An Evaluation of LoRa Coverage in Dakar Peninsula

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***Abstract*—Providing low cost, reliable and efficient applications become the major pillars of Internet of Things. According to coverage range, Low Power Wide Area Networks (LPWAN) take a prominent place at the expense of cellular networks based applications. Based on real-life measurements, we evaluate the *LoRa* (Long Range) coverage within Dakar peninsula covering a ground area of $83Km^2$. The measurements were performed with LoRa stations working in the $868MHz$ Industrial, Scientific and Medical (ISM) radio bands using $14dBm$ transmit power and a spreading factor of 12. During our tests, we criss-crossed more than $40km$ in Dakar peninsula where we observed a good coverage as well as a good Received Signal Strength Indication (RSSI) up to a maximum communication range equals to $10km$. Furthermore, the obtained average packet loss ratio is less than 30%.**

I. Introduction

Nowadays, Internet of Things (IoT) devices bring a wealth of useful information on living, working, and environment. Quite often, radio frequency identifiers, short and long-range wireless communication technologies are the the most popular technologies that are associated with IoT. Several studies showed that the number of used IoT devices by 2020 will be higher than the number of human beings present on earth [1]. Therefore, we expect more than 20.8 billion IoT devices. IoT-based applications are well distributed overall the world due to existence of large number of used cases [2]–[4], [7], [8].

Since economic activities and urban infrastructures are located in Dakar-downtown, we note a huge population growth in Dakar Region due mainly to the drift from the land. In fact, Dakar Region, which is a peninsula of $83Km^2$, is the smallest and most populated region in Senegal. Indeed, daily workers need to be transported in Dakar-downtown and then Dakar roads are in chaos during workday. Consequently, several issues are noticed such as diurnal traffic jam occurs and during rush hour, bus passengers that prefer to use private transportation even if it is more expensive, and air pollution caused by the large number of old vehicles.

In order to improve the transportation system, the authors of [3] proposed a GPS and SMS-based communication system for the passengers of the national society of transportation *"Dakar Dem Dikk"*. This information system allows the bus passengers to know either how many bus stops it remains for a given bus to reach a fixed bus stop or the estimated distance between a target bus and its position. Nevertheless, the tracking system is based on cellular network. Therefore, the SMS cost is a big concern in order to monitor the overall *"Dakar Dem Dikk"* buses.

In fact, Low Power Wide Area Networks (LPWAN) introduces radio-communication based sensing, gathering, and dissemination of various information related to intelligent transportation system, smart traffic, smart metering [2], [6]–[8]. For instance, in Rennes (France) three LoRa base stations are deployed in order to cover the city [6]. Furthermore, an evaluation of LoRa transmission according to different channel and "Received Signal Strength Indicator" (RSSI) were performed in Oulu (Finland) [7]. A recent study shows that LoRa can be a reliable link for low cost remote sensing applications [8].

Thereupon, by leveraging LoRa technologies in Dakar, we can improve social, economic, and environmental conditions, and also enables for new types of business services. For example, it helps stakeholders to make a real time monitoring system for solar panel to prevent theft and to schedule solar panel cleaning, a real time water point monitoring for disease-Prediction and Control-Model, a protection against flood threats, an electricity and water remote consumption monitoring, etc.

To the best of our knowledge, this work is the first LoRa evaluation in Dakar city. Since radio frequency within ISM bands is considered, it is mandatory to evaluate the efficiency and reliability of LoRa communication within Dakar city. Afterwards, IoT and LoRa technologies [5] can be deployed in Dakar peninsula covering the overall points of interest.

The remainder of the paper is structured as follows. Section II depicts the LoRa technology. In Section III, we introduce the various deployment phases and its methodology to cover a long range area. Following that, we present in Section IV our experimental results. Finally, Section V concludes this work.

II. Brief overview on LoRa

Several standards and providers according to long range communication exist in LPWAN fields [2]. Nevertheless, the most commonly used are *Sigfox* and LoRa. The deployed LoRa technology considers a special Chirp Spread Spectrum (*CSS*) modulation technology designed for LPWAN and used by *LoRaWAN*. It should be noted that the CSS modulation is patented by *Semtech LoRa Alliance* [5].

