Mauritania

4. REVIEW ON IOT

The IoT has continued to grow its integration into our daily life and particularly for management and monitoring in several areas such as health, environment, transport, agriculture, logistics, automotive, and even marketing. This phenomenon links the physical world to the digital world through multiple wireless technologies defined and used around the world. The first communication technology between physical objects was RFID technology [17].

After its success and that of M2M, other technical criteria for wireless data transmission technologies meeting the requirements of the Internet of Things have been developed, giving other forms of wireless communication including (BLE, WIFIHalow, Zigbee, LoRa, Sigfox, NB-IoT, and LTE).

4.1. Short-Range Wireless Technologies

Short-range IoT technologies have a range of a few meters and a maximum of one kilometer such as Bluetooth/BLE, Zigbee, Z-Wave, WIFI, NFC, and RFID. However, we will present BLE, Zigbee, and WiFi which are more popular [18-19].

BLE

Bluetooth Low Energy is the version of the Bluetooth protocol is intended for the IoT.Several fields of application such as monitoring the health of people and patients have used BLE for its low cost and ease of use [20-21].

WIFI

WiFi, standardized by IEEE 802.11, provides high-speed wireless connections to the Internet, intended for wireless networks (WLAN).
Several versions of WIFI exist and are distinguished by their speeds and their coverage ranges.

The IEEE 802.11ah or WiFiHaLow has been specially designed to meet the criteria of the Internet of Things, mainly wide coverage and low power consumption [22-23]. The coverage of this technology exceeds 1 km, and its data rate is set at 300 Mbps.

ZIGBEE

ZigBee is another short-range wireless technology in the IEEE 802.15.4 family [24-25]. This IoT technology has been widely applied for home automation, industrial monitoring, and healthcare applications.Zigbee is low power consumption, operates in the unlicensed bands, primarily 2.4 GHz and 868 MHz or 915 MHz, and its default operating mode at 2.4 GHz uses 16 channels of 2 MHz bandwidth, its range is a few meters up to 100 meters.Table 2 shows the comparison of the standards.

Table 2. Comparison of WiFi-Zigbee-BLE

Criteria	BLE	Zigbee	WiFi
Bandwidth	2Mbps	250kbps	7Gbps
Coverage	240m	100m	100m/ 1km

4.2. Long-Range Technologies

Cellular Networks

Using the cellular network (GSM, GPRS, and UMTS) for IoT is very expensive in terms of energy consumption and complex in terms of communication with smart sensors [26-27].

LPWAN

Low-Power Wide-Area Network (LPWAN) technologies have developed the exploitation of IoT by increasing the range of wireless communications and reducing power consumption [28-29].

LPWAN Unlicensed

LoRa and Sigfox are the two IoT technologies that use free frequency bands from the spectrum of spectral resources that are intended for industry, science, and medicine (ISM) which contributes to their low cost of deployments [30-31].

We present here LoRa and Sigfox which are the most used in the world. The advantage of unlicensed LPWAN technologies is the ability to deploy our own private network without the intervention of telecom operators.

LoRa

The wireless data transmission technology dubbed LoRa by Semtech Corporation is a physical layer modulation technique based on a spread spectrum.
However, LoRaWAN is a LoRa device management protocol defined by the LoRa alliance in 2015.

Several researches on this technology proved that LoRa has a data rate of about 50 kbps and has a range of 5 km in urban areas and 20 km in rural areas. As well as LoRa devices have autonomy of more than 10 years [32].

The structure of the LoRaWAN architecture is defined as a star, made up of end devices integrating LoRa modules, connected to gateways (LoRa) and a data reception server.
LoRaWAN has defined three classes of devices (A, B, and C) whose difference between these classes consists in the level of energy consumption by these devices.
Class A components are the lowest in power consumption because they only provide data transmission from end devices downlink to LoRa gateways. However, Class B terminals provide two-way uplink and downlink communication. Thus the terminals defined in class C are bidirectional and moreover are the most energy-intensive due to continuous listening on the uplink channel [33].

Sigfox

Sigfox is a Low Power Wide Area Radio Network Technology (LPWAN) protocol deployed in 70 countries around the world. These main features are distinguished for their range, cost-effectiveness, energy efficiency, and ease of operation. Sigfox is based on Ultra Narrow Band (UNB) technology, allows minimal power consumption for devices, and supports wider coverage compared to LoRa. Sigfox coverage can reach 50 km in rural areas [34]. Table 3 compares the two LPWAN Unlicensed protocols.

