SmartCity - planning a sensor network based on LoRaWAN technology

João António Cepeda Jaime
Instituto Superior Técnico, Lisbon, Portugal

June 2018

Abstract

New scientific developments made possible to monitorize and control all kinds of objects and services, by connecting them all in between themselves, giving birth to a new paradigm: the Internet of Things. This way has become possible to improve cities efficiency and accuracy on dealing with all kinds of problems. This thesis is based on the projection of a wireless telecommunications system based on LoRaWAN technology, capable of dealing with the sensor network of the project "SmartCity Abrantes". These sensors may or not have a fixed location. Firstly, a study of capacity and coverage has been developed considering only the sensor that don’t change their position and the initial system configuration. For this analysis the real scenario was theoretical simulated. It was noticed that some of these sensors were not covered, which motivated the study of the influence of the introduction of a new gateway on the system. Finally, it was made a study on network coverage for the mobile sensors, considering all the area of Abrantes region, so that it would be possible to understand were these sensors would be able to communicate. It was found that half of this territory was covered.

Keywords: SmartCity, LoRaWAN, Sensor, Coverage, Capacity.

1. Introduction

Aquando da apresentacão do projeto, a presidente da Câmara Municipal de Abrantes, Maria do Céu Albuquerque, definiu-o como um novo paradigma da governança, estando planeado a sua expansão gradual a todo o concelho, integrando todos os sistemas de monitorização dos serviços públicos e disponibilizando ao público em tempo real, incluindo ferramentas que permitem ao cidadão participar na governança do município. Este projeto resulta da parceria da CMA com as empresas IBM e Compta, o Instituto Politécnico de Tomar, entre outros parceiros.

On April 2016, city hall of Abrantes (CHA) announced an investment of approximatly 1 million euros on the so called project SmartCity Abrantes. The objective of it was creating an informatic system that could give to the CHA an optimized capacity of monitoring and managing municipal services. It is planned to cover all the area of Abrantes' county with these kind of optimized services with the intention of estimulating the participation of citizens in city’s governance.

The main objective of this thesis is to plan an wireless telecommunications system based on LoRaWAN technology, capable of dealing with the sensor network currently installed in Abrantes.

2. Background

Internet of Things is a relatively new telecommunications paradigm that lays on the idea of all surrounding objects becoming "smart". This means that these objects will become capable of understand the context around them, work together as a team and take decisions in order to achieve something. It’s expected that these concept make possible to improve substantially life quality of citizens, allowing to develop automation, monitoring and optimization of houses, cities, industries, etc. From the business point of view, it will allow to improve productivity and quality of services provided, in areas such automation, manufacturing, logistics, process management or transportation of people and goods.

Smart objects are not the only components of IoT. Although those communicate in between themselves, there is a network core responsible for processing data and decide actions to take.

Thereby, it’s possible to develop various applications and services. According to the specific requirements of each app, they can be separated in two groups: massive and critical. Massive app’s are those that require big amount of connected devices, that should be cheap, powerless consumers and low traffic generators. The massification of connections in between objects is the main focus. In the case of the critical ones, it’s required a service of high reliability and availability, with low latency. Those are app’s that require really high level of efficiency.

Smart city is the idea of using IoT to support and add quality services to the city and their citizens, resorting on the high efficient public resources, decreasing operational costs and increasing services offered to
people.

For that, there are many telecommunications protocols specially developed and adapted to IoT’s demands, known as Low-Power Wide Area Network (LP-WAN) protocols.

### 2.1. Low-Power Wide Area Networks

Low-Power Wide Area Networks should present the following characteristics: low cost, long range, low energy consumption, scalability and quality of service.

Typically a LPWAN consists in sensors, gateways and a core, just like an Wireless Sensor Network (WSN). In fact, sensors have the capacity to acquire, process and transmit data, while gateways play the role of aggregating all information and resend it to the core, where it will be properly used.

Currently, technologies as LoRaWAN, Sigfox, Ingenu or NB-IoT are the ones closer to meet all the requirements announced.