LoRaWAN is a specification protocol integrated in LoRa technology and developed by *LoRa Alliance*. It uses unlicensed radio spectrum within ISM bands and enables low power

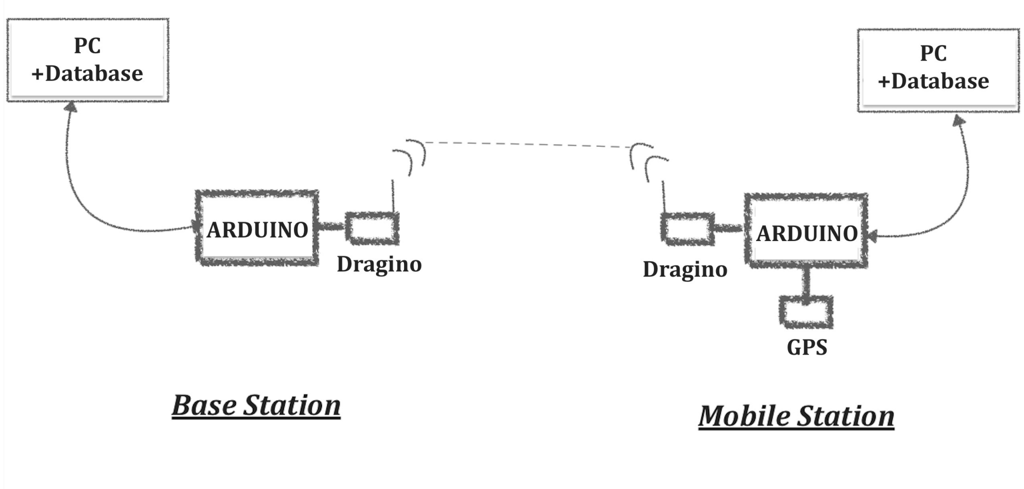

Fig. 1. Deployed Architecture.

and wide-range communication between remote sensors and gateways nodes. This standard-based approach enables a rapid deployment of public or private IoT networks that provide secure, bi-directional, interoperable and mobile hardware and software communication.

For instance, *Bouygues* telecommunications company has launched a telecommunication network based on LoRa in 2015 [9]. By January 2017, up to 4020 LoRa antennas which cover 84% of the France ground area are deployed. They argue that roughly 93% of the population are covered.

III. Measurement Setup

Fig. 2. Geographic distribution of two base stations.

By considering the line of sight (without any obstacle), the communication range between two LoRa antennas is estimated up to $15km$ [10]. In addition, it is showed that in certain situation it can reach $30km$ [7]. According to the Dakar city streets, the development and urbanization of the land, we need to figure out the geographical deployment of LoRa base station that enables to cover the whole Dakar peninsula.

Fig. 3. A given base Station located in the highest building in Dakar.

To carry out the tests, we consider the architecture illustrated in Fig. 1. The deployed architecture is formed by two components that communicate via LoRa: a fixed base station which transmits data and a station which is in motion that received data.

Firstly, the used base station is formed by an *Arduino UNO* card, a *Dragino Shield LoRa* [11] and a computer. The communication between the computer and the Arduino board is carried out via a serial port. A software tool written in Python retrieves the collected data from the serial port and stores them inside a local database hosted by the computer. For each transmitted packet, we save its id number and transmission time. According to the base station the following metrics are configured:

- spreading factor: 12 (4096 chips)
- channel size: $125khz$ within the $868MHz$ ISM band
- transmitted power: $14dBm$
- coding rate: $4/5$

In contrast to European countries where the $868MHz$ ISM band is subject to some restrictions due to regulation access, we do not have any legislation in Senegal. Therefore, it is possible to continuously send data by using this frequency. In fact, *EU* organization requires a duty cycle of 1% [12] [13].

Secondly, the mobile station is formed by an *Arduino UNO* card, a *Dragino Shield LoRa* [11], a GPS Shield module and a computer. For each received packet, the following information are saved within the database: packet id, RSSI, geographical position (longitude, latitude) of the mobile station, arrival time. We criss-crossed more than $40km$ in Dakar peninsula.

