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# A Study on LoRa Signal Propagation Models in Urban Environments for Large-Scale Networks Deployment

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***Abstract*—The development of Low-Power Wide-Area Networks is challenging in urban areas due to the terrain elevation changes, clutter losses or dense vegetation regions that attenuate the radio signals. To provide accurate coverage estimation, signal propagation models that integrate losses caused by reflections or attenuations should be used. In this study, we analyze two radio propagation models used for different urban environment configurations, Longley-Rice and ITU-R, to perform a coverage estimation of a LoRa communication network for large-scale deployments. According to our analysis results, validated by measurements, the Longley-Rice and ITU-R radio propagation models are suitable for an urban environment as they use vegetation path losses and could be adapted according to LoRa modulation requirements. Those propagation models are adjusted for real urban field measurements achieved from a point-to-point communication. The obtained results focus also on coverage optimization of a locally deployed LoRa network, considering the best gateway location for the optimum coverage. Thus, a low-cost deployment of the entire network is ensured by reducing the number of installed gateways.**

***Index Terms*—LoRa signal coverage, Internet of Things, urban areas, chirp modulation, radiofrequency interference.**

## I. INTRODUCTION

The development of the Internet of Things (IoT) has determined the explosion of the number of connected devices, applications, increasing the network size to a globally distributed configuration. A lot of applications related to smart agriculture, smart city, smart home, industry 4.0 or healthcare need the deployment of a large amount of unattended IoT devices that have an estimated net value of €3.500 - €9.800 trillion by 2025 [1]. These devices send small amount of data, sporadically, having a lifetime to more than a few years. Many studies presented at different scientific events and in journal papers have mentioned that the modern world is on a new wave of innovation and its rapidly growing thanks to the Information and Communication Technologies (ICT) [2], [3]. This massive industry of IoT will have approximately 24 billion devices by the end of 2024 and will continue to grow, due to the consumer request for new technology and smart devices [4].

A statistic about the number of sensors connected to the global IoT network can be seen in Figure 1. According to [5], this number is growing explosively and has already exceeded the number of people with Internet access. The humans are replaced by autonomous objects.

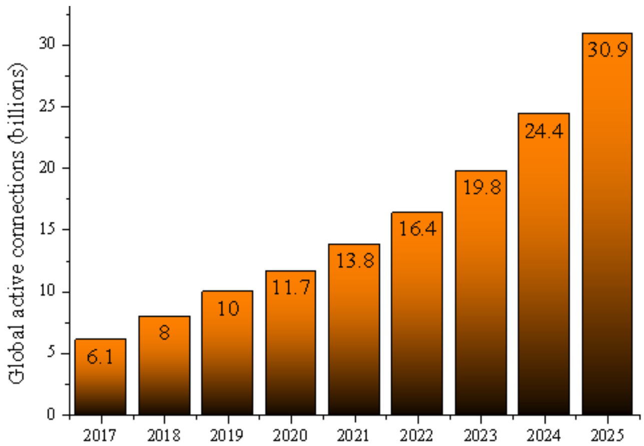


Figure 1. Number of sensors globally connected in the IoT network

Thus, for example, in the smart home concept, the users can control any home appliance for their own personal comfort using a wireless link, while other aspects are fully automated based on some collected data, such as smart energy management [6].

Moreover, energy saving is another important topic nowadays, and new technologies could help in acquiring this, by using smart devices. Greenhouse Gases emissions may be reduced indirectly by optimizing resources management in industries and directly with specific sensors and devices that can monitor any environment parameters like pollutants, air temperature or air humidity. According to some studies [7], [8], the use of ICT may reduce the gas emissions by 12% until 2030, and the percent will increase year by year if every person pays more attention and makes efforts in using smart devices linked to reducing consumption.

To simultaneously fulfill all these requirements, wireless technologies that allow connecting autonomous devices to the global network were developed since the beginning of 2015 and they gain popularity each year rapidly. Some of the wireless technologies used in the IoT ecosystem are LoRa, Sigfox, Ingenu, Weightless, LTE-M or NB-IoT and they have recently emerged with a common name of Low-

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Power Wide Area Networks (LPWANs) [9]. Typically, these technologies may communicate even under low Signal to Noise Ratio (SNR) and low Receive Signal Strength Indication (RSSI) values due to the usage of robust modulation techniques developed, some of them being proprietary and patented solutions.

From the above mentioned LPWAN technologies, LoRa and NB-IoT are by far the leaders of the IoT deployments and of the industrial community, respectively [10].

