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Performance Evaluation of LoRa Networks in an Open Field Cultivation Scenario

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***Abstract*—The employment of Internet of Things (IoT) technology in agriculture could be beneficial in managing the cultivation production in a highly-customizable way. LoRa (Long Range) is one of the most important technologies in cultivation fields mainly thanks to its ability to provide long-range transmission and low power consumption. In this paper, we evaluate the performance of LoRa networks in an open field cultivation scenario via simulations using FLoRa, an open-source framework in OMNeT++. The number of nodes, the number of gateways, the antenna gain, and the size of the deployment area have a considerable impact on both the data extraction rate and the energy consumption of a LoRa network. Our results show that the optimization of the parameters that affect the performance of a LoRa network could transform traditional agriculture into a new perspective of smart cultivation. Finally, we evaluate the impact of the density and the geometric characteristics of three types of crop (tomatoes, grapes, apples) on the number of intersections that were caused by the insertion of physical objects-obstacles in a LoRa network.**

***Index Terms*—Internet of Things (IoT), Long Range (LoRa), Smart Agriculture, Data Extraction Rate, Network Energy Consumption**

I. Introduction

Over the last few years, agriculture has faced new challenges and technological changes to cope with modern requirements. Environmentally sustainable agriculture practices are required to assist water and natural resources preservation, prevent climate change and introduce new dimensions in cultivation [1].

In this regard, innovative Internet of Things (IoT) based techniques are being developed rapidly and being increasingly popular in the agriculture domain. Internet of Things is a network of devices that can transfer data without requiring human involvement. In smart agriculture, wireless systems are applied to greenhouses and open field cultivations to monitor a wide range of environmental factors in order to enhance the cultivation productivity, reduce costs, and optimize process inputs [2]. Lots of the wireless systems are based on Low-Power Wide-Area Network (LPWAN) technology.

A LPWAN technology can achieve coverage over a wide area while enabling successful data communication in indoor and underground locations at a low energy consumption. LPWAN protocols reduce complexity and the use of unlicensed bands reduce network costs. LoRa (Long Range) is a prominent technology in wireless communication domain that can provide connectivity over large agricultural fields, with low power consumption.

In this paper, we concentrate on the performance evaluation of LoRa networks in open field cultivation scenarios which are simulated by using FLoRa simulation tool.

The remainder of this paper is structured as follows. In Section II, an overview of LoRa technology is presented. Section III describes the simulation tool which is selected in modeling the open field cultivation scenarios. Section IV the simulation scenarios and the findings are provided. The conclusion of the work is presented in Section V.

II. overview of LoRa

LoRa and LoRaWAN are two distinct components of a LoRa network, each corresponding to a different layer of the protocol stack. LoRa is a proprietary Chirp Spread Spectrum (CSS) modulation technique and, therefore, refers to the Physical (PHY) layer. LoRaWAN specifies the Medium Access Control (MAC) layer in LoRa networks.

A. LoRa

LoRa is optimized for long-range applications and low power consumption at a low transmission rate [3] and operates in the unlicensed sub-GHz ISM (Industrial, Scientific, and Medical) bands (EU: 863-870 MHz, USA: 902-928 MHz and ASIA: 470-510 MHz).

LoRa modulation depends on five configuration parameters which determine the transmission range, the data rate, the energy consumption, and the resilience to noise of a LoRa transmission [4].

- Transmission Power (TP). LoRa TP ranges from -4 to 20 dBm. A bigger TP increases the Signal to Noise Ratio (SNR) and the energy consumption.
- Carrier Frequency (CF). Depending on the ISM band selected in the region, CF can be limited to 137 MHz to 1020 MHz.
- Spreading Factor (SF). SF can be set between 6 and 12. A higher SF increases the Signal to Noise Ratio (SNR) and the energy consumption.
- Bandwidth (BW). BW usually set to 500 kHz, 250 kHz, or 125 kHz. A higher BW increases the data rate and the energy consumption but decreases the radio sensitivity.
- Coding Rate (CR). CR can be set to either 4/5, 4/6, 4/7 or 4/8 in order to offer protection against burst interference. A higher CR offers more reliability but increases the energy consumption.

