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Communication Network Systems for White Spot Areas

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Résumé

White spot areas depict geographic locations which are not covered by mobile network operators. In Senegal, the Sylvo-pastoral hosted by Ferlo's region has a prominent role according to livestock transhumance. Nevertheless, this region is roughly covered by white spot areas. The lack of cellular network infrastructure is a pitfall for vital information dissemination for agro-pastoralists. Therefore, this paper describes the deploy- ment and testbed performance evaluation in rural and urban environment of a LoRa-based COWShED communication architecture. By leveraging a mesh-based prof-of-concept, tangible results are obtained and thus promote several applications which overcome white spot areas limitations such as stakeholders geolocation, transhumance management, milk collection, etc.

Mots-Clés

LPWAN, experimentaion, testbed, white spot areas

I INTRODUCTION

Despite equipment efforts, mobile phones do not have connectivity in certain rural areas as well in a few urban areas. Low population density within a couple of rural areas is an economical barrier for operators. In fact, $Ferlo$ region that is one of the least populated Senegalese regions is largely formed by white spot areas(geographic locations which are not covered by mobile network operators). The use of satellite communications cannot be envisaged because of their low purchasing power.

Figure 1 illustrates $2G$ mobile cellular networks according to the three main Senegalese operators $Orange$, $Free$ (formerly called $Tigo$), and $Expresso$. In contrast, 2 exhibit white spot areas with respect to $2G$ across Senegalese territory. Indeed, green areas (2) illustrate locations that are not covered by $2G$ mobile network around the country. For instance, according to Fig. 2, $Ferlo$ region is located at the east-center which is mostly covered by green areas.

Livestock farming in Ferlo in Senegal is extensive, based on the exploitation of natural resources. Thus, the herds and their shepherds are constantly on the move in search of water and pasture(2). This pastoral mobility is a daily and seasonal adaptation, with transhumance, to the bioclimatic conditions of the environment. Ferlo is a semi-arid space where annual precipita-

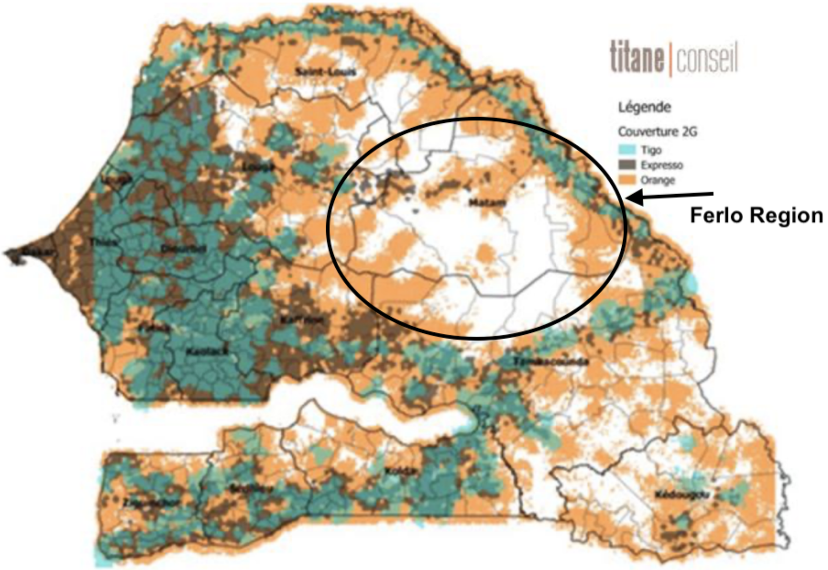


FIGURE 1 – $2G$ mobile networks operators coverage across Senegal in 2017 http ://www.numerique.gouv.sn/mediatheque/documentation/rapport-final-actualisation-de-la-stratégie-d'accès-au-service-universel

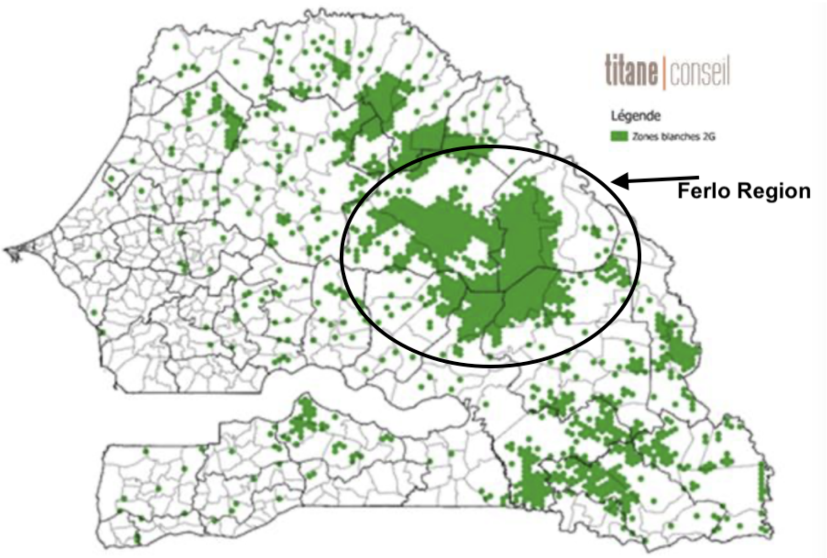


FIGURE 2 – $2G$ white spot areas within Senegal in 2017

tion is between 300 and $600mm$ ranges of water(3) (4). The low rainfall in this pastoral area directly influences the hydrological capacities, flora and fauna. It also reduces the possibility of agricultural development of the land. For instance, $SPAIF$ project (5) was launched in order to manage livestock transhumance. Nevertheless, breeders within these white spots have at no time possibility to use their mobile phone in real time to communicate or transmit useful information such as water point status, situation in boreholes and pasture, epizootic diseases (local and neighbouring countries), cattle rustling along transhumance transit roads.