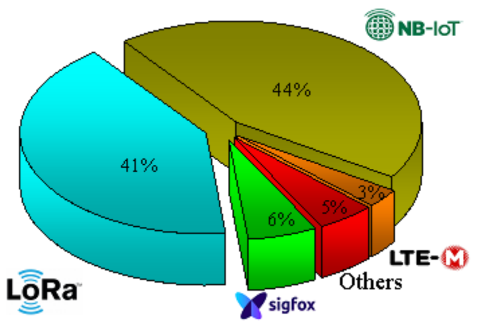



Figure 2. LPWAN technologies used for the IoT development [10]

Although, according to the statistic depicted in Figure 2, is in a head-to-head battle with NB-IoT, LoRa it is the most discussed LPWAN technology in the academic community or by the hardware/software developers, due to its unlicensed spectrum operation and its ease to use. Meanwhile, NB-IoT is operating in the license spectrum and its mostly driven by leading telecommunication companies around the world, so the flexibility for the end-user is limited. Another important aspect of LoRa technology is the low price of the end-device that is able to cover large-areas, for more than few kilometers.

When a wireless communication network is deployed, some key aspects should be considered, such as the line-of-sight (LoS) between the transmitter and the receiver, the required coverage - according to the use case, or the lifetime of the battery-powered end-devices [11]. Most of the research activity focused on different end-node location strategies to achieve good coverage and interconnectivity. This is not the optimal choice when the deployed network must cover a large area of interest, like LoRa does, using a star network topology where the sink node named gateway is centrally positioned. Thus, a powerful approach to fulfill the good coverage of the network is to rely on models that can predict the network performance - according to some of its key parameters, like optimal gateway placement [12]. These placement models may be obtained using measurements of the environment or by using computer simulations that have the signal propagation models for different scenarios.

For example, in tropical regions, where landscapes covered with thick vegetation or forest areas are common, the radiated propagation wave suffers attenuation, scattering, diffraction or absorption [13]. Thus, to successfully implement the network, an accurate propagation model is needed to establish good communication links and good coverage estimation. The attenuation of the link is called path loss and a model for different scenarios is important in the LoRa communication deployment. The path loss of a link is correlated to the packet delivery probability, parameter linked to the LoRa network performance. Thus, for coverage optimization an accurate prediction of the path loss is needed, associated with a specific LoRa gateway position.

In the specialized literature, there are a series of scientific papers which describe various radio propagation models, but few of them can be applied to the characteristics of LoRa modulation. This paper comes to fill in the gap by designing and evaluating two communication propagation models that can be used for urban crowded environments.

The paper is organized as follows: first, a brief introduction related to the state-of-the-art, followed by Section II, where the main related works are presented. The LoRa modulation and LoRaWAN communication protocol are discussed in Section III. In Section IV, path losses and propagation models are analyzed with emphasis on the LoRa modulation main characteristics. The experimental results and the developed LoRa model are discussed and presented in Section V. The final section of the paper is represented by the conclusions and the overall performance evaluation of the propagation models.

The main contribution of this paper is related to a prediction model for the LoRa gateway placement to achieve good communication coverage in an environment with elevation variation. The model is obtained using real field measurements.

## II. Literature Survey

In the scientific literature there are a series of studies that evaluate the performance level of LoRa communication in different environments but none of them try to generalize a model from the measurement data. From all the studies, the most common evaluation method is to measure the RSSI value or the SNR level of the received signal from the end-device. The obtained values are compared with some path loss empirical models, such as Okumura-Hata [14], Walfisch-Ikegami [15], Longley-Rice [16] or ITU-R [17].

In [18], Iova et al. performed some tests in a non-urban environment to demonstrate the reduction of the communication range due to the dense vegetation or mountain terrain. They used the 868 MHz band, and according to the reported results, the communication range drops by an order of magnitude when the tested end-devices are moved from open space to a dense forest environment. Also, another important mentioned aspect is that the environment temperature could influence the quality of the communication link.

In [19], Khairol A. et al. performed an evaluation related to the LoRa signal propagation in the middle of a dense foliage environment. The measurements have been performed using the 433 MHz frequency band LoRa modules. The authors used two setup configurations for the test scenario and increased the spreading factor from 128 chips/symbol to 4096 chips/symbol, or the equivalent of using SF7 and SF12, respectively. The measured value is the RSSI and as it was expected, the distance from the gateway and the sensor node decreased much rapidly when the foliage of the environment is dense.

A point-to-point LoRa communication link is tested in [20]. The scenarios implied using three different environments, coastal, forest and urban, respectively.

Considering that using only the PHY layer within LoRa modulation is much simpler than the LoRaWAN communication protocol, the authors used only one transmission channel, number 6 from the Europe spectrum channel allocation. Also, using this test setup, the expensive gateways and end-node could be avoided, and any frequency band may be assigned, avoiding interferences between the connected devices. The measured parameters were SNR and RSSI for all the mentioned scenarios. The authors divided the obtained results in three major categories. If the transmission is made using higher SF's, the RSSI value will not increase. This will change only the SNR, increasing the sensitivity of the system. The communication range is limited by the RSSI value, being the demodulation floor limit of the receiver. The long-range link between point-to-point devices is possible by using low-height terminals, reaching 4 km in the coastal environment, and 1 km in the urban scenario, respectively. These values were obtained with SF12 spreading factor, which allows for the LoRa modulation to obtain high communication distances.