Table 3. Comparison between Sigfox and LoRa

Criteria	LoRa	Sigfox
Bandwidth	125kHz & 250KHZ	100 Hz
Coverage	5 km urban, 20 km rural	10 km urban, 50 km rural

<u>LPWAN Licensed</u>

There are also various low-power, long-range connectivity technologies based on cellular systems.

NB-IoT and LTE-M are the most powerful licensed LPWAN technologies based on the cellular system (2G, 3G, and 4G) today.
These technologies benefit from the existence and advantages of cellular networks, however, the cost of the terminals and the service are higher.

NB-IoT

The wireless data transmission technology named NB-IoT is based on the LTE cellular network.
NB-IoT is defined on a single narrow band of 200 kHz. This technology allows communications over long distances at low data rates. The data rate provided varies from 20 to 250 kbps. NB-IoT terminals incorporate rechargeable batteries [35].

LTE-M

LTE-M technology based on advanced LTE is dedicated to meeting the data transmission of the internet of things. It differs mainly from NB-IoT by its high-speed transmissions [36].Table 4 shows the comparison LTE-M and NB-IoT technologies.

Table 4. Comparison of two licensed technologies for IoT: LTE-M and NB-IoT

Criteria	LTE-M	NB-IoT
Bandwidth	1Mps	250kbps
Coverage	A few kilometers	1 km urban, 10m rural

5. THE REQUIREMENT OF OUR FIELD OF APPLICATION

Defining the requirements of our scope allows us to define the appropriate IoT technologies to meet the needs of our system. Our goal is remote and real-time monitoring of water quality, quantity, geolocation, lake level temperature, Water points areas temperature and wind speed. For monitoring, we use sensors with low energy consumption. These sensors can transfer their information using IoT technologies (Cellular, LPWAN, M2M, etc.). However, we choose technologies that have the following characteristics.

- Low energy consumption
- Low cost of deployment
- Operating over long distances

6. IOT TECHNOLOGY PROPOSED FOR THE PRACTICAL CASE

We compare IoT technologies according to our application requirements.

BLE, ZigBee, and WiFi technologies have a range of a few meters which excludes them from the comparison. Cellular network technologies (2G / 3G / 4G) consume a large amount of energy and are not designed for communication with IoT sensors, which excludes them from the comparison.

Thus, for licensed LPWAN, LTE M and NB-IoT technologies are based on cellular LTE. These two technologies are expensive and the scope provided is not sufficient for our context. Then they are excluded from the comparison. However, the characteristics of Sigfox and LoRa license-free LPWAN technologies strongly coincide with the criteria of our scope. Both technologies offer a long transmission range, low power consumption, and low deployment cost. The transmission range of Sigfoxin rural area technology can be up to 50 km and forLoRa technology up to 20 km [37].

The price of IoT devices is acceptable and their battery life can reach 10 years. So these two technologies are best suited to our context. Thus, the LoRa technology allows us to create our own private network in complete freedom, unlike the sigfox technology which is proprietary and requires a subscription to the Sigfoxnetwork.So, we chose the deployment test of our practical case, using LoRa technology.

7. PROPOSED ARCHITECTURE

We have a lot of water points to monitor in Mauritania. However, some of these water points are outside network coverage, hence we propose two different architectures the first one is based on LoRatechnology and satellite communication for areas outside network coverage the second architecture is based on LoRa Technology and UMTS 3G cellular technology.

For the areas outside network coverage, we have proposed the following architecture consisting of a LoRaWAN network and a satellite communication network. LoRaWAN for monitoring the water points using LoRaWAN level sensors and the satellite network to route the information from the LoRaWAN gateways to the visualization application on the cloud through the internet by satellite (see Figure 2).

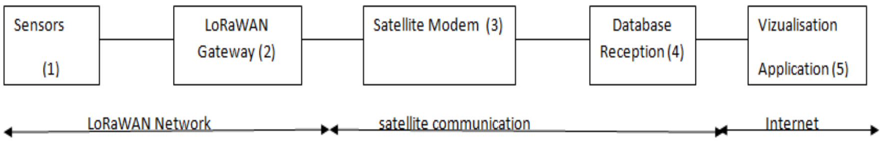

Figure 2. The architecture for the areas outside cellular network coverage

(1): LoRaWAN water level sensors placed at water points
(2): Gateway LoRaWAN has two interfaces, a LoRa interface for receiving sensor data and an IP-Sat interface for communication with the satellite network.
(3): Satellite Modem to transfer the data received from the gateways to a satellite data system.
(4): Reception database to transfer the data received from the satellite modem to the visualization application
(5): Visualization application for cloud data visualization.