In order to obtain a good line of sight between the base station and the mobile station, we consider the following sites in Dakar city as radio beacon:

- The top of "*Phare des Mamelles*" site that ranges up to $126m$.
- The esplanade of "*Monument de la Renaissance*" site which measures $100m$ and is located near the"Phare des Mamelles". The choice of "Monument de la Renaissance" as beacon is due to the fact that acts a mask for data coming from the "Phare des Mamelles" with respect to a couple of locations. Fig. 2 illustrates the geographical distribution of both hills where the "Monument de la Renaissance" are located at the right and "Phare des Mammeles" at the left. One can see that "Monument de la Renaissance" location breaks the line of sight from the "Phare des mamelles" towards the different locations that are located after the "Monument de la Renaissance" site.
- The *"Virage"* site which is the lowest point among our four beacons measure roughly $20m$. The choice of the *"Virage"* beacon is motivated by the necessity to cover the northern part of Dakar peninsula.
- The highest building in Dakar, called "*Building Kebe*", which measures $75.36m$. Fig. 3 shows the LoRa base station which is located on the top of the "*El Hadj Babacar Kebe building*.

As summary, Fig. 4 illustrates the geographic distribution of our four used sites that hosts the base stations according to Dakar peninsula.

Fig. 4. Geographic Distribution of our four Base Stations.

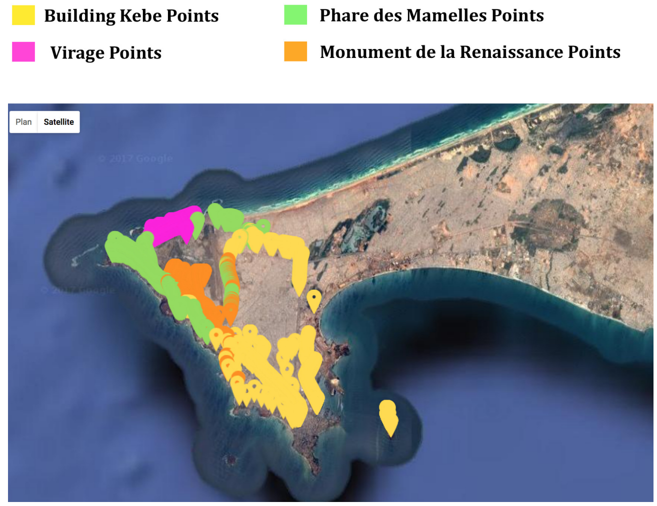

Fig. 5. Geographical location of crossed position by the mobile station.

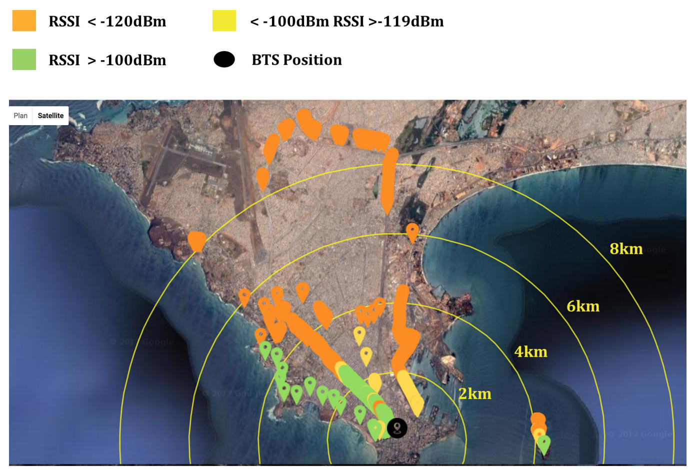

Fig. 6. Received RSSI from "Building Kebe" base station.

IV. Results

The geographical distribution of the different locations where the signal trasmitted by the four base stations is received by the mobile station is illustrated in Fig. 5, we can see that a large part of the capital has been covered by these base stations. It sould be noted that map is performed with *google map API*.

The received signal from each base station is represented by distinct colors. It is worth noticing that the points on the map that have the same color represent the received signal from the same base station according to the mobile station in motion. For instance, Fig. 5 illustrates:

- The area covered by *"Virage"* base station is not large. It can be explained by the fact that *"Virage"* is a residential area with a lot of building with at least of four floors. Therefore, we note the existence of lot of obstacles that break the line of sight. Furthermore, we face with a lack of strategic point to place other base station. However,