Therefore, $COWShED$ (COmmunication within White Spots for brEeDers) aims at collecting various information and disseminate that into the network(environmental, pastoral activity, animal health, organization and management of pastoral lands, and agriculture). The technical solution for our architecture system is based on technologies for challenged networking scenarios such as Opportunistic Networking, Internet-of-Things and Device-to-Device communication using Low Power Wide Area Networks. In fact, the interest of IoT industry towards the Low Power Wide Area Networks (LPWANs) is consequently increasing. Therefore, by 2024, the IoT industry is expected to generate a revenue of 4.3 trillion dollars (6) (7). Most LPWA networks operate in unlicensed ISM bands at 169, 433, $868/915MHz$, and $2.4GHz$ depending on the region of operation(8). One of the most pronounced LPWAN candidate is LoRa. It has a long battery life and is low cost. Coverage is also one of its most critical performance metric). A couple of works have shown the possibility to use $LoRa$ technology as a communication system. Indeed, the physical and data link layer performance of *LoRa* (8) (9) have been evaluated by field tests and simulations in (10) (11) (12).

In this paper, we built an end-to-end communication system between smart phones via relay boxes that exchange information (text and audio) through $LoRa$ transmission protocol. Therefore, a Linear regression model for path loss estimation is proposed for both urban and rural areas by means of empirical tests according to the Received Signal Strength Indicator ($RSSI$). Furthermore, we consider different use cases and scenarios that enable better management of resources and decision making in relation to milk collection and emergency management.

The remainder of the paper is organized as follows. Section II describes our LoRa-based communication architecture. Section III depicts our experimental test and the Linear regression model. Section IV describes services added to the device. Finally, Section V concludes our work.

II LORA-BASED COWSHED REQUIREMENTS AND ARCHITECTURE

In undeserved areas, satellite communications are very expensive for rural populations. In order to choose the best communication system, we have to take into account some critical metrics to make a comparison between the existing Long Range solutions. Coverage, power consumption and cost are one of the most important metrics. In fact, Ferlo's villages are very far one from another and lot of them have no electricity. Therefore, our device should not consume a lot of energy and should be low-cost. We assume that a *LPWAN* device is the best solution because it has a better coverage and consume less energy than Bluetooth and WI-FI. We chose LoRa which is one of the most used and reliable technology for large coverage with respect to *LPWAN* (9).

Due to LoRa low data rate (50kbps maximum), the data transmitted in the network is majorly based on text messages. For the users that aren't literate, we added the possibility of sending voice messages. However, we should limit the duration of the voice message because it increase the size of the message and by the same time increases the sending time due to our low data rate.

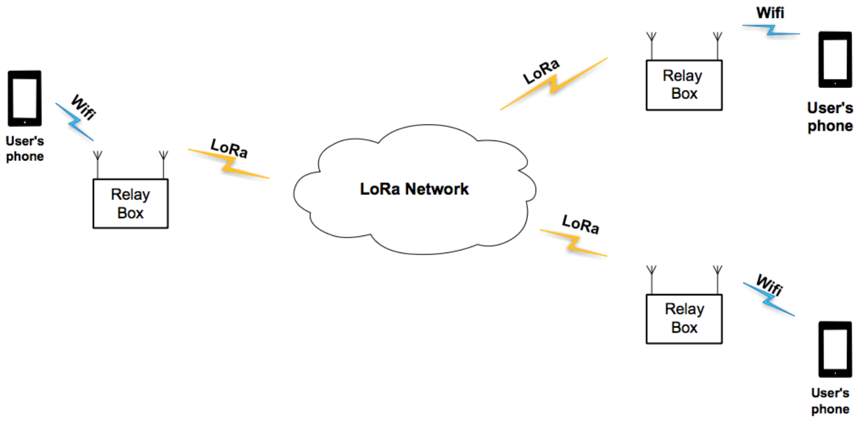


FIGURE 3 – LoRa-based COWShED communication architecture

Therefore, we built an end-to-end communication system between smart phones via relay boxes that exchange information (text and audio) through $LoRa$ transmission protocol. Fig. 3 shows the designed communication architecture between users.

