A Study of LoRa Coverage : Range Evaluation and Channel Attenuation Model

Madoune R. Seye, Bassirou Ngom, Bamba Gueye, Moussa Diallo
Polytechnic Institute (ESP), Université Cheikh Anta Diop de Dakar
Dakar, Senegal

***Abstract*—Low Power Wide Area Network (LPWAN) are nowadays taking a prominent place in Machine To Machine/Internet of Things domain. *LoRa* outdoor performance within Dakar peninsula, which covers a ground area of $83Km^2$, was evaluated based on real-life measurements. The measurements were performed with LoRa stations working in the $868MHz\ ISM$ band using $14dBm$ transmit power. Afterwards, by considering a spreading factor of 12, we observed a maximum communication range up to $10km$ with a good Received Signal Strength Indication (RSSI). Based on the collected dataset, firstly we design a channel attenuation model in order to estimate path loss. Secondly, We present a coverage-based model in which we use the results of the channel attenuation model. The obtained results show that if we fix a $-120dBm$ maximum tolerated RSSI, Dakar peninsula could be fully covered with almost 40% Packet Error rate (PER). Furthermore, with $-110dBm$ maximum tolerated RSSI, the PER is 20% but the whole city won't be covered. Another base station should be added in order to have a total coverage.**

I. Introduction

The interest of IoT industry towards the Low Power Wide Area Networks (LPWAN) is consequently increasing. Therefore, by 2024, the IoT industry is expected to generate a revenue of 4.3 trillion dollars [1]. There are numerous technologies available depending on the circumstances. Cabling, Blue tooth, Wi-Fi zones, Zig bee and other short range technologies can be used to achieve networking for nearby equipments. For a remote site, when cabling is not a solution, mobile networks are one of the alternatives: SMS 3G or 4G. Among the long range networks, there are also Low Power Wide Area Networks (LPWANs). Most LPWA networks operate in the unlicensed ISM bands at 169, 433, 868/915 MHz, and 2.4 GHz depending on the region of operation. Some of the most pronounced LPWA candidates are SigFox, LoRa, Weightless, and Ingenu [2]. They have a long battery life and are low cost. Coverage is also one of the most critical performance metrics for the low power wide area networks (LPWAN). Among the major applications foreseen for LPWAN, there are the automotive and intelligent transportation systems (fleet management, vehicle to infrastructure communication, smart traffic, real time traffic information to the vehicle, security and incident alerts and reporting,) and various smart metering cases (e.g., electricity, water and gas consumption monitoring, medical metering and alerts) [3] - [4] [6]. Thus, LoRa base stations have been deployed in Oulu(Finland)[5] and Rennes(France) [4] to evaluate their coverage performance according to the Received Signal Strength Indicator (RSSI). A recent study shows that LoRa can be a reliable link for low cost remote sensing applications[6]. In this paper, we will evaluate the LoRa performance in Dakar Region in order to make a model of channel attenuation. This can involve the development of many value added services based on LoRa transmission in a city like Dakar. In fact, Dakar is a small but very populated region in Senegal due mainly to the drift from the land. This region is encountering several issues such as diurnal traffic jam that causes by the same time air pollution. The reminder of this paper is structured as follows. Section II highlights all the resources used to carry out the coverage tests and presents the performance results. Thereafter, in Section III we show the channel attenuation model before presenting in Section IV a coverage-based model. Finally, the work is concluded in Section V.