For areas where UMTS (3G) cellular network coverage is available, we have proposed the following architecture, consisting of a LoRaWAN network and the UMTS network for routing information received from LoRaWAN gateways to a LoRaWAN network server and then display of sensor data on a visualization application (See Figure 3).

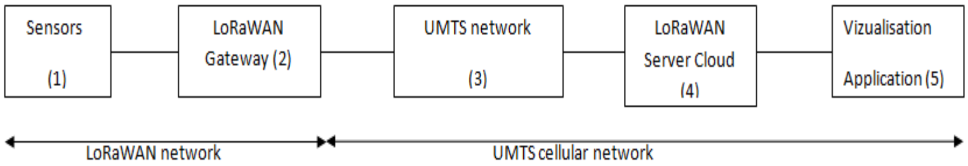

Figure 3.The architecture for areas where cellular network

(1): LoRaWAN water level sensors placed at water points.
(2): Gateway LoRaWAN has two interfaces, a LoRa interface for receiving data from LoRaWAN sensors and an IP interface for communication with the UMTS cellular network.
(3): The UMTS Cellular network is used to transfer data received from the gateways to the LoRaWAN server.
(4) The LoRaWAN server stores and processes the information received from the gateway.
(5) The visualization application for displaying data.

8. INITIAL EXPERIMENTAL RESULT

In this practical case, we have chosen Mechraawater point. Our objective is to study the range and capacity of data transmission by LoRa technology in rural areas. Cellular network coverage is therefore available in the village of Mechraa. In this case, the second proposed architecture was applied and tested at the Mechraa water point. Before the deployment of the LoRa technology transmission test at the Mechraa water point, we must study the architecture of this water point.

The objective of studying architecture is to know the number of level sensors and their sufficient location which will make it possible to determine the level and quantity of the water remotely in this water point.

Study Of The Position And The Number Of Sensors Needed For The Mechraa Water Point

To know the sufficient number of sensors to place, we proceeded to the study the architecture of the water point as follows:
The height-volume and height-surfaces curves come from the examination of the topographical surveys of the water point, before its selection. These two curves represent the characteristic of the water retention and give the different volumes of water and the areas for each curve level of the water point.
To determine the storage capacity of this water point, we proceeded with the following steps:

In a first step, we determined the surface of the water body corresponding to each level curve, which made it possible to determine the variation of the flooded surface according to the height of the water, and therefore the plotting of the highest area of the curve.

In a second step, we calculated the volume of the water point corresponding to each height of water in the water point, which made it possible to determine the variation in the storage capacity of the water point as a function of the height of the water point and by plotting of the height-volume curve of the water point (see figure 4).

Indeed, the partial volume V_i included between two successive level curves is given by the formula in Equation (1):

$$V_i = \frac{(s_{i-1}+S_i)}{2\,\Delta h 10^3} \quad (1)$$

With:
V_i: volume of water between the contour lines *i-1*and*i*;
S_{i-1}:Surface of the water body corresponding to the curve *i-1*, (h_{i-1})
S_i:Surface of the water body corresponds to the curve i, (h_i)
Δh:Difference in height between the two contour lines *i-1* and *i*;

$$\Delta h = h_i + h_{(i-1)} \quad (2)$$

The volume V of the containment zone corresponding to a height hi is given by the following formula in Equation (3):

$$V = \sum V_i \quad (3)$$

The formula is drawn up from the contour plan of the water point using parameters in Table 5.

