Performance Analysis of a Smart Street Lighting application using LoRaWan

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***Abstract* – Internet of things has allowed the development of a set of services and applications such as Smart Cities and Smart Homes. This paper proposes a realistic implementation of a large-scale smart Street Lighting Control System which allows solar lampposts to dynamically manage the street lightning. The application is simulated for the district of HLM route de Mbour in Thies, Senegal. It is a fully remote-controlled city of lampposts based on LoRa technology. Lamps are equipped with sensors that sense and send information to a network server for management. Simulation results show a high packet loss rate when only one gateway is deployed due to collisions. We then increase the number of gateways and study the performances of the network. Results show that multiple gateways deployment in large scale LoRa network achieves better packet delivery ratio and lower energy consumption.**

***Index Terms*— Internet of things, LoRaWAN, smart lighting, smart cities, ADR.**

I. INTRODUCTION

INTERNET OF THINGS (IoT) has emerged as a new computing paradigm, in which a variety of devices and objects are interconnected with a multitude of communication technologies like WIFI, GSM, ZigBee, etc. As more and more things are going to be connected to Internet, low-cost and low-traffic devices are starting to be demanded. Short range wireless technologies like WIFI consume much energy while long range technologies like GSM are too expensive and are not suitable for IoT applications. Thus, Low-Power Wide Area Networks (LPWANs) gained momentum due to low power consumption and long range and their multiple applications in Internet of things. LoRa [18] is an emerging LPWAN technology that is widely deployed and is considered by many industries as a base for their IoT applications. WSNs have been used in different applications, such as military, agriculture, sports, medicine, and industry. Smart cities [1] are one of the most favorable facilities for WSNs to develop applications like video surveillance, smart grid, cities lighting. LoRa has gain momentum due to its simplicity. LoRa uses unlicensed bands ISM and enables power efficient wireless communication over very long distances.

In recent years, street lighting has become very important in urban or rural area. Solar street lights are alternative for the nighttime in order to keep roads safe. Street lightning aims to reduce human intervention and use the help of intelligent systems. When the sun lighting goes under the region of eyes, this system automatically switches ON lights while the system automatically switches OFF lights when the sun rises. The system also manages the lamppost by analyzing collected data like battery level, dust accumulation, lamp status. Street Lighting System (SLS) presents many advantages [2]:

- Reduce public lighting energy consumption;
- Enhance public safety with an adequate lightning;
- Collected data allow for a better control of the system, maintenance, planification and failure detection;
- Help municipality to quickly detect and fix failures and then reduce intervention time and improve management maintenance.

More and more solar street lightning projects are deployed in Senegal. Given the scarcity of natural resources, solar energy is a credible alternative to the global energy crisis. Indeed, Senegal is a sunlit country with more than 3000 hours of sunlight in a year. However, there is much dust and little rain, about two months in a year, which causes layers of dirt on panels. Municipalities and authorities plan to replace electric lamps with solar panels. This paper is the result of a research for a pilot phase project in the town of Thies city. Solar panels require periodic maintenance throughout the year to keep the system clean and operational.

This paper aims to design a street lightning system that automatically switch ON or OFF according to the sun light and periodically collect data on lampposts to plan maintenance tasks. The proposed application provides remote lighting control with a network server that can adjust the amount of time the light turned on and the light intensity to minimize the energy cost without degrading the quality of the lighting. The application dynamically adjusts its light according to the time, the weather, the movement and the lighting level. It also monitors the level of the batteries, the level of accumulated dust and the state of the solar panel. Lampposts are equipped with sensors nodes that sense and send information to the network server using LoRa (Fig.1).

The remaining of the paper is organized as follows: Section II gives an overview of LoRa technology. Section III presents the related work. Section IV depicts the SLS implementation.

Section V details the simulations and analyses the performances. Finally, section VI presents the conclusion and future works.