II. Measurement Setup and Performance Results

A. $Measurement\ Setup$

The measurements were done in the city of Dakar (Senegal). We deployed an architecture formed by two components that communicate via LoRa. A fixed base station sending data at regular intervals to a mobile station. The base station is made of an Arduino UNO card, a LoRa Shield [7] and a computer. The mobile station is formed by an Arduino UNO card, a Dragino Shield LoRa [7] , 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 base station was configured with:

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

The required duty cycle of 1% [8],[9] in EU organization for the 868MHz ISM band is not applied in Senegal. So our base station is able to send data with a minimum interval time. We had to figure out the best geographic position to deploy our LoRa base station in order to have a good line of sight between the base station and the mobile station in motion. Since Dakar is a city with more than 3 million people living in there and there are lots of buildings of at least four floors, we decided to place 4 base stations to be able to cover the whole city. Thus, we considered the following sites in Dakar as radio beacon:

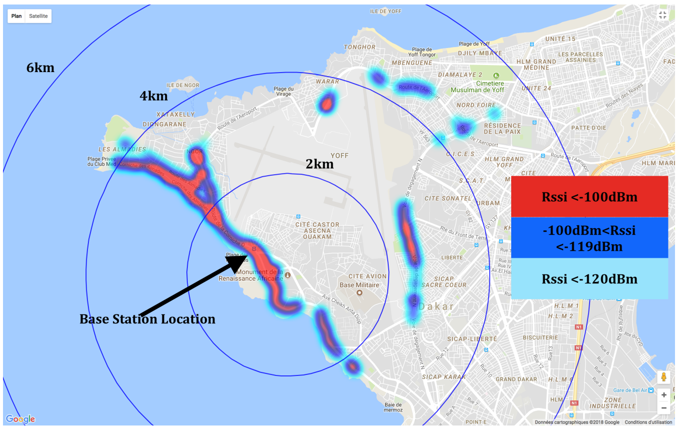

Fig. 1. Received RSSI from "Phare des Mamelles" Base Station

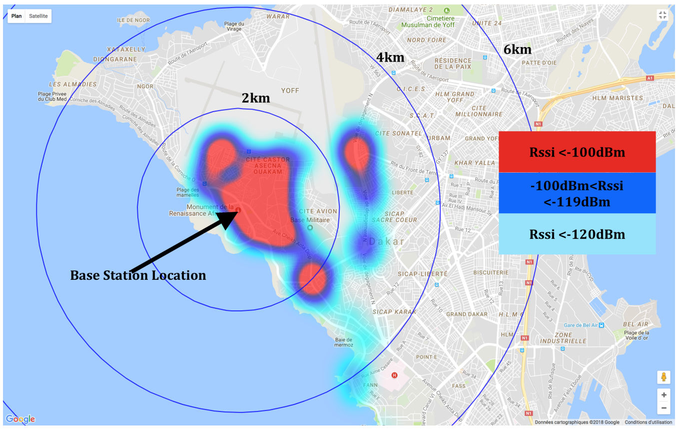

Fig. 2. Received RSSI from "Monument de la Renaissance" Base Station

- 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.
- The highest building in Dakar "Building Kebe" with $75,36m$ of height.

B. *Performance Results*

Nearly 10.000 packets were transmitted, the maximum range is 10km. "Building Kebe" has the longest range and "Virage" has the shortest one. "Monument" and "Phare des Mamelles" have almost the same results for the range(near $6km$). We notice that the areas covered by "Monument" are impossible to be covered by "Phare des Mamelles". This can be explained by the fact that "Monument" acts as a mask for it in couple of locations. In Fig.1 and Fig.2 we can see for examples locations where the signal transmitted respectively by "Monument base station" and Phare de "Mamelles base station" is received. The map is done with Google Map API.

TABLE I shows the packet loss ratio as a function of covered distance. This table shows that the packet loss ratio increases when the range goes up.

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%

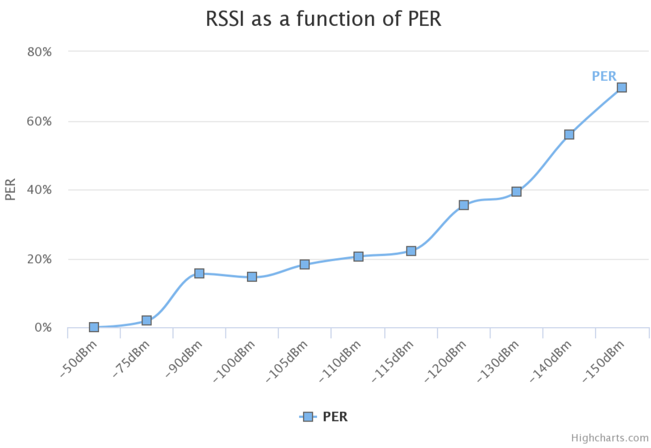

Fig. 3. The mean RSSI as function of the PER.