Another approach is in [21] where the authors predict the range of the LoRa communication in Dakar region. The measurements were performed using SF12 and a power transmission of +14 dBm. All the obtained values were used to propose a channel attenuation model. Thus, different values of RSSI and SNR were depicted, and an estimation of range coverage was made to estimate the required gateway density in the region.

Different conclusions on LoRa coverage made by the empirical studies mentioned above reveal that the path loss increases with communication distance at different rates in various environments. The influence of SF and communication channel bandwidth needs to be carefully evaluated as to estimate the real coverage of a LoRa gateway.

## III. LoRa Modulation and LoRaWAN Overview

LoRa is a technology developed by Semtech Corporation and it's designed for reduced infrastructure, is scalable [22] and may be used for large areas within a radius of 2-3 km in urban and more than 10 km in rural areas, respectively [23]. The communication stack can be seen in Figure 3.

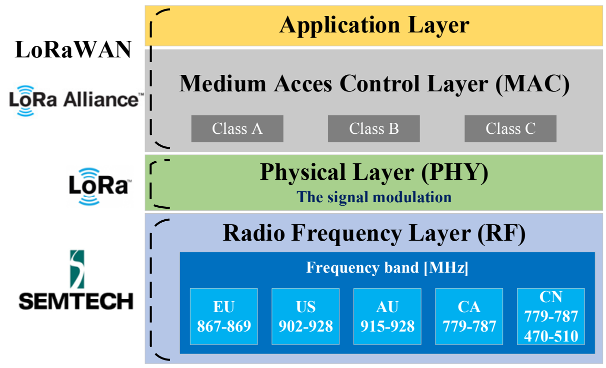



Figure 3. LoRaWAN communication stack

The LoRa Alliance defines the Application and the MAC layer over the physical LoRa modulation layer.

According to Federal Communications Commission (FCC) and European Telecommunications Standards Institute (ETSI), LoRa communication exploits the Industrial Scientific Medical (ISM) or Short-Range Devices (SRD) frequency bands, with some regional regulations and limitations in transmission. Several LoRa communication technical specifications may be seen in Table I.

TABLE I. LoRa Specifications for US and EU

| | United States | Europe |
|---|---|---|
| Frequency band | 902 - 928 MHz | 867 - 869 MHz |
| TX Power | +30 dBm | +14 dBm |
| RX Power | +27 dBm | +14 dBm |
| TX Channels | 903.9 – 905.3 MHz | 867.1 – 868.8 MHz |
| RX Channels | 923.3 – 927.5 MHz | 867.1 – 868.8 MHz |
| Bandwidth TX | 125/250 kHz | 125/250 kHz |
| Bandwidth RX | 500 kHz | 125 kHz |
| Spreading Factor TX | 7 to 10 | 7 to 12 |
| Spreading Factor RX | 7 to 12 | 7 to 12 |
| Data rate | 980 bps – 21.9 kbps | 250 bps – 50 kbps |

LoRa physical layer uses a proprietary modulation, called LoRa modulation, which is a variant of Chirp Spread Spectrum (CSS) that modulates frequency chirp pulses to encode the information by varying the frequency without changing the phase between adjacent symbols. On top of the physical layer, is the LoRaWAN protocol, which is developed and maintained by the LoRa Alliance, an open association of collaborating members.

LoRaWAN defines the star network topology, and ALOHA as the transmission protocol in the MAC layer. Also, it defines three distinguished functional classes based on how uplink and downlink are managed by the network.

- Class A (All nodes): It is the best choice in terms of power consumption, the end-devices being battery-powered. The end-device will transmit the information and will wait for the downlink in two well defined short time intervals. In case if the downlink packet is received, the second time interval will be ignored. This class is the most common for sensors or devices where uplink communication is preferred. Some use applications are environmental monitoring, location tracking, fire detection or animal tracking.
- Class B (Beacon): It is an extension of Class A, by adding additional scheduled downlink time frames. The end-devices have lower latency than Class A and the power consumption is affected due to the more time spent in active mode during beacons. Some applications are for smart metering or temperature reporting.
- Class C (Continuous): Are the least efficient from the power consumption point of view. After the uplink, the end-device keeps the downlink window open unless it's making a new transmission. The devices are main powered and are used for low latency downlink applications like utility meters or streetlight monitoring systems.

Power consumption, coverage area, robustness against noise and interference of the LoRa devices may be adjusted through the carrier frequency (or channel allocation), the bandwidth (can be user defined), coding rate (forward error correction mechanism) or the spreading factor allocation. The spreading factor allows for orthogonal channel configuration, so the collision of links with different spreading factors will be avoided [24]. Thus, LoRaWAN propose a collision avoidance technique that uses frequency diversity and time diversity by using different spreading factors and different communication channel bandwidths.