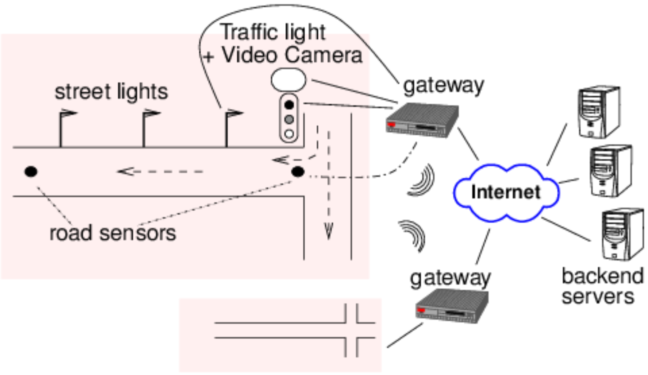


Fig. 1. Smart Lighting System architecture [3]

II. LoRa Overview

This section provides an overview of physical (LoRa) and LoRaWAN medium access control (MAC) layer protocol. LoRa technology has been proposed by LoRa Alliance. The main goal of LoRa is to connect a multitude of IoT devices over long distances, low rates and in an energy-efficient manner.

A. *LoRa physical layer*

LoRa is a physical layer radio modulation based on Chirp Spread Spectrum (CSS). LoRa allows low data rates communication across long distances (2-5 km in urban areas and 15 km in suburban areas) with low power consumption. The use of CSS allows LoRa receiver to decode transmission at 19.5 dB below the noise floor [4]. LoRa is characterized by its long-range communication, multipath resistance, robustness, low power consumption, Forward Error Correction (FEC) and doppler resistance [5]. LoRa uses free unlicensed ISM bands at a lower frequency, for example it’s 433MHz for Asia, 868MHz for Europe and 915MHz for North America. It is also regulated by standards for transmission with regional variabilities. For Europe these restrictions [4] are: transmission power is limited at 14dB, the duty-cycle at 1% and the maximum bandwidth at 125kHz. Senegal uses the same frequency bands as Europe. Therefore there is no restriction about duty cycle for 868 MHz band in Senegal [16].

LoRa provides several physical parameters that can be customized. These parameters include Spreading Factor (SF), Bandwith (BW), Coding Rate (CR). These parameters affect the Data Rate (DR), the resilience against interference and easy decoding. Depending on the SF in use, LoRaWAN data rate ranges from 0.3 kbps to 27 kbps. Equation (1) gives the formula of the DR :

$$DR = SF \cdot \frac{BW}{2^{SF}} \cdot CR \qquad (1)$$

B. *LoRa MAC layer (LoRa communication protocol)*

LoRaWAN is organized in a star of star topology composed of three elements: end-devices also call nodes, gateways and network server. End-devices correspond to sensors which communicate with the network server through gateways (Fig. 2) and vice versa (bidirectional communication). End-devices send data to gateways over single wireless hop and communication between gateways and network server is IP based or 3G/4G cellular communication.

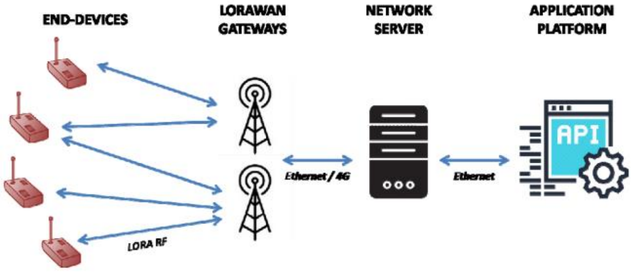


Fig. 2. LoRawan architecture

LoRa defines three classes of end-devices (Class A, B and C) with different capabilities.

Class A is the basic LoRaWAN and must be implemented by all end-devices. It allows bidirectional communication and use pure ALOHA access for the uplink.

Class B is conceived to guarantee uplink and downlink separation. Nodes are synchronized using a beacon transmitted by the gateway. Thus, they can receive information from Internet without sending requests.

Class C: the node has a continuously opened receive windows that are closed only while transmitting. Compared to A and B classes, C class consumes much energy to operate but it offers the lowest latency.