A communication between a given mobile box (smart phone) and a relay box (based on $Dragino$ $LG01-P$) is done by $WiFi$ based on $IEEE802.11n$ (14). We consider a $LG01-P$ box which contains a $400MHz$ CPU that hosts $openwrt$ with $16MB$ flash and $8MB$ of storage memory, a LoRa chip ($SX1276$) transmitter, and an *arduino Yun* card. We build a mobile application in which we can connect to a web server installed in the relay box and send/receive data through $WiFi$. A $MySQL$ server is installed in the box to save both data sent from the mobile application and data coming from the network. Then we made a *Shell* script that takes data from the database and send it to an $arduinoYuncard$. The arduino Card reads the data by running Linux process with the *Bridge library's Process class*. Once the data is in the arduino card, we send it through LoRa to the destination node. According to LoRa configuration, we had :

- spreading factor : 12 (4096 chips)
- channel size : $125khz$
- Power transmission : $14dBm$
- coding rate : $4/5$

It is worth noticing that LoRa uses the 868MHz ISM Band in Senegal which is a free band. Communications are then free of charge for the users. The prototype is as depicted in Fig. 4 where the communication, between both previous components, is based on $IEEE802.11n$ (WiFi).

We also made a Bluetooth-based communication prototype which is formed by two components. The first one is illustrated in Fig. 5 and formed by : (i) a Long Range transmitter (LoRa chip $Sx1272$) card which acts as relay and can either broadcast received information from breeder's smart phone towards next hops or transmits received information from neighborhood to breeder's smart phone ; (ii) an $arduinoUno$ card which acts as processing unit ; (iii) a Bluetooth Low Energy (BLE) card which either transmits received information from LoRa card to smart phone, or from smart phone to LoRa transmitter. It should be noted that the considered smart phone is our second component. Indeed, both components communicate through their Bluetooth interfaces. In so doing, a mobile application is deployed within each smart phone and enables to send information (message text or emoticon) from breeder's smart phone to our gateway (Fig. 5).

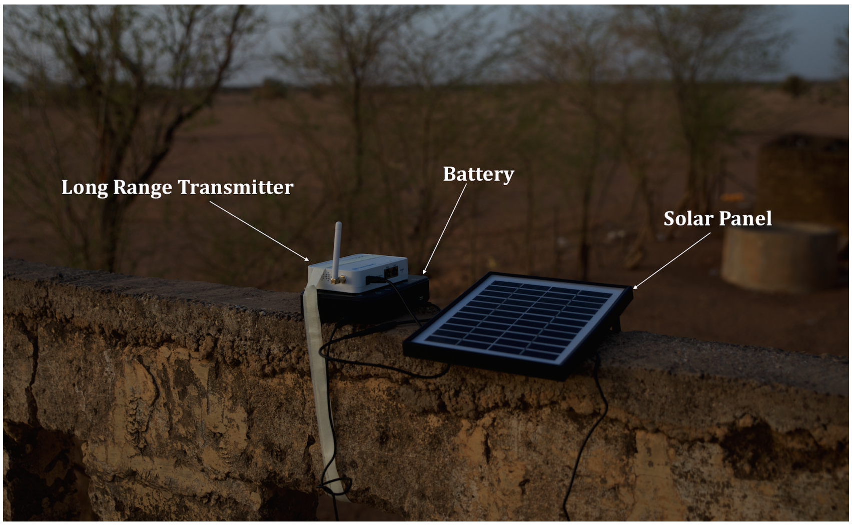


FIGURE 4 – WiFi-based communication prototype

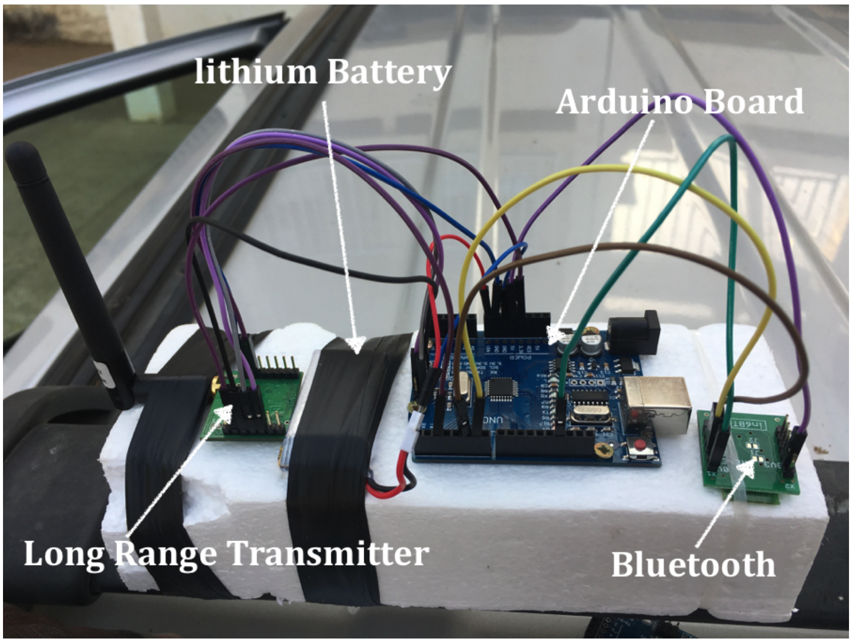


FIGURE 5 – Bluetooth-based communication prototype

Fig. 6 illustrates a communication scenario with respect to COWShED architecture. By leveraging LoRa transmission between two relay boxes, it depicts an end-to-end communication between two mobile boxes (smart phone) using bluetooth or WiFi. The store and forward concept is due to the large distance that separate different users of the network, and the lack of central equipment to interconnect all the users. In fact, this network has to be seen as a Delay tolerant network with an ad hoc architecture. We assume that it is a sparse and intermittently connected mobile adhoc network where reliable communication and end-to-end connectivity is not always available for message transmission

Furthermore, $Ferlo$ is an area in Senegal where solar irradiation is very important. Sunshine duration ranges from 7 to 12 hours by day overall the year (17). Therefore, to ensure power supply, we use solar power systems with replaceable batteries of $7.4V$ and $5200mA$ which have 8 hours of autonomy with our device. The battery is recharged by a $4W$ solar panel.