## IV. Path Loss and Propagation Models

A radio signal may be transmitted between two points through a communication environment. The corresponding Friis equation is presented in (1):

$$L_{bf}(d) = 20\log\left(\frac{4\pi fd}{c}\right) \quad (1)$$

where $f$ is the frequency, $d$ is the link distance, and $c$ is the speed of the electromagnetic wave.

However, the free space path loss model can be considered only when no obstacles and no reflections conditions on the signal propagation paths are met. This isn't possible for LoRa network deployment, so other propagation models need to be considered and evaluated.

Longley-Rice path loss model is a mathematical model for predicting the attenuation of radio signals for a telecommunication link in the frequency range of 20 MHz to 20 GHz. This is one of the most used models for signal propagation estimation as it is developed for an irregular terrain model (ITM), considering free space losses, diffraction or scattering effects.

To obtain accurate data with this model, are needed some other parameters besides those from the Friis equation, like:

- $\Delta h$ (terrain irregularity parameter)
- $k$ (wave number)
- $N_s$ (surface refractivity)
- $\gamma_e$ (the earth's effective curvature)
- $Z_g$ (surface transfer impedance of the ground)
- climate geographical zone.

The Longley-Rice model is based on thousands of measurements taken from the environment. From those measurements, an effective radius of the earth is calculated, which is a function of the refractivity index and the Earth terrain irregularity, being of approximately 4/3 of the actual Earth radius. The $\Delta h$ parameter is related to how the terrain is changed with respect to the sea level. Some typical values of the model are listed in the Table II [25].

TABLE II. Terrain Irregularity Parameter Typical Values

| Terrain | Δh (m) |
|---|---|
| Water | 0-5 |
| Smooth plains | 5-20 |
| Slightly rolling plains | 20-40 |
| Rolling plains | 40-80 |
| Hills | 80-150 |
| Mountains | 150-300 |
| Rugged mountains | 300-700 |

The wave number $k$ can be evaluated using (2).

$$k = \frac{2\pi}{\lambda} = \frac{f}{f_0} \quad (2)$$

where $\lambda$ is the wavelength, $f$ is the carrier frequency and $f_0$ = 47.7 MHz.

The surface refraction $N_s$ is considered in terms of $N_0$ which is the surface refractivity "reduced to the sea level". When this is the situation, one must know the general elevation $z_g$ of the region involved, measured in km.

$$N_S = N_0 e^{e^{\frac{-z_g}{9.46}}} \quad (3)$$

The Earth's effective curvature is the reciprocal of the earth's effective radius and may be expressed using (4).

$$\gamma_e = \frac{\gamma_a}{K} \quad (4)$$

where $\gamma_a$ is the actual Earth's curvature and $K$ is the effective earth radius factor.

The surface transfer impedance is normally defined in terms of the relative permittivity $\varepsilon_r$ with the conductivity $\sigma$ of the ground, and the polarization of the radio waves involved, respectively.

$$Z_g = \begin{cases} \sqrt{\varepsilon_r^{'} - 1} & \text{for } H \text{ polarization} \\ \sqrt{\dfrac{\varepsilon_r^{'} - 1}{\varepsilon_r^{'}}} & \text{for } V \text{ polarization} \end{cases} \quad (5)$$

where $\varepsilon_r^{'}$ is the complex relative permittivity defined by (6).

$$\varepsilon_r^{'} = \varepsilon_r + \frac{iZ_0\sigma}{k} \quad (6)$$

with $Z_0$ = 376.62 Ω.

All the mentioned parameters are the key points for obtaining accurate results. Determining the environment parameters considering the variation of elevation due to the relief structure of the Earth is needed as to depict the path losses and can calculate the needed distance between the transmitter and the receiver. Additional information is needed when the point-to-point mode is considered, like:

- $h_{g1}$ and $h_{g2}$ (the transmitter and the receiver antenna height from the ground)
- $d_{L1}$, $d_{L2}$ (distance from each terminal to its radio horizon)
- $\theta_{e1}$, $\theta_{e2}$ (elevation angles of the horizons from each terminal, at the height of the antennas).

If the deployed communication system works on SRD860 frequency band, with the central frequency of 868 MHz, and considering the effective Earth radius of 4/3, the minimum distance for which the attenuation caused by the scatter phenomena is equal to the one caused by diffraction is at 33 km, which is much larger than the area considered for LoRa communication, with the receiver sensitivity of -138 dBm and the SF12.