III. Related works

Smart city-based applications are gaining importance nowadays. Multiples works on smart street lightning projects have been deployed and studied in literature. Authors of [6] presents a LoRaWAN testbed that was deployed at the Campus of the University of Lille. The tests were conducted in both outdoor and indoor environments using one gateway and showed that LoRa provides good performances over the major part of the Campus. However, collisions were not evaluated in the paper.

In [16], authors evaluated the LoRa coverage in Dakar, capital of Senegal, by deploying four gateways. They show that a gateway can cover a range of 10Km with a mean packet loss rate of 30%. However, they didn’t consider loss due to collisions and they didn’t study end-devices energy consumption.

The same authors proposed in [17] a channel attenuation model that is capable to estimate the coverage and predict packet loss rate based on RSSI and SNR. The proposed model can estimate the required number of gateways to cover a given area. Although, they didn’t consider the probability of collisions in dense networks when sizing the number of gateways. In addition, they only study the configuration for SF = 12.

Authors of [7] did an estimation of the collision rate. Since there is no listen-before-talk or CSMA mechanism end-devices and gateways can transmit at any time like ALOHA [15]. Consequently, the performance degrades quickly when the load on the link and the number of end-device increase. Street lighting system should be able to manage large number of lamps with low loss rates.

Authors of [8] proposed the RIGERS lightning application. They study the maximum coverage in a dense urban environment and they show that it's in the order of 1–2 Km which is below the theoretical 15 Km claimed by LoRa manufacturers. They also show that, to cover an entire district, it will be necessary to deploy multiple gateways and/or use different spreading factors. For large scale networks, SF equals to 12 is not the best configuration because when SF increases, the airtime increases as well resulting a larger collision probability and a reduction of the packet delivery ratio when the number of nodes increases. All nodes start using SF equals to 7 and then, every two retransmissions, SF is increased by one to mitigate coverage issues. After three hours of simulation, SF is reset to 7. Since nodes use a simple ALOHA protocol to access the channel, an increase in airtime brings to a performance worsening in interference limited scenarios. However, they do not compute the amount of collisions and use ADR (Adaptive Data Rate) mechanism [13].

Obviously, street lighting system based on LoRa is an important and useful project that will allow to save much energy. However, LoRa technology faces some limits like high packet loss rate in large scale network, packet collisions occurrence, network gateway sizing [9]. In [10] author shows that packet loss rate is directly link to the number of nodes in the network and that a gateway can manage 64 end-devices on an area of 3.8 ha. The study also shows that LoRa networks can scale quite well if they use dynamic transmission parameters selection and/or multiple gateways.

In this paper, we study the impact of the number of gateways in a SLS network performances.

IV. STREET LIGHTNING SYSTEM IMPLEMENTATION

This section describes the detailed SLS application implementation. The main objective is twofold. First, simulate a deployment of solar lampposts is an area that is capable to increase the efficiency of the current lighting infrastructure. Second, study the LoRa network performances.

We consider a district in the city of Thies in Senegal called "HLM route de Mbour" wide of almost 700 000 m^2 (Fig.3.). The goal is to change the current lightning system and replace it with a solar lightning system. We compute the linear of roads and place a lamp each 50 meters on the roads with OpenStreetMap [11]. 458 lampposts were placed on district roads. A network server collects and process data with a dedicated application, gateways are fix (Fig.4.). Lamps power is provided by a battery recharged from a solar panel throughout the daytime. The lamp turns on with a gradual intensity at the twilight according to the current luminosity and reach the maximum intensity at the midnight. The lamp presence is also equipped of presence detector that allows to activate the standby mode that reduces the luminosity at 50% in absence of movement. End-devices generate 20 bytes of data every 30 minutes and send it to the network server. Fig.3 presents a scheme of a lamppost with example of sensors. The following information is periodically transmitted:

- Lightning level: measures the external light intensity and provides assurance to a minimum level of illumination and the road as needed reflation;
- Dust accumulation: measures the fouling of the solar panel to be sure that the solar capture is done correctly;
- GPS position: gives the position of the lamppost;
- Lamp status: gives the operation status of the panel i.e. if the lamp or its components like: battery, panel, are working or not;
- Battery level sensor: gives the solar battery level.