B. LoRaWAN

LoRaWAN is a communication protocol and a system architecture for LoRa network [5]. LoRaWAN relies on an ALOHA-based MAC protocol [6]. This protocol provides lower complexity to the end-devices. The communication between LoRa nodes and gateways is provided over the physical layer but each node is not associated with a specific gateway. Each gateway within a specific transmission range can receive data from a LoRa node. The received data are forwarded to the network server. The network server and the gateways communicate over standard IP (Internet Protocol). Finally, the network server forwards the massages to the application server.

III. LoRa Simulation Scheme

The LoRa networks were modeled on OMNeT++ [7] discrete event simulator by using the FLoRa (Framework for LoRa) simulation tool [8] and the INET framework [9]. FLoRa is an open-source simulation tool that includes various modules of a LoRa network such as the LoRa physical layer, the LoRaWAN MAC protocol, network elements and a module to characterize the energy consumption of the network. FLoRa enables end-to-end simulations by modeling LoRa elements - nodes, gateways and network servers - as shown in Fig. 1. Each gateway is able to receive data from LoRa nodes on multiple channels. Moreover, a network server communicates with multiple gateways over IP connections, filters out duplicate packets, and sends downlink data to nodes through the gateways. Finally, the INET framework was used in order to implement the physical layer.

The open field cultivation was modeled by using the log-distance path loss model with shadowing [10]. Using this model, the path loss is calculated based on the distance between the transmitter and receiver. This path loss model can be described as:

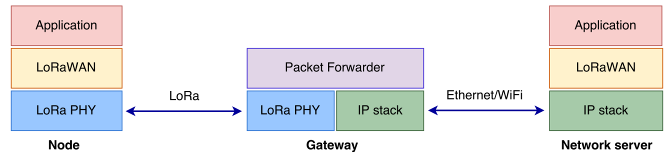


Fig. 1: Modules in FLoRa and the corresponding protocol stack [8].

$$PL(d) = \bar{PL}(d_0) + 10 \times n \times log\frac{d}{d_0} + X_\sigma \quad (1)$$

where $PL(d)$ is the path loss in dB, $PL(d_0)$ is the mean path loss at the reference distance d_0, n is the path loss exponent, X_s is a zero-mean Gaussian distributed random variable and σ is the standard deviation. In our simulations n was set equal to 2, and σ equal to 5 dB.

To evaluate the performance of LoRa networks we define the following performance metrics:

- Data Extraction Rate (DER), as the ratio of correctly received messages to the total number of transmitted messages. DER is a value between 0 and 1. The LoRa network is more efficient when the value is closer to 1.
- Network Energy Consumption (NEC), as the ratio of the total amount of the energy consumed by LoRa nodes to the sum of the messages which were successfully received by the server. The network is more effective when the metric is low.

IV. Simulation Scenarios

In this part, we discuss four scenarios in an attempt to evaluate the performance of LoRa Networks.

We utilized the European regional parameters to model the LoRa physical layer in three different deployment areas (Fig. 2). Deployment area A was set to 300m by 300m, deployment area B was set to 500m by 500m, and deployment area C was set to 1000m by 1000m. The transmission power was fixed at 10 dBm, the chosen CR was 4/8, bandwidth was set to 125 kHz, SF was selected to 7, and carrier frequency was set to 868 MHz (Table I). Each scenario included one or multiple LoRa gateways arbitrarily placed in the deployment areas. Nodes were uniformly distributed over the areas. Each simulation was completed in 7 days of simulated time.

TABLE I: Simulation parameters.

Parameter	Value
Transmission Power (TP)	10 dBm
Carrier Frequency (CF)	868 MHz
Spreading Factor (SF)	7
Bandwidth (BW)	125 kHz
Code Rate (CR)	4/8

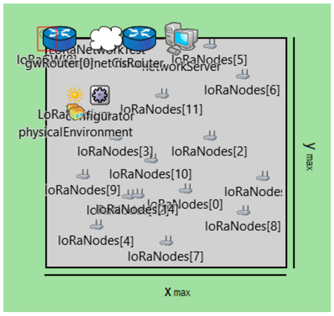


Fig. 2: The deployment area of a LoRa network.