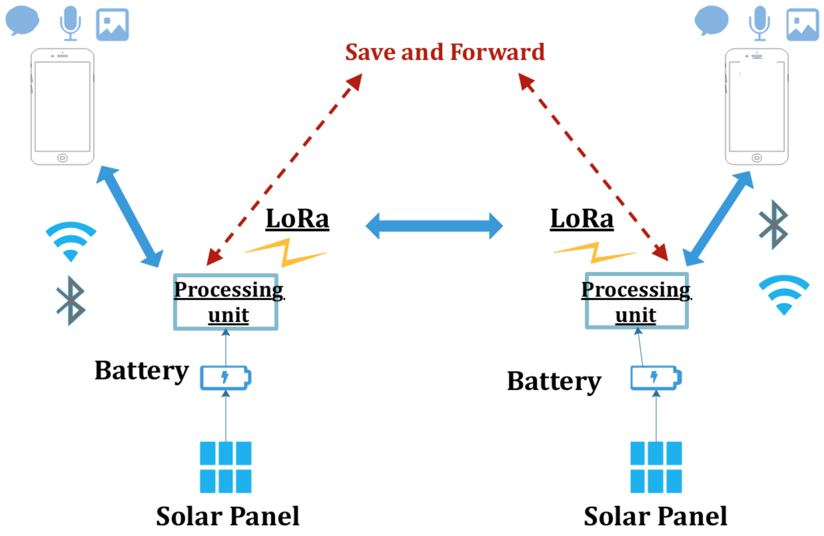


FIGURE 6 – COWShED communication Architecture

FIGURE 7 – Breeder in communication through COWShED architecture

For instance, Fig. 7 shows a herder wearing a bag containing our $LG01$ box which is powered by a solar panel. The whole sytem is embedded in bag designed by us.

Table 1 illustrates a brief comparison between both designed prototypes. It is worth noticing that Bluetooth-based communication prototype is useful for text messages service, warning system or other IoT applications that do not require to transfer big amount of data with LPWANs. In

TABLE 1 – Performance evaluation of prototype-based on Bluetooth and WiFi

Device	Range	Bit rate	energy consumption	Storage
Bluetooth Based	-	-	+	-
WiFi based	+	+	-	+

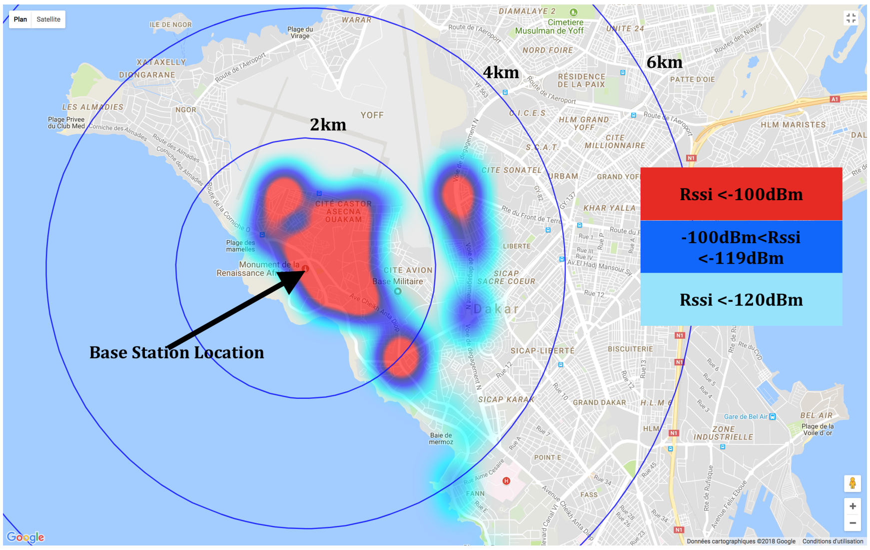


FIGURE 8 – Received $RSSI$ from a Base Station located within urban area

contrast, WiFi-based communication prototype is more relevant when we consider a store-and-forward transmission scheme. In case of voice messages or pictures, it will be more suitable.

III TESTBED MANAGEMENT AND LINEAR REGRESSION MODEL

3.1 Urban and rural testbed deployment

In order to evaluate transmission devices reliability, we perform extensive tests by considering urban and rural areas. The measurements were done in “$Dakar''$ (14.754048, -17.489429) peninsula (urban area) and “$Namarel''$ (16.040129,-14.750423) village located in Ferlo region (rural area). We deployed an architecture made of two components that communicate via LoRa. A fixed base station sends data at regular intervals to a mobile station. The base station is made of an $ArduinoUNO$ card, a LoRa Shield (14) and a computer. The mobile station is formed by an $ArduinoUNO$ card, a $Dragino$ LoRa Shield (14) , a GPS Shield module and a computer.The communication between the computer and the $Arduino$ board is carried out via a serial port. The collected data from the serial port are stored in a local database hosted by the computer. The required duty cycle of 1% (15), (16) in EU organization for the $868MHz$ ISM band is not currently applied in Senegal. Therefore, our base station is able to send data with respect to a fixed interval time.