#### 2.1.1 Cellular vs non-cellular networks

LPWAN’s technologies can be divided in two different groups: the ones based on cellular networks (NB-IoT) and the ones based on non-cellular networks (LoRaWAN, Sigfox and Ingenu). These groups are technically very different, so the kind of app’s they best fit are also different.

To prove that non-cellular technologies are better than cellular ones for the SmartCity Abrantes project, a comparison between them is presented next. It was chosen LoRaWAN and NB-IoT as examples to make this comparison. Figure 1 summarizes this research.

![Figure 1: Comparison between LoRaWAN and NB-IoT](image)

It was concluded that LoRaWAN is a good solution for app’s where cost, battery lifetime and coverage range are the main requirements. NB-IoT is the best option for app’s that require high QoS and low latency.

#### 2.1.2 Comparison of non-cellular technologies

There are several non-cellular technologies with potential to being used on the implementation of a smart city. However, all of them have unique characteristics and so different advantages and disadvantages.

They can also be divided in two different groups according to modulation used: ultra narrow band (UNB) or wideband. Sigfox is an example of UNB technology, whilst LoRaWAN and Ingenu are wideband technologies. Table I presents a comparison in between these three protocols.

Thus, it’s concluded that despite some differences and specificities, all the presented non-cellular technologies are very similar in between them. Actually, all of them meet the requirements needed for an IoT scenario. However, taking in count the freedom and autonomy that LoRaWAN offers to their users by not requiring any subscription to services, seems to be the one that shows lower costs of implementation. As such, it should be the best option to apply on this thesis context.

#### 2.1.3 LoRaWAN

As seen before, LoRaWAN is a telecommunication protocol, optimized to low power and throughput devices, designed to be used on top of physical layer LoRa (Long Range), developed by SemTech. This company is the only manufacturer of devices that use this technology.

**Physical Layer: LoRa**

LoRa uses a modulation technique known as Chirp Spread Spectrum (CSS), where the information is modulated into chirps - sinusoidal signals whose frequency varies linearly in between a maximum and a minimum value of frequency. It’s possible to vary the initial point with an offset, however all the available frequencies are always used. Some of the key characteristics of LoRa will be presented next.

*Spread Factor:* is the parameter that defines how widespread the signal gets and is computed by the following expression:

\[
2^{SF} = \frac{R_c}{R_s}
\]

The number of different symbols available to transmit is equal to SF. The duration of a symbol is given by:

\[
T_s = \frac{1}{R_s} = 2^{SF} \times T_c = \frac{2^{SF}}{LB}
\]

Signals modulados com diferentes *spread factors* so ortogonal entre si, ou seja, possibilitam a partilha de um mesmo canal de frequencia ao mesmo tempo. Em [5], verificou-se que de facto esta separao recorrendo aos SF funciona de forma perfeita, no interferindo na receo.

Signals modulated using different SF are orthogonal in between them, which means that they can share
Table 1: Comparison in between LPWA non-cellular technologies, adapted from [2] and [3].

<table>
<thead>
<tr>
<th></th>
<th>LoRaWAN</th>
<th>Sigfox</th>
<th>Ingenu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governing body / Standards</td>
<td>LoRa Alliance</td>
<td>Sigfox</td>
<td>Ingenu</td>
</tr>
<tr>
<td>Frequency (MHz)</td>
<td>868/915</td>
<td>868/915</td>
<td>2.4</td>
</tr>
<tr>
<td>Physical Layer</td>
<td>CSS</td>
<td>UNB</td>
<td>RPMA</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Downlink - 125, 500 kHz</td>
<td>Uplink - 125, 250, 500 kHz</td>
<td>Base station listening bandwidth: 200 kHz, 100 Hz UL channels, 600 Hz DL channels</td>
</tr>
<tr>
<td>Multiple access</td>
<td>Proprietary Chirp Spread Spectrum (CSS)</td>
<td>Proprietary UNB/FHSS</td>
<td>Random Phase Multiple Access (RPMA)</td>
</tr>
<tr>
<td>Simultaneous active users in UL channel bandwidth</td>
<td>6</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>Peak data rate</td>
<td>0.3 - 50 kbps</td>
<td>100 bps up, 600 bps down</td>
<td>20 kbps</td>
</tr>
<tr>
<td>Maximum range/coverage (link budget)</td>
<td>≈150-157 dB</td>
<td>≈146-162 dB</td>
<td>4km (urban)</td>
</tr>
<tr>
<td>Subscription</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

the same frequency channel at the same time. In fact, this signal separation using SF works perfectly without interferences according to [5].