Another propagation model is proposed by the ITU-R (International Telecommunication Union) with the Radiocommunication Sector [26]. In the P.1812-4 report, they discuss the path loss models for terrestrial services, in the frequency range of 30 to 3000 MHz. Beside the landforms, they integrate in some reports the effects of the signal propagation when one of the radio stations is in vegetation area. Also, for more accurate results of the propagation model, they also consider the antenna polarization loss or the attenuation variation due to the wind.

The propagation model is an accurate one and implies important elements, like [26]:

- Line-of-sight (LoS)
- Diffraction (embracing smooth-Earth, irregular terrain, and sub-path cases)

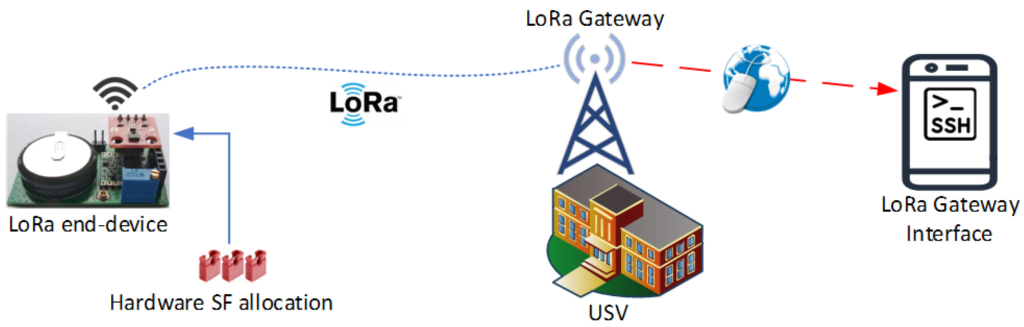



Figure 4. LoRa testing architecture

- Tropospheric scatter
- Anomalous propagation (ducting and layer reflection/refraction)
- Height-gain variation in clutter
- Location variability
- Building entry losses.

The Longley-Rice and ITU-R propagation models are the best for urban environment including vegetation path losses and will be further used in our study.

The mentioned path loss models are available in the RadioPlanner emulator [27]. The terrain variation is linked in the simulation using the Google Satellite, so accurate predictions may be obtained for any communication system that uses the ISM or SRD frequency bands. Also, they provide a LoRa communication model, being much easier to simulate a network deployment for a large-scale coverage.

## V. LoRa Propagation Model Development

In this paper, we focus on coverage optimization for a locally deployed LoRa network, so our goal is to find the best location for the gateways, to ensure low-cost deployment of the entire network.

The first step in the LoRa deployment coverage determination is by using the results of the measurements performed with a mobile LoRa end-device to collect some field data for the simulator configuration. We used RadioPlanner software to emulate the coverage of the LoRa network and validate the propagation models.

The communication architecture is presented in Figure 4. For testing some path loss values, the LoRa gateway is installed at the Stefan cel Mare University of Suceava, with the antenna on the building C roof top at a height of 354 meters, elevation related to the sea level. The LoRa gateway is the one discussed in [28], configured for a point-to-point communication. Thus, we tried to avoid MQTT (Message Queuing Telemetry Transport) data encapsulation, so only the LoRa communication is tested, and especially the RSSI and the SNR values, respectively. For the measurements, on the gateway side is mounted an omnidirectional antenna with a gain of 12 dBi from Taoglas and at the end-device side a whip omnidirectional antenna with a gain of 2.15 dBi.

The communication is initiated once at every 10 second interval, and only one communication channel is used for these tests (868.3 MHz). In this test setup scenario, none of other LoRa interferences are met, other LoRa systems being not available in the region. To record the proper SNR and RSSI values, the limit of the spreading factor is also tested. Thus, all the performed field measurements started with SF7 and go to the SF12. Each time, when the packet is not received by the LoRa gateway, the hardware spreading factor is adjusted manually with external jumpers and a software routine uploaded in the end-device. Once the spreading factor allocation is adjusted, the communication is re-initiated. All the received values are stored locally in the LoRa gateway, and they have been accessed with a mobile device through an SSH connection.

For a proper integration of the measurements in the RadioPlanner simulator, the GPS position, RSSI values, SNR levels and altitude values are added to the model. With the use of all the mentioned parameters, we could predict an accurate model of the propagation using simulations, thus we may obtain a realistic coverage of the entire LoRa network. A total of 200 measurements have been performed with a communication radius of approximately 2 km. The test area is with terrain altitude changes, buildings, and dense forest vegetation.