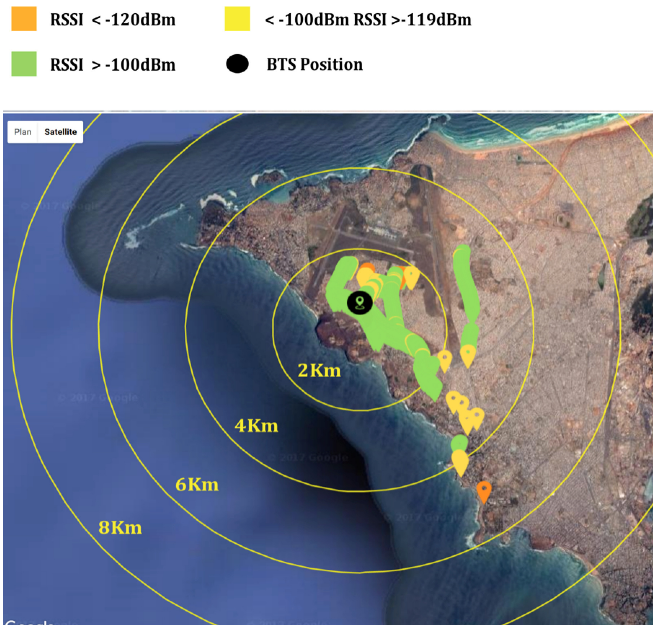

Fig. 7. Received RSSI from “Monument de la Renaissance” Base Station.

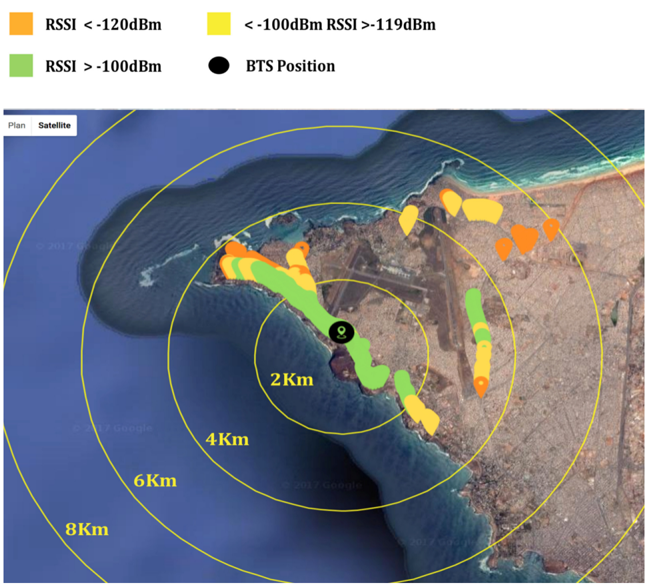

Fig. 8. Received RSSI from “Phare des Mamelles” Base Station.

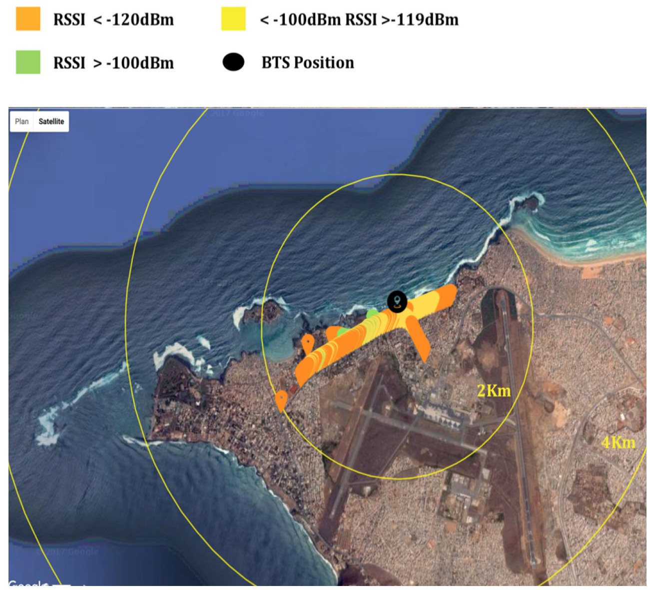

Fig. 9. Received RSSI from “Virage” Base Station.

TABLE I
PERFORMANCE EVALUATION

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

it is possible to extend the coverage if we place a pylon that host the base station.

- Since the “Monument de la renaissance” base station is very close to “Phare des Mamelles” we can see that a lot of locations have been covered by the “Phare des Mamelles” base station but the height of the hill is clearly a mask so these points were only recheable with “Monument de la Renaissance” base station.
- According to geographic locations where the other breasts are not present, we note that “Phare des Mamelles” base station is able to cover large areas.
- Although the building Ndiouga Kebe is not our highest base station, it is the one which transmits the farthest (more than $8km$). It can be explained by the fact that there is no significant obstacle in front of this base station. Therefore, a good line of sight is noted within its vicinity.