*Coding Rate:* LoRa also includes a Forward Error Correction that offers protection over interferences. The Code Rate is given by:

$$CR = \frac{4}{(4 + n)}$$

where \(n \in [1, 2, 3, 4]\), which means, \(CR\) may take the following values: 4/5, 4/6, 4/7 or 4/8. The greater the \(CR\) value, greater the tolerance to interferences and transmission time.

*Bandwidth:* increasing the bandwidth it’s possible to get lower transmission duration. The typical values of bandwidth are 125, 250 e 500 kHz.

*Data Rate:* it’s possible to compute data rate by knowing SF, CR and bandwidth of the signal, using the following expression:

$$R_b = SF \times \left(\frac{CR}{2^{SF}}\right)$$

*MAC Layer*

Currently, LoRaWAN is being developed (independently from LoRa) by LoRa Alliance - a consorcium of companies working on research and promotion of this technology. Some of its characteristics are presented next.

*Available bands:* LoRaWAN was created to transmit on non-licenced bands, which may vary depending on region. In Europe, the European Telecommunications Standards Institute (ETSI) defined that it may operate on the following bands:

- EU 863-870MHz ISM Band;
- EU 433MHz ISM Band.

*Architecture:* as described on [6], LoRaWAN presents a star topology that consists of multiple devices communicating with a gateway through a LoRa connection. The gateway is responsible for retransmitting to core network usually through an Ethernet or 3G connection.

*Channel access:* devices willing to communicate, do it using the a similar method to ALOHA: select a random channel to transmit without concerning if it is available ro not and without any synchronism. Then two reception windows are initiated on different moments, so that the device may receive an answer if needed. It’s possible to transmit acknowledged and unacknowledged messages.

In order to prevent the congestion of bands available to communicate, there is a duty cycle limitation. This means that a device has to wait some time after a transmission. If this transmission lasts for \(T_{on\,air}\), then the interruption time \(T_{off}\) is given by:

$$T_{off} = \frac{T_{on\,air}}{Dutycycle} - T_{no\,air}.$$  

*Radio channels available:* based on SemTech SX1272/3 device, it was developed a study on feasibility of those devices on non-licensed bands [7]. Table [2] presents the results, where is possible to observe
the radio channels available on EU 863-870MHz ISM Band, using the three typical values of bandwidth on LoRaWAN.

3. Initial Scenario

This thesis is based on SmartCity Abrantes project, where currently there is a system consisting in various sensors, one gateway LoRaWAN and a core network. At the moment, LoRaWAN protocol is used in some watering sensors to communicate to the gateway, that aggregates all the data that receives and retransmit it to the core network through cellular networks.

The first approach was to verify the possibility of the current system on Abrantes of supporting all communications of every sensor, if all of the transmissions were made based on LoRaWAN technology. For this to happen, the system has to assure that meet the requirements of capacity and coverage.

3.1. Transmitter and receptor characteristics

To make this study as close to reality as possible, it was tried to understand what was the actual hardware present on Abrantes. However that information was missing, so it was considered that sensors and gateway were the ones that SemTech company offers. It was considered that sensors were devices SX1272/3 [8] and gateway was SX1301 [9]. Some of the characteristics of these devices are now presented.

Frequency band and channel

Currently, EU 863-870MHz band is the one used by the system. For every computations made through this work, it was assumed the frequency channel 868.1 MHz.

Data Rate

SemTech made available a calculation tool to compute real values of data rate of their devices [10]. Those values were used in this work.