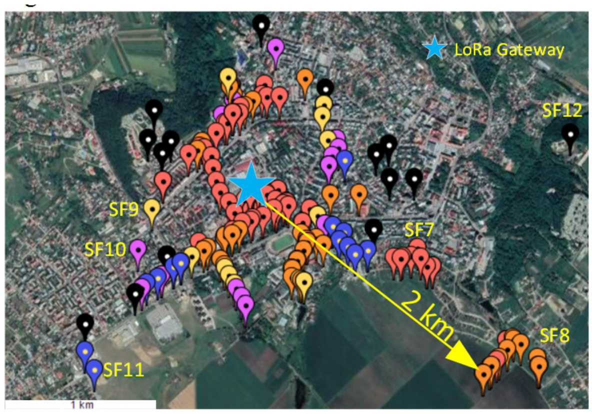
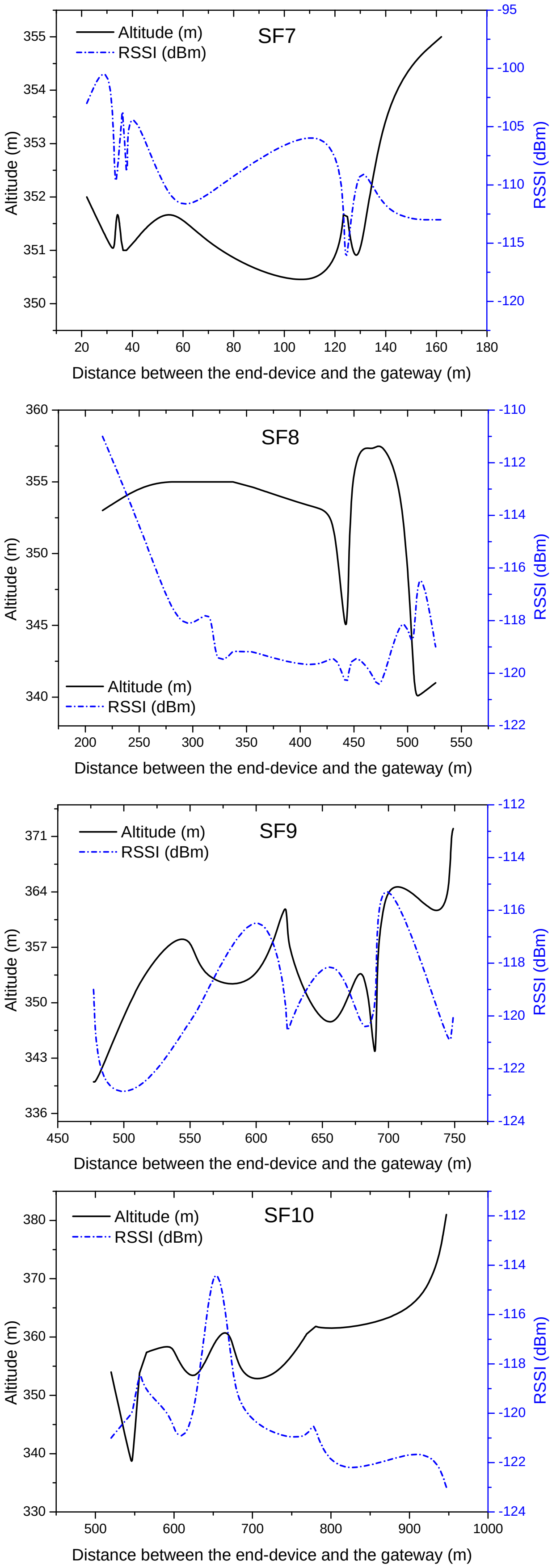



Figure 5. LoRa measurements area with some points of interest

From the measurements depicted in Figure 5, one may see the spreading factor allocation vary with the distance and with the measured point (each of them marked with a color, according with the indicated label). Thus, the received values are not distance dependent, being affected only by the environment. In Figure 6 we represented the terrain elevation for all the measured values. One may see that each spreading factor value depicted for communication has a different altitude level. Thus, no communication is possible for this scenario, due to the missing LoS, even if no other perturbing elements, like buildings or vegetation were present between the end-device and the gateway. Also, on the same Figure 6 the RSSI value is depicted. Only the values associated with SF7 are following a descending pattern from -98 dBm to approximately -113 dBm, the rest of the values being approximately the same, the variation of the RSSI parameter is from -113 dBm to -123 dBm.