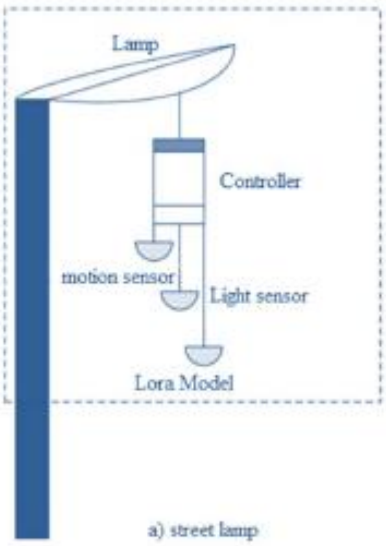


Fig.3. Scheme of lamppost with sensors [12]

We implement the SLS in FLoRa (Framework for LoRa) [13], a simulation framework based on the OMNeT++. We used European regional parameters for the LoRa physical layer shown in TABLE 1. Experiments lasted 10 days of simulation time. We run 30 iterations of each experiment according to independent replication method. The results report the average value obtained over all replications.

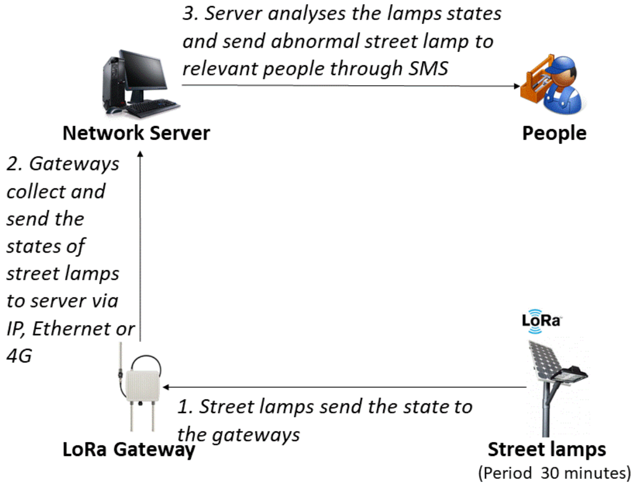
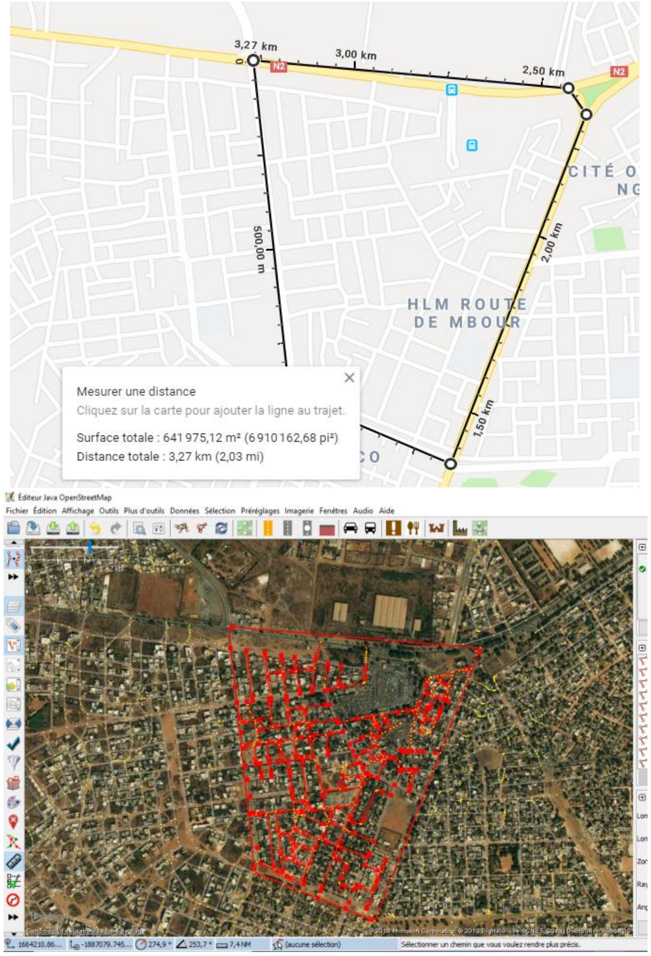