Sensitivity

Sensitivity value varies with SF and BW. Value considered were the ones provided by SemTech for their devices.

Maximum transmission power

Concerning ANACOM restriction, these were the maximum transmission power values considered:

- Sensor - 14.65 dBm;
- Gateway - 8.15 dBm.

Radiation diagram Antennas used in this project are not isotropic, so they don’t radiate equally through all directions. It’s important to study antennas radiation diagrams, in order to calculate gain value depending on radiation angle.

3.2. Sensors

It was decided to call ”sensor” to all devices responsible for data acquisition, processing and transmission. In SmartCity Abrantes there are three types of sensors: watering, energy and vehicle. Only some watering sensors already communicate through LoRaWAN.

By collaborating with CHA and his partner company, Compta, information about characteristics and circumstances of existing sensors was gathered. Table 3 sums up all information collected.

The first objective was to try to understand if existing LoRaWAN system would be capable of also supporting communications by sensors that currently use 3G technology. Therefore, by interpreting available sensors data, it was possible to understand that sensors using 3G technology could be migrated to LoRaWAN without interfering with system’s performance. On the other side, some information needed for the rest of this study was not provided by CHA and Compta, which motivated to assume some approximations.

The final result of this deliberation is presented on table 4.

3.3. Propagation Models

Regarding some parameters as frequency, transmission distance, transmitter (Tx) and receptor (Rx) antennas height and surrounding environment, it’s possible to understand which propagation model should be used.

3.3.1 ITU-R 526-5 model

The majority of sensors don’t have line of sight with the gateway, due to the presence of obstacles, such as terrain and building. As such, it should be calculated the attenuation that obstacles introduce. Some methods as Bullington, Epsein or Deygout are used to this purpose [11]. Deygout appears to be the one that presents higher consistency between theoretical and practical values [11]. Based on Deygout’s method, ITU-R developed a method that can be used in various different situations, presented on its recommendation P.526-5 [12]. This was the one adopted for this study.

3.3.2 Okumura-Hata model

Besides that, there are theoretical-empirical propagation models that may fit the problem. Okumura-Hata [13] and Walfish-Ikegami [14] are two of the best-known.

Due to the fact of Abrantes city being located in an area of significant slope, where the gateway’s antenna is located on top of a hill, Okumura-Hata’s model seems a good option, since it’s a model based on measurements made in similar circumstances. Taking this into account, Okumura-Hata model was also considered to this study.
Table 2: Radio channels available on EU 863-870MHz ISM Band, adapted from [7].

<table>
<thead>
<tr>
<th>Band</th>
<th>Limit frequencies [MHz]</th>
<th>Number of channels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mn.</td>
<td>Mx.</td>
</tr>
<tr>
<td>g(note7)</td>
<td>865</td>
<td>868</td>
</tr>
<tr>
<td>g1</td>
<td>868</td>
<td>868,6</td>
</tr>
<tr>
<td>g2</td>
<td>868,7</td>
<td>869,2</td>
</tr>
<tr>
<td>g3</td>
<td>869,4</td>
<td>869,65</td>
</tr>
<tr>
<td>g4</td>
<td>869,7</td>
<td>870</td>
</tr>
</tbody>
</table>

Table 3: SmartCity Abrantes’ sensors characteristics.

<table>
<thead>
<tr>
<th>Function</th>
<th>Technology</th>
<th>Message type</th>
<th>Frequency (monthly)</th>
<th>Data traffic (monthly)</th>
<th>Payload</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watering</td>
<td>LoRa</td>
<td>Metering</td>
<td>120</td>
<td>16 280 kB</td>
<td>5 kB</td>
<td>uplink</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming</td>
<td>8</td>
<td></td>
<td>4kB</td>
<td>downlink</td>
</tr>
<tr>
<td></td>
<td>3G</td>
<td>Metering</td>
<td>240</td>
<td>700 MB</td>
<td>410 kB</td>
<td>uplink</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming</td>
<td>8</td>
<td></td>
<td></td>
<td>downlink</td>
</tr>
<tr>
<td>Energy</td>
<td>3G</td>
<td>Medies</td>
<td>240</td>
<td>3 000 MB</td>
<td>0,625 MB</td>
<td>uplink</td>
</tr>
<tr>
<td>Cars</td>
<td>3G</td>
<td>Location</td>
<td>?</td>
<td>270 000 kB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste trucks</td>
<td>3G</td>
<td>Location and collection</td>
<td>?</td>
<td>50 000 kB</td>
<td></td>
<td>uplink</td>
</tr>
</tbody>
</table>