Scenario 1. In our first set of simulations, we compare the impact of four antenna types (isotropic, 0.173m dipole antenna, constant gain 3 dBi, constant gain 5 dBi) on the performance of LoRa networks. LoRa networks were modeled in three deployment areas (A, B, C). A gateway was placed at the top right point of each area (x=0, y=0). Moreover, 100 nodes were placed at random locations uniformly distributed in each deployment area. The results of the first set of simulations are provided in Fig. 3 and Fig. 4. By choosing antennas with higher gain, the performance of the LoRa network increases.

Scenario 2. In these simulations, we explore the impact of the number of gateways on the obtained performance metrics (DER, NEC). The number and the distribution of nodes were the same as the Simulation Set 1. Isotropic antennas were selected. For each simulation, an increasing number of gateways was used. For the first simulation we placed the gateway-GW_0 at the top right point of each area (x=0, y=0). For the second simulation a second gateway-GW_1 was located at ($x=x_{max}/2$, $y=y_{max}/2$). In the third set we used the gateway-GW_0 and we add two more gateways GW_2 and GW_3. Gateway-GW_2 was placed at ($x=x_{max}/2$, 0), and gateway GW_3 was placed at (0, $y=y_{max}/2$). In the last simulation set, the four gateways were placed in each deployment area. We chose this gateway placement strategy for simplicity. Fig. 5 and Fig. 6 show that the use of multiple gateways has a huge impact on LoRa network performance. For example, by using 4 gateways the performance of the network is increased by 28.6%.

Scenario 3. In the third set of simulations, we evaluate the performance of the network with a growing number of nodes uniformly distributed over the deployment area which was set to 500m by 500m. Fig. 7(a, b) shows that while we increase the number of nodes, the performance of the network decreases due to the increase in the occurrence of collisions between the packets. For example, by increasing the number of nodes from 10 to 1000, the collisions are increased from 1.7% to 65.7%.

As demonstrated by the previous simulation sets, the dimensions of the deployment area affect both the obtained performance metrics (DER, NEC). By increasing the size of the deployment area, the same number of nodes must be distributed over a wider area.

Scenario 4. A gateway was placed at the top right point of the deployment area (x=0, y=0) and 100 nodes were located at random spots uniformly allocated to the deployment area which was set to 300m by 300m. Isotropic antennas are selected. Each simulation scenario lasted for 1 day of simulated time.

In this scenario we compare the number of intersections caused by the physical objects-obstacles we insert in the model. We used physical objects to model three types of crops: tomatoes, grapes, and apples (Fig. 8).

- We modeled the tomato crop by using 120 cuboid physical objects. The length of each physical object was set to 298 m, width was set to 1m, height was set to 1.5 m and the distance between two objects was selected to be 1.5 m. The dielectric constant was set to 75 (Table II).
- To model the grape crop, we use 75 cuboid physical objects. The length of each physical object was set to 298 m, width was set to 1m, height was set to 1.5 m and the distance between two objects was selected to be 3 m. The dielectric constant was set to 74.
- We modeled the apple trees by using a grid of 49 by 49 cuboid objects. The length of each physical object was chosen to be 4 m, width was set to 4m, height was set to 5 m and the distance between two objects was selected to be 2 m. The dielectric constant was set to 71.

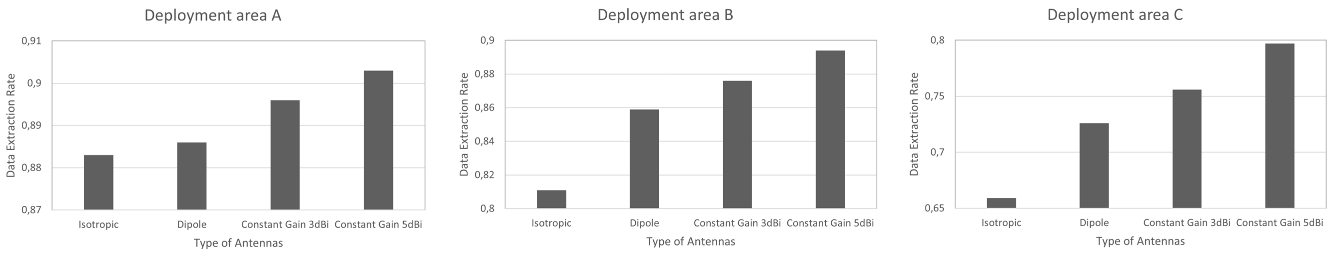
TABLE II: Dielectric constant of crops [11].