Fig.4. Communication architecture

TABLE 1: Simulation parameters

Parameters	Value
Number of lamps	458
TP	2dBm to 14 dBm
CF	868Mhz
SF	7 to 12
BW	125kHz
CR	4/5
Packet size	20 bytes
Packet periodicity	30 min



Mesurer une distance
Cliquez sur la carte pour ajouter la ligne au trajet.
Surface totale : 641 975,12 m² (6 910 162,68 pi²)
Distance totale : 3,27 km (2,03 mi)

Fig.4. Map of HLM route de Mbour district

We use the well-known log-distance path loss model [14] which is commonly used to model deployments in built-up and densely populated areas. We parameter the standard deviation in path loss σ to simulate an urban scenario (TABLE 2). We evaluate the network performance with different number of gateways in the deployment area.

TABLE 2: Standard deviation of path loss (σ) in dB for urban deployment

Scenario	σ
Ideal	0
Moderate variability	1.785
Typical variability	3.57

We evaluate the following performance metric:

- Data Extraction Rate (DER): defined as the ratio of received messages to transmitted messages over a period.
- Network Energy Consumption (NEC): defined as the necessary energy to send a packet. We compute the total energy consumed by the network divided by the number of packets successfully received by the server.

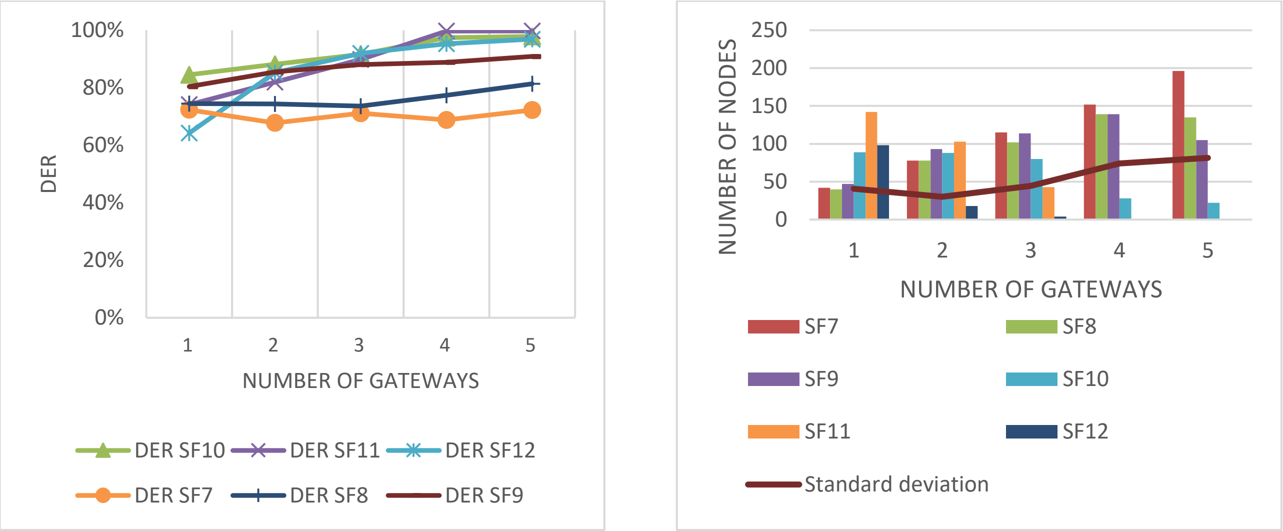
V. SIMULATION RESULTS

We evaluate the performance of a realistic IoT smart street lighting application through simulations. We implement the application on FLoRa simulator that include LoRa physical and MAC layer. The number of LoRa nodes is 458 as the number of lampposts. The number of gateways varying from 1 to 5 are located at the center of the deployment area and connected to one network server. We use European regional parameters for the LoRa physical detailed in section II. Nodes initially use a SF = 12 and a transmission power TP = 14dB as shown in TABLE I. Each node sends a packet of 20 bytes every 30 minutes [4]. We consider an urban scenario with different channel variability: moderate and typical (high).