3.3.3 Building entry loss

Some sensors are located inside buildings and may suffer a higher signal attenuation. Based on [15], it was decided to add 10 dB attenuation due to this phenomenon.

3.3.4 Slow fading

Slow fading effects will be considered. The received signal power varies due to variations happening over signal’s path. This phenomenon should not interfere with signals correct reception. Therefore, it should be taken a certain reception power margin to prevent possible problems.

Slow fading is described by a log-normal distribution [11]. Thereby, if values used will be on a logarithmic scale with a mean value equals to the signal’s attenuation, slow fading will be described by a normal distribution with mean equal to zero. It was assumed a standard deviation of 10 dB according to [16].

Since sensors communicate on a low periodicity and a big number of transmitted messages may be redundant, it was assumed that the minimum availability that should be guaranteed would be 75% of time.

4. Study of initial system

Initial system available on Abrantes when this thesis began to be developed consisted in one gateway located on the transmission tower of Abrantes city. Antenna’s gateway is at 18 meters from ground. Devices considered were the ones presented previously.

4.1. Duty cycle

Vehicular sensors were the ones that transmitted more data monthly, so were the ones with a bigger risk of violating duty cycle restrictions. By proving these sensors were not compromising these limits, everyother sensor should be ok.

Transmission duration of vehicular sensors was computed for every data rate values available on LoRaWAN. Results are presented on table 5. Duty cycle restrictions are fulfilled for DR5 or higher.

4.2. Capacity

System’s capacity was studied in order to understand if it was prepared to deal with all sensors communicating using LoRaWAN. Firstly, channel load was computed considering every data rate available. Channel load consists on the percentage of time that a channel has to be busy so that all data is transmitted. Channel load depends on data rate and number of system’s available channels.

Theoretical study of LoRaWAN channel behaviour, varying channel load and observing throughput, was done in [11]. Conclusion was that LoRaWAN is described by a curve very similar to pure ALOHA, as can be notice in figure 2. It’s simplicity may be an advantage in terms of energy consumption and processing time, but it leads to a high collision rate and low throughput.

Taking channel load values and based on figure 2, throughput and collision rate values were computed. Based on the results, current SmartCity Abrantes’ system was able to assure duty cycle restrictions and capacity to support all transmissions, with collision rate equal or lower than 5%, by using DR6 or all
Table 4: SmartCity Abrantes’s sensors final characterisation.

<table>
<thead>
<tr>
<th>Function</th>
<th>Technology</th>
<th>Message type</th>
<th>Frequency (monthly)</th>
<th>Data traffic (monthly)</th>
<th>Payload</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watering</td>
<td>LoRa</td>
<td>Metering</td>
<td>120</td>
<td>600 kB</td>
<td>110</td>
<td>5 kB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming</td>
<td>8</td>
<td>32,4 kB</td>
<td>45</td>
<td>4 kB</td>
</tr>
<tr>
<td></td>
<td>3G</td>
<td>Metering</td>
<td>240</td>
<td>1 200 kB</td>
<td>5</td>
<td>uplink</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming</td>
<td>8</td>
<td>32,4 kB</td>
<td>4</td>
<td>downlink</td>
</tr>
<tr>
<td>Energy</td>
<td>3G</td>
<td>Metering</td>
<td>240</td>
<td>1 200 kB</td>
<td>5</td>
<td>uplink</td>
</tr>
<tr>
<td>Waste trucks</td>
<td>3G</td>
<td>Location and collection</td>
<td>10 000 kB</td>
<td>27</td>
<td>-</td>
<td>uplink</td>
</tr>
</tbody>
</table>

Table 5: Duty cycle restrictions verification for vehicle sensors (worst case).