Table 5. The different levels of the Mechraawater point

Side	Height (m)	S(km²)	Volume (10^6m3)
-11	0	0.00	0.00
-10	1	0.19	0.10
-9	2	0.48	0.43
-8	3	0.88	1.10
-7	4	1.40	2.23
-6	5	2.02	3.93
-5	6	2.79	6.32
-4	7	3.71	9.55
-3	8	4.74	13.77
-2	9	5.81	19.04
-1	10	6.70	25.32
0	11	7.66	32.45
1	12	15.69	44.18
2	13	19.54	62.02
3	14	22.48	83.05

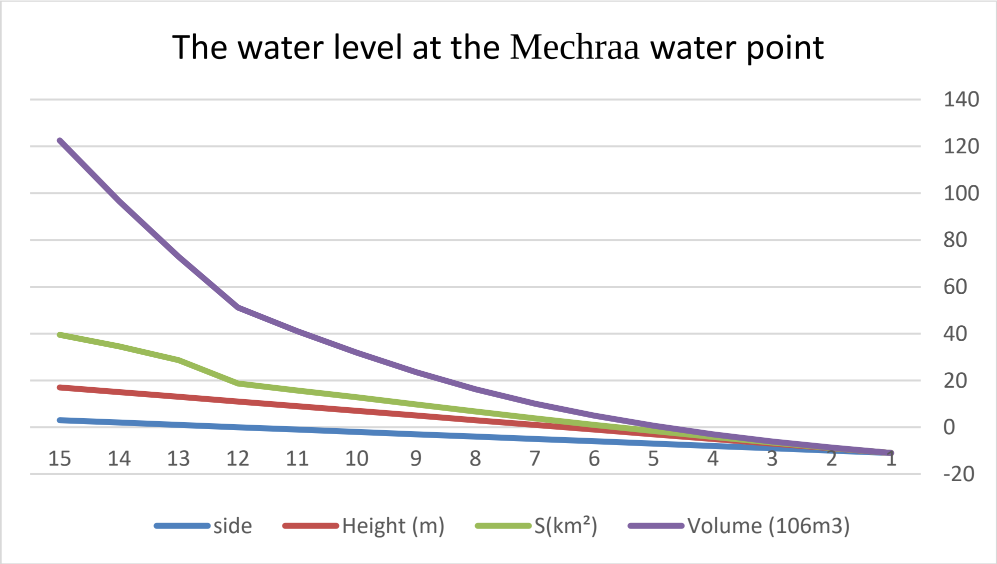

Figure 4. The different levels of the Mechraa water point

From this study, we found that monitoring of the water level and quantity at the Mechraa water point will need to place 14 level sensors for each level of the water point.

However, due to insufficient hardware, we performed the deployment test of a LoRaWAN network with a single LoRaWAN sensor. For this purpose, we used an LDDS75 draginoLoRaWAN level sensor and a LoRaWAN LPS8 dragino gateway to analyze the feasibility ofLoRa technology in our context.

We placed our LoRaWAN gateway at the village of Nbeika located in Tamourt Naaj and we placed our LoRaWAN sensor at the Mechraa water point located in Tamourt Naaj too (see Figure 5 and Figure 6). The distance between Mechraa water point and Nbeika is about 15 km. The two villages Nbeika and Mechraa are covered by good cellular network coverage in 2G and 3G.


Figure 5. Gateway Position

Figure 6. SensorLevel Position

For the LoRaWAN server, we used the Internet Things Network and we can see the communication between the two devices in Figure 7 and Figure 8.

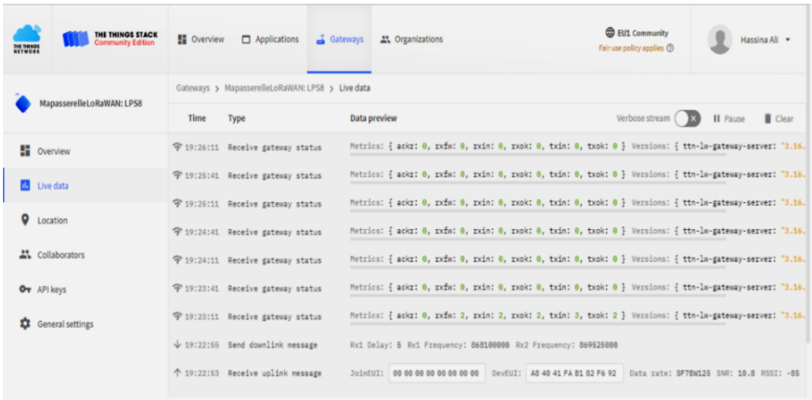

Figure 7. Connection of the LoRawAN Gateway on the Things Network through the 3G cellular network.