In order to evaluate how far the signal can be received with a good RSSI, we drawn several circles with the same center but with different circumference. In fact, the center of circles is the actual geographical location of a fixed base station. We considered different radius such as 2, 4, 6 ,8 and $10km$. Afterwards, the locations crossed by the mobile station in motion with respect to received RSSI from each base station are illustrated in Fig. 6, Fig. 7, Fig. 8 and Fig. 9. According to Fig. 6, the base station placed on top of “Building Kebe” is able to transmit more than $8km$. By recall, it is the one which has the better line of sight. In contrast, Fig. 9 exhibits the huge amount of obstacles that faces the “Virage” base station. To overcome this limitation, we can use a pylon in order to heighten the base station for better line of sight.

TABLE I shows the packet lost ratio as a function of covered distance. It is worth noting that the packet loss ratio increases when the range goes up. For instance, the obtained results show that the packet loss ratio is up to 70% at $8km$.

Fig. 10 depicts the mean RSSI as function of mobile covered distance whereas Fig. 11 illustrates the Packet Error Rate (PER) as function of mobile covered distance. These results

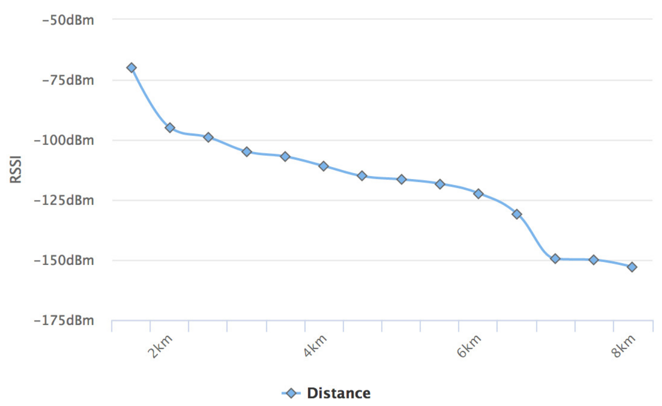

Fig. 10. RSSI as function of coverage distance.

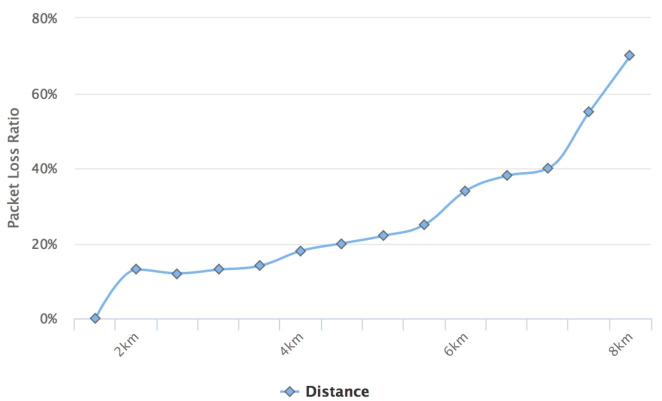

Fig. 11. PER as function of coverage distance.

are based from all measurements that have been done by our four base stations. Indeed, the quality of received signal fall down when the distance between the base station and the mobile station in motion increases. Consequently, the PER is high for long range distance. It can be explained by the shadowing effect that is faced by a couple of base stations.

V. Conclusion

We evaluated the LoRa coverage within Dakar by using four base stations deployed in different locations. By considering a mobile station as receiver, we criss-crossed roughly $40km$ in Dakar city in order to measure the signal strength from our four radio beacons. The obtained results show that a LoRaWAN gateway can cover a range up to $10km$ with a packet loss ratio less than 30%.

Afterwards, we will investigate the LoRa coverage in the Ferlo desert, northern-central Senegal, covering the main traveling routes by breeders in the region. In fact, the livestock transhumance in Senegal is done in several areas and more specifically in the sylvo-pastorale areas located in the Ferlos region where it is difficult or impossible to communicate with terrestrial communication systems. The main reason is due to the existence of white spots.

Therefore, the COWShED project aims to provide a real time communication system for breeders based on RF transmission within ISM bands for no cellular coverage areas. We plan to collect various information such as pastoral activity, organisation and management of pastoral lands, and disseminate that into the network.

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