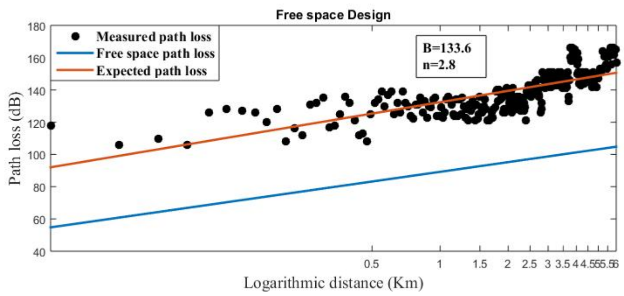

Fig. 4. Path Loss for Phare des Mamelles base station.

By combining the results of the map and the PER table, we made a chart to highlight a link between the PER and the RSSI in Fig.3.

III. CHANNEL ATTENUATION MODEL

With the packets received all over Dakar, we want to make a channel attenuation model for each base station. The models will allow us to estimate the path loss in Dakar using LoRa Technology. This model will be done in two parts.

- For every received packet with the mobile station in motion we saved the Received Signal Strength Indicator (RSSI) and the signal-to-noise-ratio (SNR). We used it

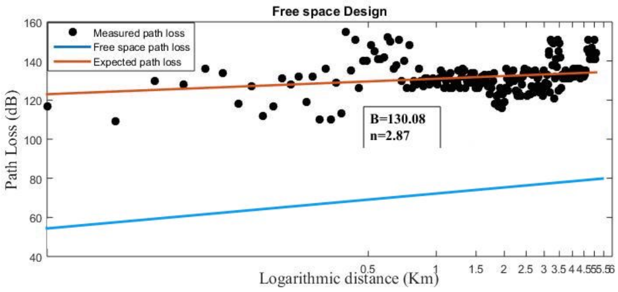

Fig. 5. Path Loss for Monument base station.

to calculate the Path Loss (PL) with the following link budget.

$$PL = |RSSI| + SNR + Ptx + Grx \quad (1)$$

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

- We derived the expected path loss (EPL) of the measured data from the linear polynomial fit. We calculated it as [10] with :

$$EPL = B + 10nlog10(d/do) \quad (2)$$

"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. Fig.4 and Fig.5 show the measured path loss (black dots) and the expected path loss (red curve) for two bases stations as an example. In blue we have the free space path loss.

Since it is almost impossible to model the obstacles when the tests are done in a real environment, in our results, we take the free space path loss as a reference to highlight the effect of the environment on the received signal. The presented results show the maximum range for each base station, we can notice that with building Kebe we had the highest range (up to $10km$).It can be explained by it's position and the height of the building.

Virage base station has the lowest range and also the highest measured path loss (up to $175dB$) compared to Monument where we have $157dB$ as maximum path loss. On the other hand, Monument presents a low path loss when approaching $2km$. In fact there were a perfect line of sight between the base station and the mobile station in the area where the tests were done.

For a future work we plan to make more tests with that base station in different areas so that we can have better results and improve the model. This proposed model can be used to estimate the communication distance in Dakar and areas similar to Dakar in West Africa. Thus, since we couldn't browse all the places in the city during real life test, we made coverage prediction depending on the results of the models. For each base station, we can now predict its coverage by giving a maximum RSSI Fig.6, Fig.7, and Fig.8. It's worth noticing that for each figure the base station(black dot) is the center of each circle. Depending on the maximum RSSI, we have the radius of the circles.