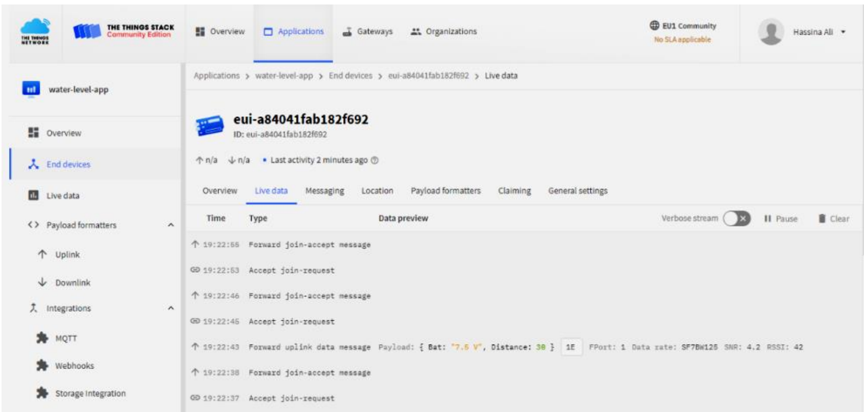

Figure 8. Connection of the LoRawAN Sensor on the Things Network through the 3G cellular network.

The communication parameters between the two devices are mentioned in Table 6 and Table 7.

Table 6. Parameters of the LoRaWAN gateway

Bandwith	spreading factor	SNR	RSSI	Frequency Range
125khz	SF7	10.8	-85	86810000 hz-869525000 hz

Table 7. Parameters of the LoRaWAN Sensor

Bandwith	spreading factor	SNR	RSSI	Frequency Range
125khz	SF7	4.2	42	86810000 hz-869525000 hz

The data collected by the devices and display on the Lorawan Server of the Things Network, show the establishment of a communication between the two remote Lorawan devices.The quality of the signal changed several times depending on the different position of the gateway that has been adapted.We also found a 40% loss by the Lorawan gateway. This can be explained by low cellular network coverage.

The deployment results prove that communication between the two devices has been well established over a distance of 14 km.

We have compared the articles in the same contexts "reach of LoRa technology". According to our review studies, our research is the last to mention a 14 km range of LoRa technology (see Table8). This can be explained by the ability of antennas add to the Lorawan sensor and gateway and the absence of obstacles (large buildings, trees) between our devices.

Finally, we can say that the LoRa technology is well adapted to our context.

Table 8. Comparison of our results with the articles [14] [15] [16]

Research paper	Aim	The proven LoRa technology coverage range	Materials used for the practical case	Results
Article [14]	LoRa technology evaluation in rural areas	500 m	- The TTGO ESP32 card - LoRa module SX1276 - Temperature sensor	The distance varies from a few meters to 500 meters depending on the choice of the SF parameter.
Article [15]	Evaluation of a wildlife monitoring application for IoT animal repellers capable of covering large areas	2050 m	- The IoT device board: ARM Cortex® M0+ 32-bit ATSAMD21G18A - The LoRa RN2483A module - A PIR sensor to detect targets and activate the animal repelling function.	The maximum measurement range reached a very dense Area of forest vegetation is 2050 m for SF12. This drastic reduction is due to the difficult propagation conditions in the forest environment. LoRa was shown to be sensitive to the presence of obstacles and reflectors, despite a more CSS modulation technique robust against interference.
Article [16]	Intelligent automation system using Long range technology (LoRa).	12 km	- The ESP32 module - LoRa module - Wifi module - Temperature sensor and humidity	Obtaining correct environmental data with an accuracy of 92.33% at a distance of up to 12 km demonstrated the high performance of the system.
Our case study	Performance evaluation of LoRa technology for remote water level monitoring in rural areas	14 km	-Dragino LDDS75 LoRaWAN sensor -Dragino LPS8 LoRaWAN gateway	The percentage of communication between the two devices varies according to the height of the devices in relation to the ground.

9. CONCLUSION

In this article, we have presented and compared the IoT communication technologies against the requirements of our scope. Our goal was to provide a dynamic solution, adaptable to our context and based on the Internet of Things. The proposed solution based on LoRa technology has the advantage of being more flexible, low cost of deployment, and adaptable to rural areas, due to its long range over several kilometers. Thus, a field deployment test has been realized, which proves the feasibility of the Technology Lora to our context.

In future work, we plan the remote monitoring of water quality by adding Lora sensors at the ground level. Thus we will also test the addition of a satellite modem to the Lora Communication System to confront the low coverage of the cellular network.

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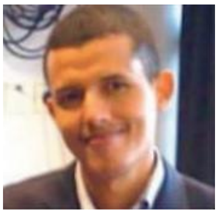

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