<table>
<thead>
<tr>
<th>DR</th>
<th>Transmission duration (days)</th>
<th>Duty Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5,06</td>
<td>16,86%</td>
</tr>
<tr>
<td>1</td>
<td>2,76</td>
<td>9,19%</td>
</tr>
<tr>
<td>2</td>
<td>1,52</td>
<td>5,06%</td>
</tr>
<tr>
<td>3</td>
<td>0,84</td>
<td>2,81%</td>
</tr>
<tr>
<td>4</td>
<td>0,47</td>
<td>1,58%</td>
</tr>
<tr>
<td>5</td>
<td>0,27</td>
<td>0,90%</td>
</tr>
<tr>
<td>6</td>
<td>0,13</td>
<td>0,45%</td>
</tr>
<tr>
<td>Todos</td>
<td>0,12</td>
<td>0,41%</td>
</tr>
</tbody>
</table>

Figure 2: Throughput and collision rate depending on channel load, adapted from [6].

DR at the same time, considering 8 channels in both cases. Due to the fact that DR6 requires only one signal in each carrier, contrary to all DR at the same time, DR6’s spreading factor (SF=7) and bandwidth (BW=250 kHz) were chosen for the rest of this study.

4.3. Sensors characteristics

Some sensors were chosen to represent the various situations happening on the scenario. In order to choose wisely which ones should be analysed, some factor as terrain, buildings and transmission distance were taken into account.

Therefore, sensors located behind a terrain elevation without line of sight were chosen. Sensors inside or behind buildings were considered. Most distant sensors were also studied.

On the other side, there were sensors in similar circumstances. In that case only one was chosen to avoid redundancy. It was the case of co-located sensors were not studied and also sensors at similar transmission distance or obstructed in suchlike conditions.

Firstly was decided to study only sensors in fixed locations, which enable a point-to-point analysis. Mobile sensors will be studied ahead.

4.4. Results

ITU-R 526-6 and Okumura-Hata models were applied to the chosen sensors. Different values of signal attenuation were achieved. The selection criterion was the worst case, since that would lead to a more feasible study.

It was concluded that there is a coverage problem, since sensors number 8, 20, 29a, 29f, 29g, 29h, 29i and 31a don’t meet the minimum require of availability percentage of 75%. Therefore SmartCity Abrantes original system is not sufficient to support all the communication.

Taking into account the fact that the existing gateway is already located on the highest place of the area, the solution may not be to change its location. The addition of a new gateway may solve the actual problem and so it was studied.

5. Study of the system with 2 gateways

LoRaWAN gateways listen to every sensors under their range of coverage. It may happen that different gateways receive the same transmission, however the
system’s core network is capable of deciding which one of them will transmit an answer if needed.

The majority of sensors with coverage problems were located behind Abrantes’ Castle hill or around it.

In fact, there are two great terrain elevation in the city: one where is located the transmission tower and other where is located the city’s castle. It’s always a good principle to consider the highest spots of the area as possible antenna locations. On this case it’s evident that castle’s hill should be chosen as the location for the new gateway, since all the problematic sensors should have line of sight with it.

While producing this thesis, the system on Abrantes was improved by CHA which consisted in introducing a new gateway LoRaWAN exactly in the same location predicted by this study. Therefore, it was decided to use this new gateway parameters such as antenna height for the rest of this study.

This gateway’s antenna is installed exactly on Abrantes’ Castle, at a height of 10 meters above ground with a terrain elevation of 196 meters.

5.1. Results

Okumura-Hata and ITU-R 526-5 models were also applied in this case and again different signal attenuation values were obtained. Selection criterion was to consider the worst case.

After the introduction of the new gateway all the sensors had coverage, since it’s percentage of time available was always greater than 75%. This way it was guaranteed the system would be operating without problems.