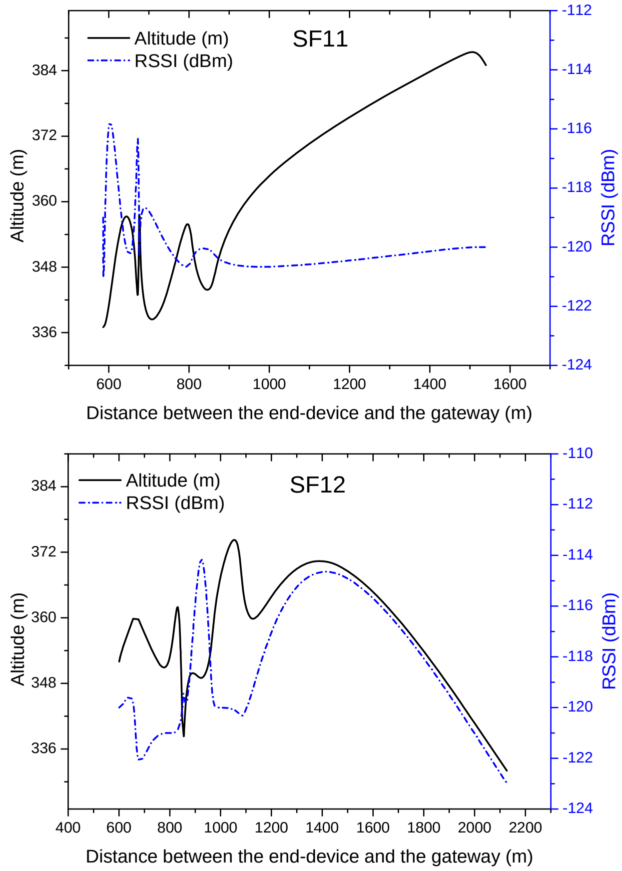




Figure 6. Measurements for altitude and RSSI for each spreading factor

One may see the distance between the end-device and the gateway. In some cases, the communication was possible by using SF12 at approximately 500 m from the gateway, other spreading factor allocation not worked in non-LoS urban area. This may be explained due to existence of high buildings in that area that blocks in path of the LoRa signal.

The next step is to configure the RadioPlanner simulator with the propagation model. Both earlier discussed propagation models are supported. To obtain accurate results, we need to adjust the simulation parameters. The simulator may integrate data from Google Satellite view, so all the terrain elevations are considered in the results. Also, for buildings, vegetation or other obstacles that are on the path of the radio wave, the simulator has clutter losses integration. Some of those values may be observed in the Figure 7. These values are according to the ITU-R P.1812-4 propagation model and can be selected or modified by the user to ensure the best simulation results.

| Clutter type | Mobile Unit №1 loss, dB | Clutter height, m |
|---|---|---|
| Open/rural | 0 | 0 |
| Water | 0 | 0 |
| Trees/forest | 22.7 | 15 |
| Suburban | 19.1 | 10 |
| Urban | 22.7 | 15 |
| Dense urban | 25.1 | 20 |
| Open areas in forest | 0 | 0 |
| Open areas in suburb... | 0 | 0 |
| Open areas in urban | 0 | 0 |

Figure 7. Clutter losses parameters used in the developed LoRa propagation model

## *A. Longley-Rice model*

The Longley-Rice model needs to input values discussed in Section IV. The path loss parameters may be selected manually by the user, according to the region where the propagation simulation is performed. Thus, in our case, the surface refractivity $N_s$ is of 301 N-units, the σ conductivity is of 0.02 S/m, and the relative permittivity $\varepsilon_r$ is of 15. For the simulation scenario, the climate is selected as continental temperate. Also, we used the vertical polarization of the gateway antenna, this option being available in the simulation parameters. From the simulation results, one may see that the propagation model is accurate, and the obtained values are close to the real measurements performed. Also, there is a difference between the case when we used clutter losses (Figure 8) and the case when they are absent (Figure 9). Due to the urban environment, the simulator may integrate the losses caused by buildings or other structures, defined in the simulation parameters as urban and dense urban losses.