Figures 5 and 6 give a detailed evaluation of ADR by presenting nodes repartition and DER for each SF. Simulation results show that for 1 and 2 gateways the nodes are distributed on the SF but for greater number of gateways the nodes tend to use small SF (SF = 7, SF = 8). For 4 and 5 gateways most of the nodes use SF7, SF8 and SF9 and SF11 and SF12 are unused.

Figure 7 presents the Data Extraction Rate, Network Energy Consumption and the mean number of collisions for the network with different number of gateways in moderate and typical channel variability. Figure 7(a) and (b) shows that increasing the number of gateways from 1 to 2 improves the DER by 20% and 11%, the energy consumption is reduced from 47% and 59% respectively for moderate and typical channel variability. Figure 7(c) shows a reduction of collision of more than 20% and 49% for moderate and typical channel variability. The improvement is less important and sometimes inexistent for more than 3 gateways. The channel variability highly impacts the networks performance, high channel variability causes in mean 50% more packet loss and collisions than moderate channel.

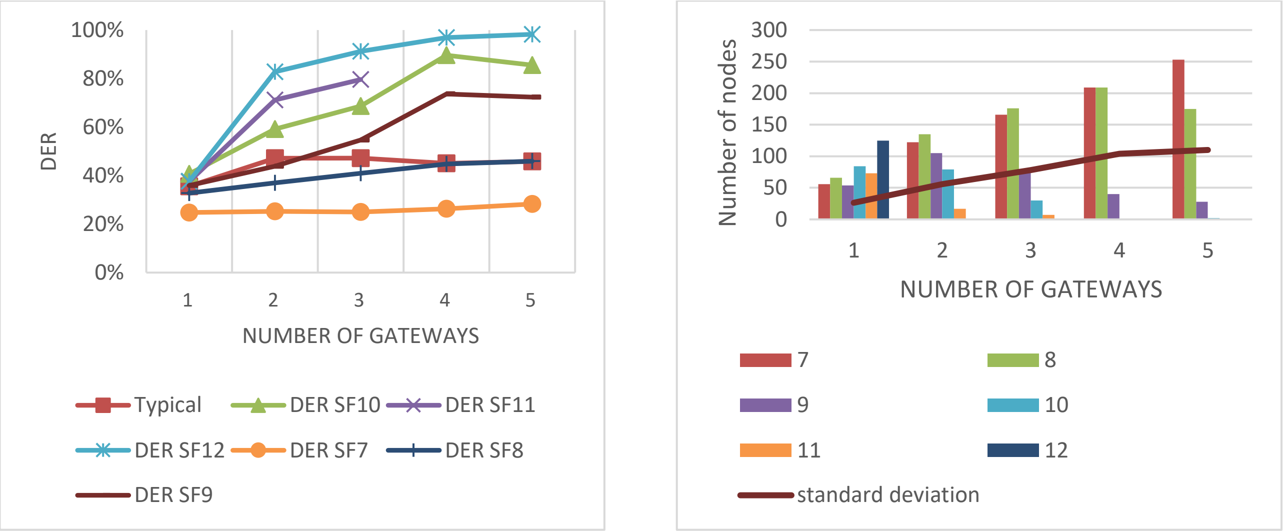
In conclusion simulations prove that channel variability and the number of gateways substantially affects the performance of the LoRa applications. Increasing the number of gateways improves the network performances but the improvement is not unlimited. The performances are almost similar from 3 to 5 gateways due to the fixed number of nodes. It is obvious that increasing the number of lampposts, the performance will be better with 3 or more gateways.