6. Study of coverage of mobile sensors

Mobile sensors considered correspond to the vehicular ones, located at 15 meters height above ground. This vehicles were free to ride through all Abrantes area and communicate everytime its trajectory would suffer any change.

Since sensors may communicate in uncountable different locations, the coverage study of them was done considering divind the territory into small areas, as will be described next.

Transmited signal power is influenced by the presence of obstacles (mainly due to terrain and buildings). CHA provided digital level contours of all area, which made possible to study terrain’s influence. However, there is no similar information about buildings, so it’s effect on signal’s attenuation was despised. Nevertheless, this is a realistic approximation, since the majority of locations considered for mobile sensors are outside city center and gateways are located on some of the highest points of the region.

Since ITU-R 526-5 model contemplates the effect of terrain obstacles, it was decided to use it rather than Okumura-Hata model.

6.1. Abordagem

Using ArcGIS PRO [17] software it was possible to create a grill over the region map with squares of approximatly 200 meters of side. Every square has a mean value of terrain elevation based on the level contours.

From here were extracted data to a table, where each entry is composed of: square ID, latitude, longitude and terrain quota. Values of latitude and longitude are the ones of the central point of the square, marked as orange circles on figure 3.

![Figure 3: Grill over Abrantes map.](image)

The idea was to fix the square where gateway is located and compute the signal’s receiving power for every other squares of the map. Firstly, a terrain profile was created between gateway and every other square, so that computing attenuation due to obstacle (using ITU-R 526-5 model) was possible. From there is also possible to compute radiation angles and antennas’ gains. Summing up transmission power to antennas’ gains and subtracting attenuation due to obstacle and free path loss, it’s possible to compute the signal’s receiving power.

To execute this automatically, a MATLAB script was developed.

6.2. Results

Process described before was executed for every square twice: firstly, considering only one gateway located on transmissions tower; secondly, considering only one gateway located on Abrantes’ Castle.

From these results a colour map was conceived, so that analysis could be easier. Analysing it, it was discovered that generally areas with coverage problems were the ones where terrain was more rough, as expected.

Using ArcGis Pro functionalities, it was discovered that XX % of total area of Abrantes region was covered.

Crossing this map with population distribution available in [18], it was realised that the great majority of the population lived in covered regions.

7. Conclusions

The main objective of this thesis is to plan an wireless telecommunications system based on LoRaWAN technology, capable of dealing with the sensor network currently installed in Abrantes.
Firstly, SmartCity Abrantes’ system was analysed. This way hardware, communication protocols and data transmitted became known.

Channel occupation, collision rate and throughput were computed and system’s capacity was confirmed if LoRaWAN’s DR6 mode was selected, using 8 frequency channels. A collision rate lower than 5% was assured. After a coverage analysis to location-fixe sensors, by applying two different propagation models, it was verified that some sensors would have coverage problems, since it’s percentage of time availability would be lower than 75% - value assumed as threshold.

Then, the possibility of introducing a new gateway on the system in order to improve it’s coverage was studied. It was concluded that problematic sensors would no longer have coverage problems.

Mobile sensors coverage was studied by dividing Abrantes county’s area in squares of approximately 200 meters of side, using an original MATLAB script. Surrounding Abrantes city (in about 5 km) there is almost full coverage. In the rest of the area, coverage depends a lot on terrain’s slope. Areas where terrain was rough presented problems, while areas where terrain was plan or plateaus, with similar terrain elevation as the gateways, appeared to have good coverage, despite sometimes distance from gateway was about 10 km.

This thesis proves that theoretical engineering studies of this type before practical implementation may traduce in several gains. In fact, if the conclusions from this work were known before it would be possible to preview the absolute need of two gateways to assure coverage in Abrantes city. This way, it would be possible to have lower costs in system’s implementation due to possible material reuse, greater bargaining power with construction company and providers.

8. Acknowledgements
The author would like to thank Prof. António Rodrigues, Prof. Paula Queluz and Ivo Sousa, from IST; Eng. Paulo Fernandes, from Compta and Paula Grij from Cmara Municipal de Abrantes, for all the help provided.

References