Since $Dakar$ peninsula hosts more than 3 million people and lots of buildings having at least four floors, we planned to place 4 base stations to be able to cover the whole city. For this reason, we considered the following sites within $Dakar$ as radio beacon :

- The top of “Phares des Mammelles” that ranges up to $126m$.
- The esplanade of “Monument de la Renaissance” which measures $100m$.
- The “Virage”, our lowest point with roughly $20m$ of height.

TABLE 2 – Urban area performance evaluation

Range (km)	Number of transmitted packets	Number of received packets	Packet Error Rate
0-2 km	2501	2176	13%
2-4 km	2560	2199	15%
4-6 km	2300	1620	31%
6-8 km	2110	633	70%
Total	9471	6628	30%

— The highest building in Dakar “Building Kebe” with $75.36m$ of height.

On the other hand, $Namarel$ is in a semi desert area where the overall environment across several kilometers has the same trend as shown in Fig. 9. During our visit, we found large areas of land which own few trees as well a couple of neighboring villages. We placed a base station on the roof of the $Namarel$ headquarters as depicted in Fig. 4. Furthermore, a device is placed on a pickup in motion. It is worth noticing that the pickup has criss-crossed around the village in order to evaluate transmission range.

During our performance evaluation, 10.000 packets were sent according to the urban area with a maximum transmission range of $10\ km$. In contrast, according to rural use case scenario, 3017 packet were sent with a maximum transmission range of $16\ km$. Indeed, in rural area we have a better line of sight which enables efficient transmission. Fig. 8 shows received $RSSI$ from a Base Station located within an urban area. Table 2 and Table 3 show evaluation performance of Packet Error Rate (PER) as a function of covered distance in urban and rural areas respectively. We found that packet error rate ratio increases a bit when the range goes up. Furthermore, by taking into account a fixed transmission distance, the PER obtained in urban area is upper than one estimated in rural area. As example, for transmission range up to $4km$, we obtained 0% PER (respectively 13%) for rural area (respectively urban area).

3.2 Linear Regression model

According to received packets, we aim to make a channel attenuation model for each base station. The obtained models enable to estimate path loss by using LoRa Technology. Our model can be divided into two parts.

— For every received packet with the mobile station in motion we saved the Received Signal

FIGURE 9 – Namarel testbed overview

TABLE 3 – Rural area performance evaluation

Range (km)	Number of transmitted packets	Number of received packets	Packet Error Rate
0-4 km	757	757	0%
4-8 km	807	793	1.7%
8-12 km	803	760	5.3%
12-16 km	650	601	7.5%
Total	3017	2911	4%

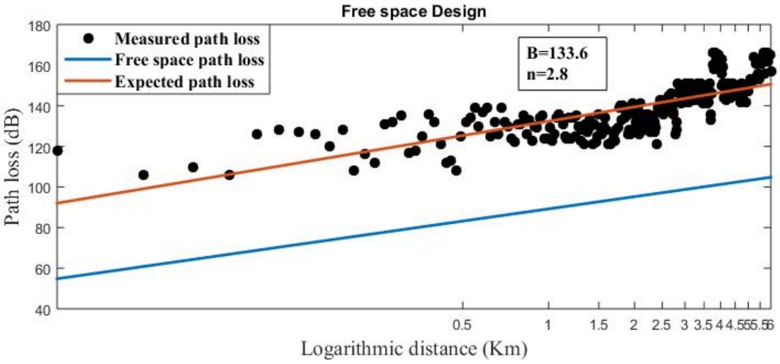


FIGURE 10 – Path Loss for an urban base station.

Strength Indicator ($RSSI$) (20) and the Signal-to-Noise-Ratio (SNR). We used it to calculate the Path Loss (PL) with the following link budget.

$$PL = |RSSI| + SNR + Ptx + Grx \tag{1}$$

"Ptx" is the effective isotropic radiated power and "Grx" is receiver's antenna gain.

— We derived Expected Path Loss (EPL) of measured data from the linear polynomial fit. We calculated it as (18) with :

$$EPL = B + 10nlog10(d/do) \tag{2}$$

"B" represents the path loss, "n" is the path loss exponent, "d" is the distance between the node and the base station and "$d0$" means the 1km reference distance. For each base station, we measured the path loss. For instance, Fig. 10 and Fig. 11 depict measured path loss (black dots) and expected path loss (red curve) for two bases stations. The curve tagged in blue represents the free space path loss.

In order to evaluate our linear regression model, we take into account free space path loss as a reference to highlight the effect of the environment on received signal because it is almost impossible to model obstacles when tests are done in a real environment (19).

Since we could not browse all places within a fixed city during real life test, we performed coverage predictions depending on the results of the models. For each base station, we can now predict its coverage by giving a maximum $RSSI$.