Crop type	**Dielectric constant**
Tomatoes	75
Grapes	74
Apples	71

Fig. 7(c) shows the results of this set of simulations. Comparing the results of the tomato and grape crops we observe that the number of intersections, which were caused by the obstacles, increases while we increase the density of the crops in the deployment area (Fig. 8). The number of intersections obtained in the crop of apple trees is higher due to the geometric characteristics we used to model the apple trees.

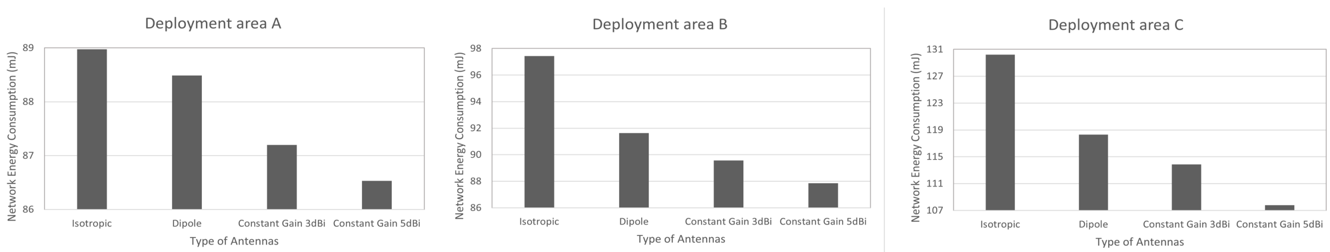
V. Conclusions

In this paper a performance evaluation of LoRa networks in an open field cultivation scenario has been presented. Different parameters were explored in order to evaluate the data extraction rate and the energy consumption of LoRa networks. As shown by the presented results, the type of antennas, the number of gateways, and the number of nodes affect the performance of a LoRa network. We obtain that by increasing the number of gateways from 1 to 4 the performance of the network is increased by 28.6%. Moreover, when we increase the number of nodes from 10 to 1000, the collisions are increased from 1.7% to 65.7%. The optimization of these parameters could transform agriculture into a new era of smart cultivation. Moreover, from the results, it can be concluded that the dimensions of the deployment area have an impact



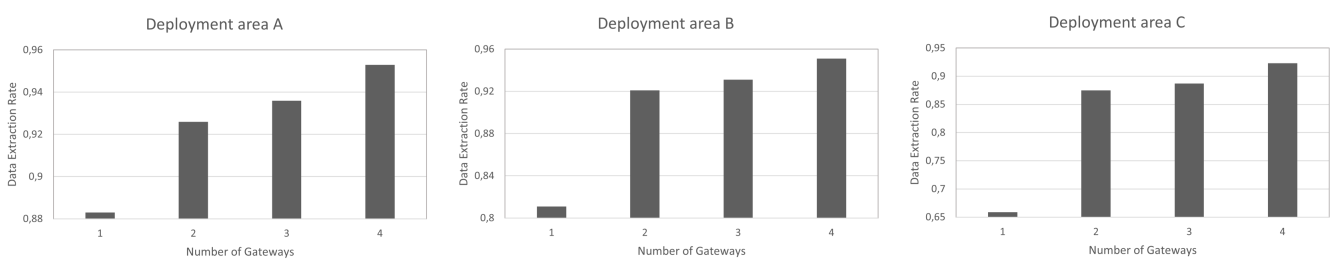
(a) (b) (c)

Fig. 3: Comparison of the data extraction rate relative to the type of antennas in the deployment area: (a) A (300m by 300m), (b) B (500m by 500m), (c) C (1000m by 1000m).