(a) DER per SF

(b) Nodes repartition per SF with ADR algorithm

Fig.5: Impact of ADR on DER and nodes repartition for low variability channel



(a) DER per SF

(b) Nodes repartition per SF with ADR algorithm

Fig.6: Impact of ADR on DER and nodes repartition for high variability channel

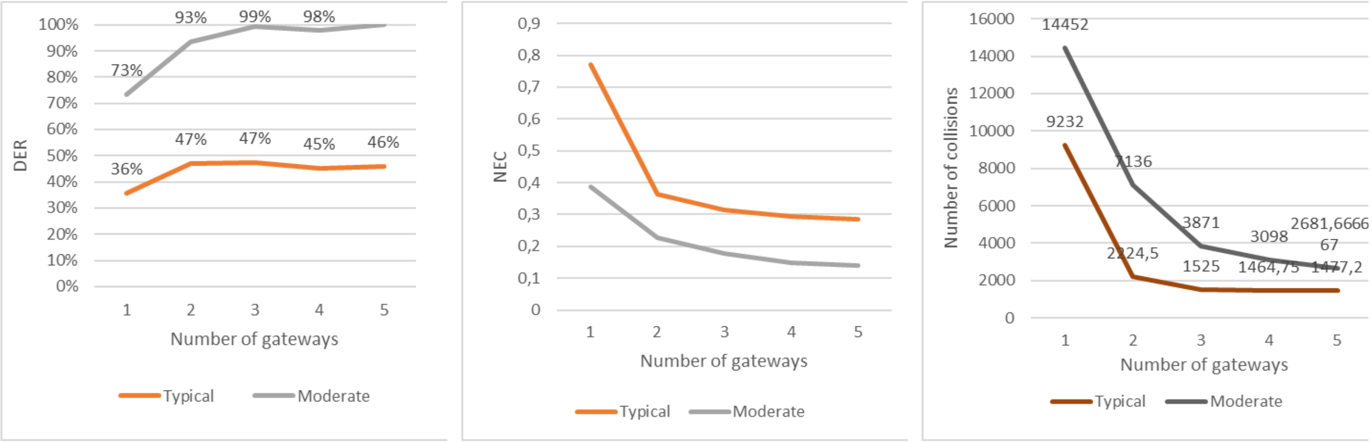
ADR is based on SNR to set the suitable SF. For great number of gateways, nodes use small SF: SF equals to 7 and SF equals to 8. This shows that multiple gateways help balance the load among the different gateways and reduce noise. Using small SF reduces energy consumption and extends network lifetime.

SF equals to 10 gives the best results with a mean DER of 92% and 69% in respectively moderate and high variability channel. We found that the optimal number of gateways to successfully implement our application is 2.

VI. CONCLUSION AND FUTURES WORKS

Remote and timely information gathering about equipment's failures, battery level and natural accidents is critical for ensuring proactive, real-time and reliable diagnosis of possible failures in a city lightning. In this paper we proposed an application based on LoRa to manage a street lighting system. We study packet loss, collisions occurrence and energy consumption. We use ADR mechanism to set the spreading factor and transmission power. Simulation results show that multiple gateways can significantly improve network performances by reducing packet loss rate and collision up to 20%. For more than three gateways, the improvement is not significant. Contrary to the recommended LoRa parameter (SF equals to 12), SF equals to 10 gives better results than other data rates.

The followings are possible directions for future work. First, we'll investigate impact fading due to obstacles like building on packet loss. Second, it would be interesting to find some mechanism on MAC layer to avoid collisions. Third, since ADR does not operate well in high lossy networks, it would be interested to improve it.



(a) Network DER (b) Network Energy Consumptions (c) Mean number of collisions on gateways

Fig.7: Impact of channel condition on performances

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