By combining obtained results, we made a chart to highlight a link between the PER and the $RSSI$ in Fig. 12. It shows the mean $RSSI$ as function of PER. This could help to show packet error rate compared to a chosen $RSSI$ to cover a place.

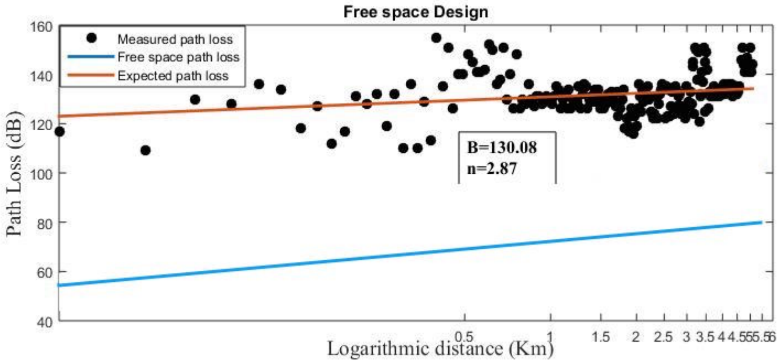


FIGURE 11 – Path Loss for a rural base station.

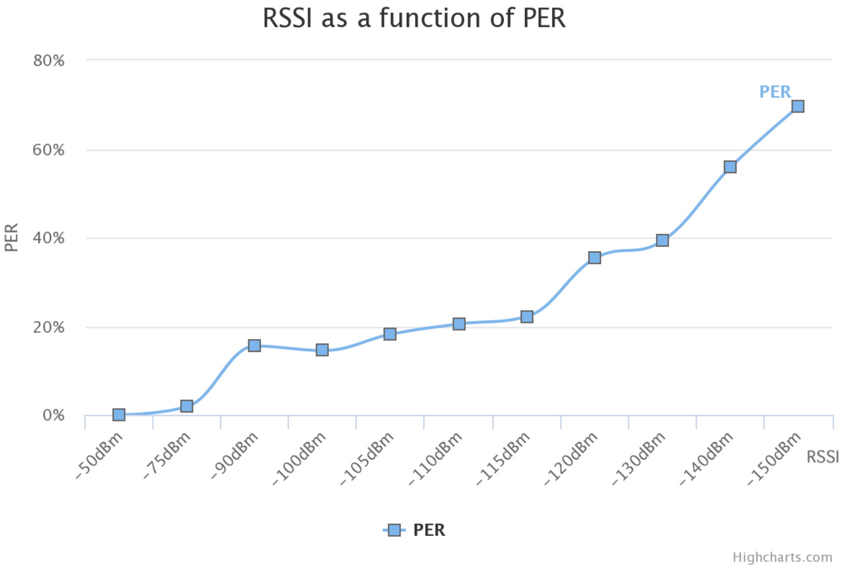


FIGURE 12 – The mean RSSI as function of the PER.

IV APPLICATIONS AND FEATURES OF COWSHED NETWORK

Providing a low cost and reliable communication system for people living within white spot areas in order to help them communicating with their surroundings for various usages is the major objective of our work. For that, we added some functionalities in $COWSheD$ project in order to meet those objectives.

4.1 Voice message

It's worth noticing that people who live in the Ferlo area are not often literate. Although we met representatives in the villages with a sufficient level of education to exchange text messages, we thought it would be useful to add to our system the possibility to send voice messages limited to 5 seconds. we have added an option in the mobile application to send a voice message that stops automatically after 5 seconds, this voice message is sent by the same method as when sending text messages to the Web server and is stored in a database. A shell script that runs like a daemon(refers to a type of computer program, process, or set of processes that runs in the background rather than under the direct control of a user) comes to retrieve it and send it to the $Arduino$ card thanks to the process and the message is sent to the LoRa network by the arduino card.

LoRa bit rate is very low so sending voice notes takes a bit of time (approximately 5 minutes).

FIGURE 13 – A refrigerated milk car in Namarel village

In fact, we send 4000 bytes for a 5 seconds voice note with payloads of different sizes depending on the range and the transmitter configuration to reduce the packet loss ratio or to optimize the data rate.

All relay boxes receive the first payload of a voice note and are paused for the duration of the transmission in order to avoid possible collisions. It is important to remember that the receiver of the message is added during the sending process in the mobile application as for the text message.

4.2 Geographic location

In order to enable a geographical information system, we considered an offline map ($maps.me$) which is deployed in breeder's smart phones. The device can get data from remote connected devices using LoRa network. Therefore, geolocation service can be used in order to locate available water points and boreholes. According to our application, herders geographic location are retrieved from a GPS, and thus, we are able to send geographic location. These coordinates can be displayed by considering an offline maps like $maps.me$. Furthermore, $LG01$ box is able to store herders geographic location (longitude, latitude) along transit transhumance roads.