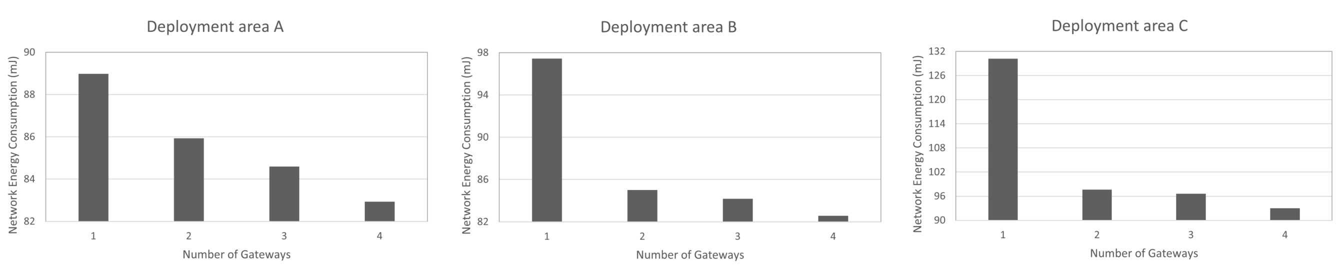
(a) (b) (c)

Fig. 4: Comparison of the energy consumption relative to the type of antennas in the deployment area: (a) A (300m by 300m), (b) B (500m by 500m), (c) C (1000m by 1000m).



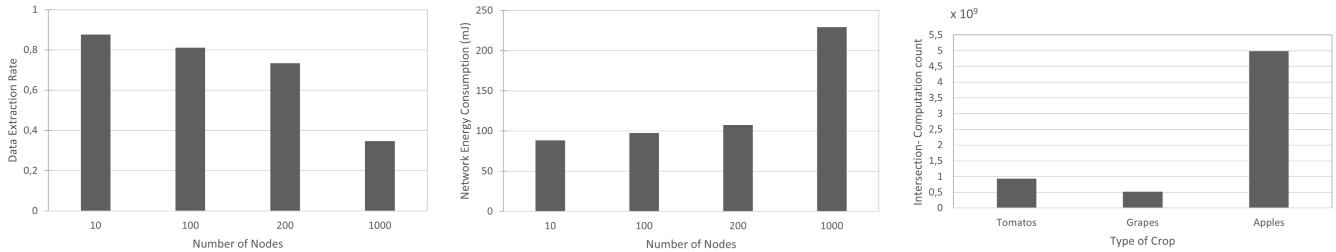
(a) (b) (c)

Fig. 5: Comparison of the data extraction rate relative to the number of gateways in the deployment area: (a) A (300m by 300m), (b) B (500m by 500m), (c) C (1000m by 1000m).



(a) (b) (c)

Fig. 6: Comparison of the energy consumption relative to the number of gateways in the deployment area: (a) A (300m by 300m), (b) B (500m by 500m), (c) C (1000m by 1000m).



(a) (b) (c)

Fig. 7: (a) Data extraction rate in the deployment area B (500m by 500m) relative to the number of nodes. (b) Energy consumption in the deployment area B (500m by 500m) relative to the number of nodes. (c) Intersection-computation count in the deployment area A (300m by 300m) relative to the type of crop.

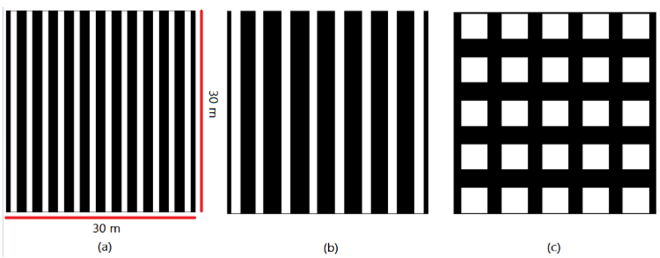


Fig. 8: Two-dimensional graphic representation of density in (a) tomato crop, (b) grape crop, (c) apple crop.

on both the data extraction rate and the energy consumption of the network. With an increasing size of deployment area, the performance of the network is significantly reduced. Finally, the simulation results confirmed that the density of the crops in an open field cultivation scenario and the geometric characteristics of the crops have notable influence on the number of the observed intersections. For that reason, as future work, we intend to examine the impact of these parameters on the performance metrics of a LoRa network and perform experimental measurements in a real-world environment to evaluate the simulation results.

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