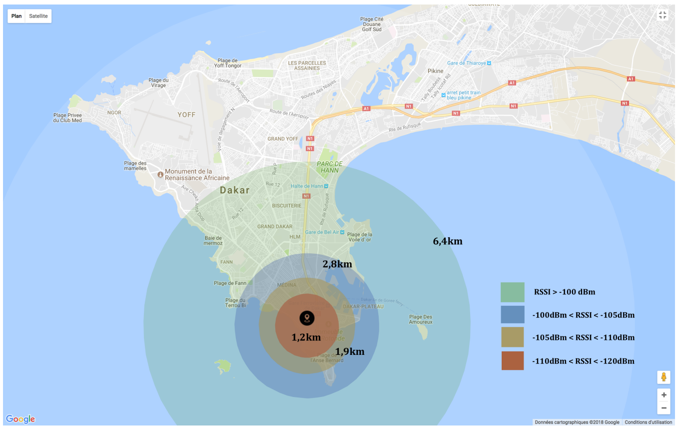

Fig. 6. Coverage prediction for Building Kebe base station.

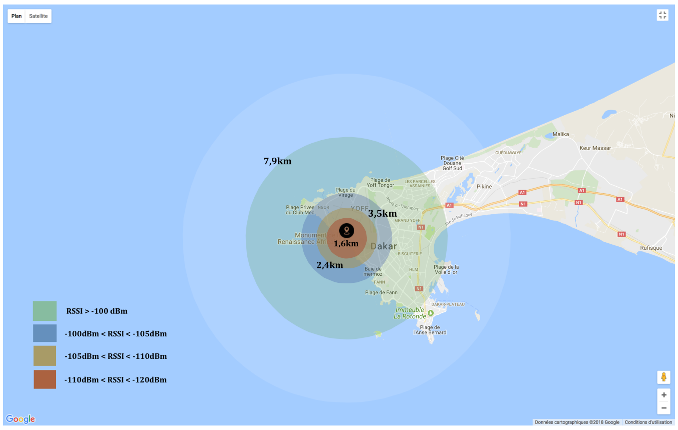

Fig. 7. Coverage prediction for Monument base station.

Fig. 8. Coverage prediction for Virage base station.

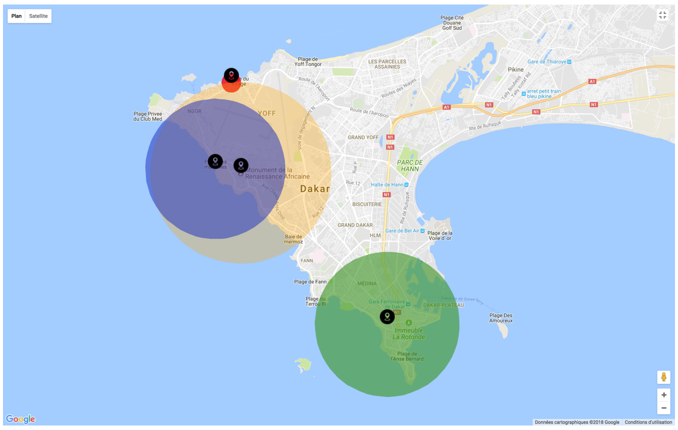

Fig. 9. -110 dBm coverage for Dakar City with 4 bases stations.

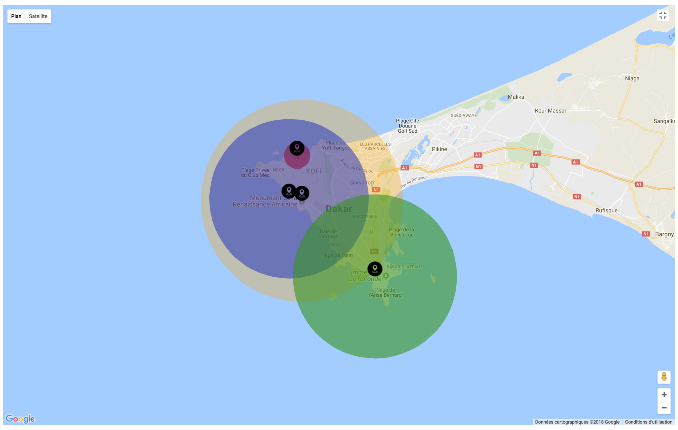

Fig. 10. -120 dBm coverage for Dakar City with 4 bases stations.