4.3 Milk Collection

According to Ferlo region, the main source of women income is based on milk collection (25). There is a collection system based on the milk collection with pick-up cars (milk is contained in plastic buckets or aluminum cans) or at the collection centers equipped with refrigerated milk cars as illustrated in Fig. 13. The product of the collection is then transferred to a dairy where the milk is processed and bagged. The inhabitants of the nearby villages make the route on foot to bring their stocks. For the most distant villages, the use of the cart is more common. In case of high demand, the pick up moves to collect the milk but that has a cost. Indeed the fuel and the material resources necessary for the collection and the safeguarding of the milk are loads to be taken into account. On top of all those constraints, the impossibility to communicate with surroundings villages is a big issue for those women. $COWShEd$ enables a new framework that helps in decision making to support logistical management for milk collection. (26)

TABLE 4 – Performance Evaluation

Range (Km)	Number of transmitted packets	Number of received packets	Packet error rate
0-5Km	1057	1037	2%
5-15Km	1727	1685	3%
15-20Km	903	862	5%
20-22Km	459	351	13%
Total	4146	3935	5%

4.4 Geographic localization system for artisanal fishery

Although, fisheries sector hold a prominent role in Senegalese economy according to foreign exchange earnings (exports) and vital needs of population (27), Senegalese GSM cellular networks do not cover distance upper than 7 km from coasts. We obtained this information from real life test that has been done. We used two mobile applications ($inViu\ OpencellID$ and $network\ cell\ info\ lite$) and took screenshots of signal quality with respect to fixed positions as depicted in Fig. 14 and Fig. 15. The crossing positions during the test were mapped in Fig. 16. By considering geographical coordinates of position where screenshots was taken, $RSSI$,

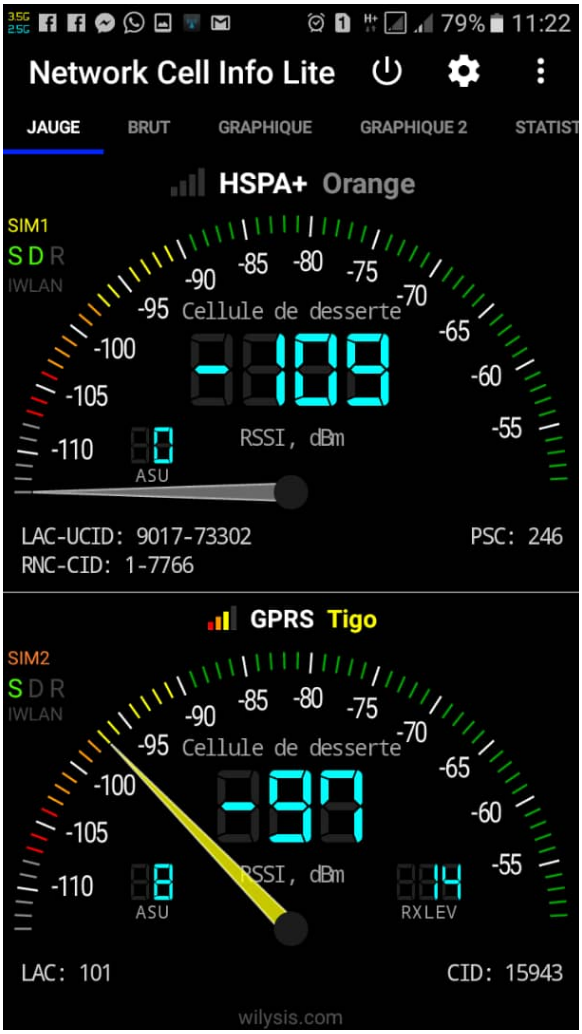
domaine du réseau actuel
cell-ID : 166345
MNC : 01
MCC : 608
LAC : 9008
réseau : Orange
force du signal : -107 dBm

position actuelle
latitude : 14,704191
longitude : -17,543672
satellites : 18

domaines de réseau rassemblés
aujourd'hui : 0
pas encore envoyé : 0
total : 0

emplacements rassemblés
aujourd'hui : 0
pas encore envoyé : 0
total : 0

FIGURE 14 – $2G$ RSSI with “inViu OpenCellID” application



HSPA+ Orange

-109

0 ASU

LAC-UCID: 9017-73302

PSC: 246

RNC-CID: 1-7766

GPRS Tigo

-99

8 ASU

14 RXLEV

LAC: 101

CID: 15943

FIGURE 15 – 2G RSSI with Network Cell Info Lite application

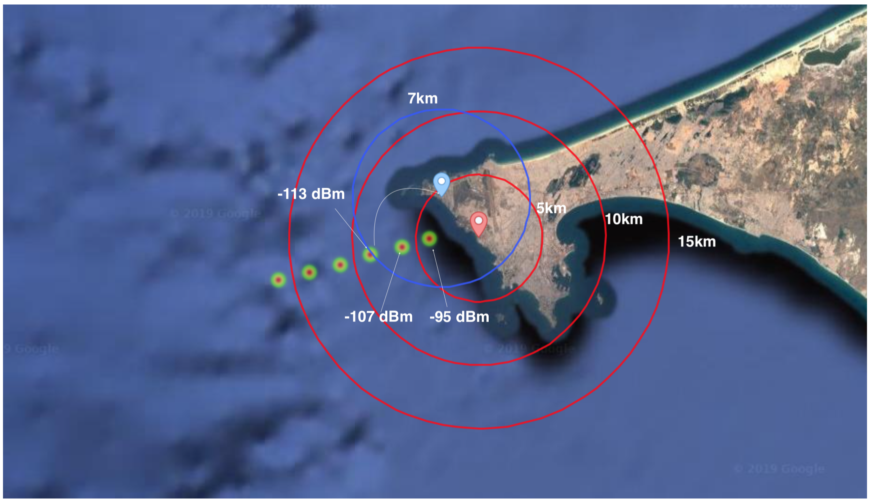


FIGURE 16 – 2G RSSI during test

Mobile Network Code (MNC), Mobile Country Code (MCC) and Location Area Code (LAC), we can find geographical coordinates of the Base station to which the cell phone was connected thanks to (24) and then know the distance between cell phone and Base Station. Blue and red center of origins are base station of operators to which our cellphone was connected. So the