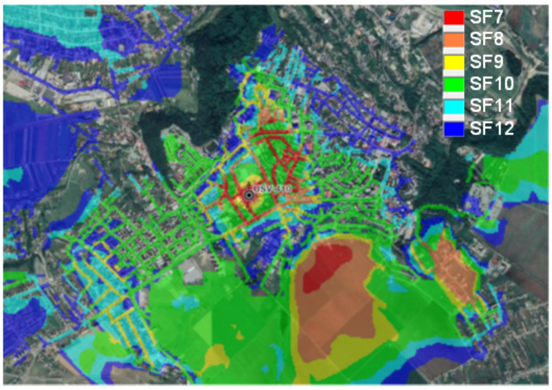



Figure 8. LoRa propagation using Longley-Rice model with clutter losses

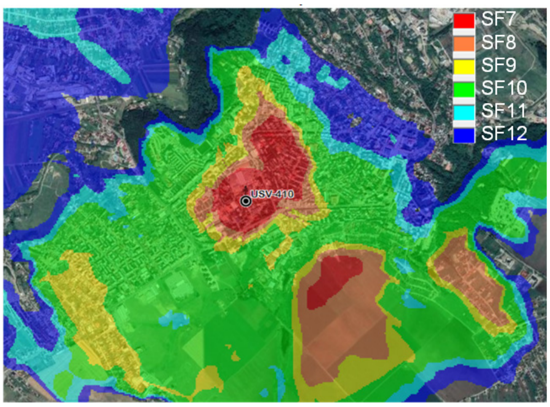



Figure 9. LoRa propagation using Longley-Rice model without clutter losses

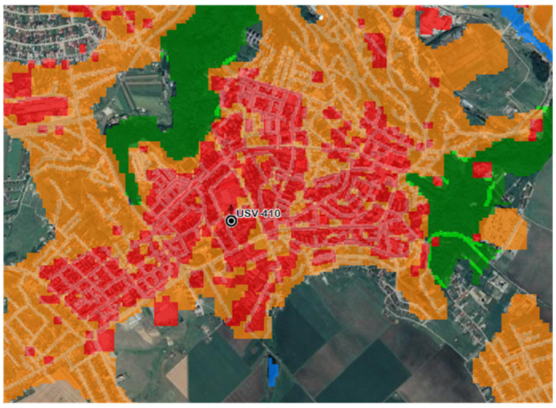



Figure 10. Clutter losses in the simulated area

An overview of the clutter losses in the simulated area can be seen in Figure 10. The colors from the map are the same with those depicted in the Figure 7.

*B. ITU-R model*

Approximately the same results may be seen when we used the ITU-R P.1812-4 propagation model. However, for the ITU-R model, there are very few parameterization alternatives. If for the Longley-Rice model we can choose the terrain surface parameters, here those values are integrated into the simulation model and may not be altered by the user.

If we analyze the values in Figure 11 and Figure 12, we may see the differences between the two developed LoRa propagation models with and without the clutter, respectively. Due to the simplicity of the parameter optimization, the ITU-R model is slightly less accurate than the Longley-Rice model. However, both models are adequate to be used successfully when a simulation of the radio wave propagation is needed to deploy long-range and large-area networks.

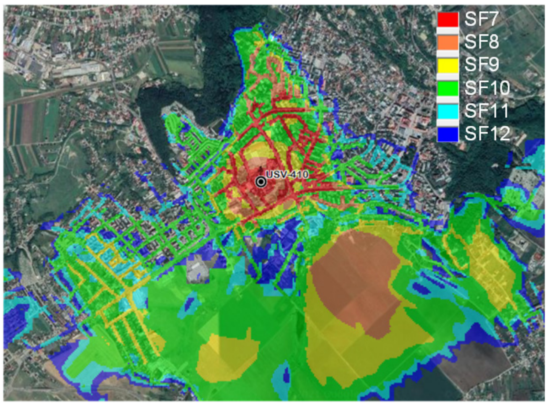



Figure 11. LoRa propagation using ITU-R model with clutter losses

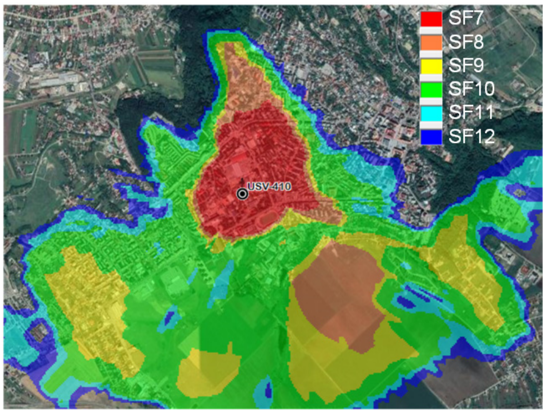



Figure 12. LoRa propagation using ITU-R model without clutter losses

## VI. Conclusion

The developed of new radio communication propagation models is very important and must keep up with the design of new IoT communication protocols. To obtain a high level of performance, the LoRa gateway and node optimal position placement must not be neglected. Nowadays, many new IoT technologies that promise long-range communications emerge and must provide good communication link, even if they are deployed in harsh or urban environments. The need for good radio propagation models is a topical issue.

The main contribution of this paper is related to the evaluation of two radio propagation models that could open new research directions on LoRa modulation, providing a useful insight to the LoRa performance level in crowded urban environments.

The propagation models' parameters were selected and determinate from real urban field measurements using a point-to-point configuration. The obtained results focus on coverage optimization for a locally deployed LoRa network, considering the best gateway location for the optimum coverage to ensure low-cost deployment of the entire network, by reducing the number of installed gateways.

Two important propagation models, Longley-Rice and ITU-R are discussed and evaluated in this paper and the results obtained from the RadioPlanner are compared with the measurements performed in a real LoRa communication network. According to our analysis, the Longley-Rice and ITU-R propagation models are suitable for urban environment including vegetation path losses and can be adapted according to LoRa modulation parameters.

The elevation or the environment structure may cause diffraction, reflections, attenuation of the propagated signal and the communication can be strongly affected. From the obtained measurements, we determined that a maximum distance of only approximately 500 m may be practically achieved with a LoRa communication that uses SF12. That value is less than the standard one, where the range can be up to 3 km in the urban dense area. Using the designed test setup, LoRa providers can evaluate the performance level prior to installation and with accurate parameterization, one may avoid poor deployments of the wireless networks, by covering the blind spots and optimize the communication links.

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