IV. Coverage Based Model

In Fig.3 we showed the mean RSSI as function of the PER. This could help to show the packet error rate corresponding to a chosen RSSI to cover Dakar City. With the results of the attenuation model, we try to make a map where we could see the coverage of Dakar with our four base stations. Fig.9 shows a $-100dBm$ maximum tolerated RSSI coverage for Dakar and Fig.10 shows a $-120dBm$ maximum tolerated RSSI coverage. With $-110dBm$, we have 20% PER but the entire city is not covered. However, this one can be improved if a higher place is found in virage location otherwise we have to put a pylon high enough to extend its coverage. With $-120dBm$, we are able to cover the whole city but the PER is almost up to 40%.

V. Conclusion

Wide area coverage, low power consumption, and inexpensive wireless connectivity are the most important metric in LPWA technologies. In this paper we evaluated the performance of LoRa technology with real-life measurements.

The results of the measurements were used to propose a channel attenuation model. We derived the Expected Path Loss (EPL) of the measured data from the linear polynomial fit. This was possible to be done because the Received Signal Strength Indicator (RSSI) and the Signal-to-noise Ratio (SNR) received from every base station by the mobile station were saved to calculate the Path Loss (PL). Furthermore, the attenuation model was used to make estimation about the coverage of each of the four base stations. Finally, we proposed a coverage based model.

The proposed model can be used to estimate the required base station density for a network provider. This could help to deploy a large number of IoT services such as : bus tracking, smart grid, electricity and water remote consumption monitoring...

In a future work we plan to work on other LPWAN solutions once they will be available in order to do the same work as we did with LoRa and compare their results with LoRa technology.

Acknowledgement

This work is supported by ISOC in the COmmunication within White Spots for brEeDers (COWShED) project.

References

[1] E. Berthelsen and J. Morrish, "Forecasting the internet of things revenue opportunity," Machina Research, Tech. Rep., April 2015. [Online]. Available: https://machinaresearch.com/report pdf/313

[2] U. Raza, P. Kulkarni, and M. Sooriyabandara, "Low Power Wide Area Networks: A Survey," arXiv preprint arXiv:1606.07360, 2016.

[3] Usman Raza, Parag Kulkarni, Mahesh Sooriyabandara, "Low Power Wide Area Networks: An Overview", *IEEE Communications Surveys and Tutorials*, vol. 19, no. 2, January, 2017.

[4] Tara Petri, Mathieu Goessens, Loutfi Nuaymi, Laurent Toutain, Alexander Pelov, "Measurements, Performance and Analysis of LoRa FABIAN, a real-world implementation of LPWAN", *27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2016.

[5] Juha Petajajarvi, Konstantin Mikhaylov, Antti Roivainen, Tuomo Hanninen, "On the Coverage of LPWANs: Range Evaluation and Channel Attenuation Model for LoRa Technology", *14th International Conference on ITS Telecommunications (ITST)*, 2015.

[6] Andrew J Wixted, Peter Kinnaird, Hadi Larijani, Alan TAit, Ali Ahmadinia, Niall Strachan, "Evaluation of LoRa and LoRaWAN for wireless Sensor Networks", *IEEE SENSORS*, 2016.

[7] Dragino Technology, http://www.dragino.com/products/module/item/102-LoRa-shield.html.

[8] E. C. Committee and Others, ERC Recommendation 70-03, ed. Tromso, http://www.erodocdb.dk/docs/doc98/official/pdf/rec7003e.pdf, October 2016.

[9] F. C. CommissionFCC Part 15 Radio Frequency Devices, Code of Federal Regulation 47 CFR Ch. 1 (10-1-15 Edition).

[10] P. Heino et al., "Deliverable D5.3, WINNER+ Final Channel Models V1.0, CELTIC CP5–026 WINNER+ Project"