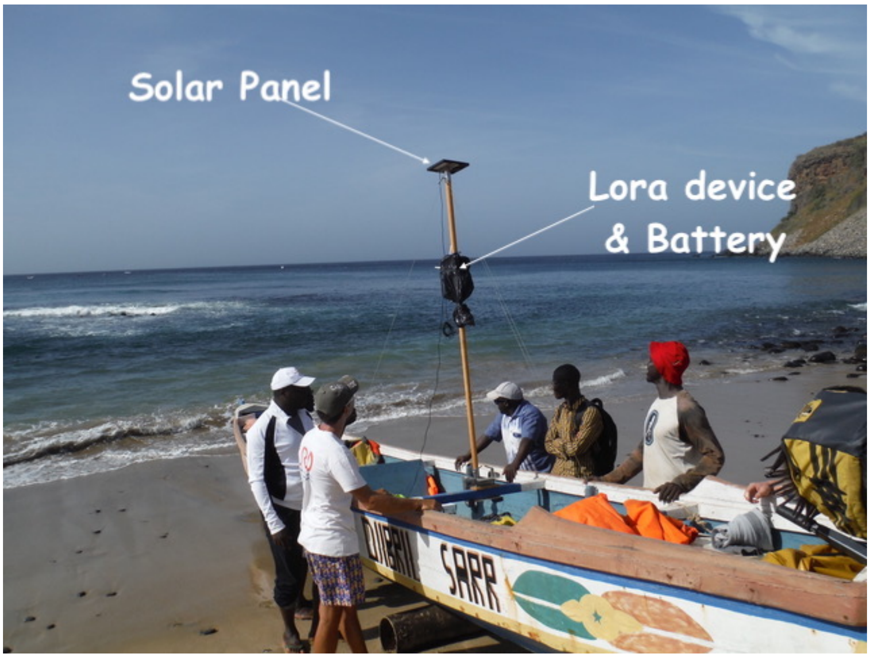


FIGURE 17 – Mobile Relay in the Canoe

FIGURE 18 – Received Signal with RSSI higher than $-95dBm$

distance between the cell phone and the base station is not the same depending on it. We then made two circles to calculate and highlight the exact distance. This lack of coverage is the reason why there is no rescue communication system for dugout canoes that fishes over that limit. The social and human conditions are difficult, including safety problems at sea (21) (around 100 deaths per year). Artisanal fishing boats are usually made of a wooden shell of local design, on which is fitted an outboard engine that can go up to at 60 horses. Dugout canoes are emblematic in Senegal, therefore their integration into modern fishing landscape of tomorrow will rely on their capacity for modernization. Indeed, at present, the embedded electronics is at best made up of the cell phones of the crew and a GPS "hand" of the captain (22). Similarly, conventional centralized marine positioning systems (VMS or AIS) are not shipped for economic reasons. As results, the distribution of dugout canoes remains unknown to the institutions in charge of fisheries monitoring. Although Senegalese government is trying to equip some dugout canoe with geolocation system, they still have issues to equip everyone because of the equipment price. Proposing a low cost solution is one of their critical objectives. *COWSheD* enables a given fisherman to send maydays in case of crash to a control center or other fishermen that are located within its vicinity. It would also allow fisherman to communicate one to each other when when they are further than 7 km from the coast, a geographical localization system that sends to neighborhood the actual position of each dugout canoe is added.

We perform real life test where we have a base station located at $105m$ of height and mobile relay in a boat as illustrated in Fig. 17. We sent 4146 packets and received 3935. The packet error rate was roughly 5%. Table 4 shows test performance with packet error rate as a function of covered distance. Fig. 18 shows received signal with $RSSI$ higher than $-95dBm$. We had up to $22km$ distance coverage with respect to test done within the sea.

V CONCLUSION

By leveraging Low Power Wide Area Networks (*LPWANS*), we proposed a mesh-based prof of concepts communication system for white spot areas. In order to achieve an efficient transmission system either on urban area or rural area, we proposed a linear regression model for path loss estimation. Afterwards, a communication architecture that underpins use cases and scenarios deployment, such as text and voice messages, geolocation system, milk collection and geographical localization system for fishery, within $Dakar$ peninsula and $Namarel$ village is outlined.

However, due to large distance that separate inter-tier users and the lack of centralized equipment our mesh network acts as a delay tolerant network. In addition, the use of radio channel for communication can lead to co-channel interference. As future work, we plan to ensure channel availability, enable frequencies reuse and provide an efficient information routing. Considering fixed collector boxes that are located at points of interest such as water points or boreholes is also planned as part of this work.

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