Mobile Coverage Improvement in Madeira Island Communications Network

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Abstract- Wireless communications, especially mobile ones are now indispensable, not only because they improve the daily lives of users who are not "stuck" to cabling service, but also because of the reduction in costs for the implementation of fixed networks by communications operators, especially in areas with difficult access. This project is essensially based on the 4G network managed by MEO and required the identification of the problematic areas in Madeira Islands in terms of coverage. Firstly the base station to which the mobile terminal is connected and the nearest ones are located, then an analysis of the area is carried out and, through simulations, alternative solutions are provided that effectively improve coverage in that location. A cell is projected in a tourist location where there is no coverage.

Keywords- *Wireless Communications, Mobile, Base Station, Cell, Coverage.*

I. INTRODUCTION

The history of radio communications began with James Clerk Maxwell, with his discoveries in the area of electromagnetism as a starting point and foundation, as well as other discoveries of extreme importance, among which those of Michael Faraday, Alexander Graham Bell, can be highlighted, among others. [1]

This type of communication has the great advantage of mobility. This aspect clearly has the first position regarding the usability of communications. Since mobile communications guarantee a coverage area, guaranteeing a minimum availability service, it is possible for its users to communicate between remote points on the planet. This point has as its main highlight the fact that it allows communication between two points to be established in an imperceptible time for users, without the latter having to worry about their location. [1]

The first generation of mobile systems (1G) appeared then in 1980, allowing only voice communication, through an analog system. At this time, because they are analogue transmissions, the systems were very limited in quality, besides this, there were many interferences and very low security, wiretapping being a relatively simple task. [2] [3]

In the second generation, the main objective was the evolution of the systems, which is characterized by the transmission of digital signals, unlike the first generation. 2G emerged in the early 90s and in addition to digital transmissions, it brought the possibility of sending SMS (Short Message Service) and MMS (Multimedia Message Service). The technology used is GSM (Global System for Mobile Communications), which is still used today. Multiple access is guaranteed through the combination of FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access). At that time, mobile phones already had much smaller dimensions and used an identification card (Subscriber Identity Module), which is still used today in order to identify the user and his tariff characteristics. [2] [3]

Between the second and the third generation, it is important to emphasize the transition to the use of package technology such as GPRS (General Packet Radio Service), thus making internet access much faster and more efficient. [2] [3]

The third generation emerged in the early 2000s as a solution to the limitations of the second generation networks at the time. With the increase of subscribers, there was a need to increase their capacity, improving the quality of services, such as voice transmission and speed of access to the Internet. [3]

With the evolution of GSM, UMTS (Universal Mobile Telecommunication System) arises, having as its main objective the definition of a universal standard that guarantees the quality of the service with a large quantity, in face of a large number of users through high transmission rates, being symmetrical and asymmetrical, allow greater spectral efficiency through the use of CDMA (Code Division Multiple Access) as a multiple access system, transmission in circuit mode and in packet and multimedia mode. [4]

The fourth generation emerged in 2011 with practically the same objectives as the previous developed, adding the novelty of pure use of IP systems. Also called LTE (Long Term Evolution), it is the technology currently used. In this generation, the limitations are relatively small since communications have high transmission rates, security systems that guarantee the integrity and privacy of communications, and a quality of service that corresponds to most of the service time. [5] [6]

The major limitation of the fourth generation and of nowadays is the autonomy, since for all these evolved and high-potential features to work, they require energy, and with the evolution of mobile communication systems, users intend to have an increasingly mobile device, that is, relatively small, light and thin, which further complicates the energy issue since the space for the battery is limited, which results in a limited autonomy capacity as well. [6]

II. PROPAGATION MODELS

Propagation models are an extremely relevant tool, used to perform power estimates on the receiver or mobile terminal. Built on the basis of numerous measurements made in different types of environments and under different conditions or resulting from approximations to reality, with a strong dependence on the resolution of the geographic database and which do not have all factors, but with the advantage of allowing changes in parameters easily, are the characteristics that differentiate the empirical and theoretical propagation models, respectively. [7]

Most propagation models are based on both types and no model is suitable for all types of environments and scenarios and therefore always have an associated error. The error of approximation of the propagation models is inevitable, not least because the environments are constantly changing, either by the passage of cars, growth and movement of vegetation resulting from the wind, or even by the movement of the terminal, these factors contributing to the existence various and different paths of reflection. [7]

The power that arrives at the mobile terminal is defined by the following expression.

$$P_{r[dBm]} = P_{t[dBm]} + G_{t[dB]} - L_{p[dB]} + G_{r[dB]} - L_{u[dB]} \quad (1)$$

The received power then corresponds to the sum of the transmitted power sum with the transmission gain and the reception gain subtracted from the attenuation, which, depending on the model used, has different expressions and may also have an addition of complementary attenuations resulting from factors existing in the environment Propagation. The parameter L_u corresponds to the losses per user, which in the case of voice signal transmission takes between 3 and 10 dB and in the case of data transmission, a value between 0 and 3 dB. [8]

A. *Free Space Propagation*

As its name identifies it, free space propagation is free from any kind of obstacles and is considered a uniform, homogeneous and isotropic medium. This type of propagation is characteristic of some mobile communication environments, and is normally used when reflection on the ground is irrelevant and when there is a line of sight between the emitter and the receiver. [7]

In equation 2 we have the expression that allows to obtain the power in the receiver in an environment characterized by free space propagation.

$$P_{r[dBW]} = -32{,}44 + P_{t[dbW]} + G_{t[dBi]} + G_{r[dBi]} - 20\log(d_{[km]}) - 20\log(f_{[MHz]}) \quad (2)$$

This model depends on the antenna parameters, the transmitted power, but is essentially dependent on the distance and frequency. [7]

It appears that technologies that use higher frequencies, as is the case with 3G, 4G and the future 5G, are more sensitive in radio propagation aspects, thus preventing great distances between the transmitter and receiver antennas. [6]

B. *Flat Earth Propagation*

This model is used in environments where the transmission distance is not very high, free of obstacles and the floor has roughly flat characteristics. Taking into account the interference resulting from the interference of the direct ray with the reflected ray, this model is ideal for situations in which a large part of the floor consists of calm water (lake, river or even sea) or a very little rough surface. [7]

The general expression for calculating the power at the receiver is given by the equation nº3.

$$P_{[dBW]} = -120 + P_{t[dBW]} + G_{t[dBi]} + G_{r[dBi]} + 20\log(h_{t[m]}) + 20\log(h_{r[m]}) - 40\log(d_{[km]}) \quad (3)$$

Due to the strong presence of the reflection phenomenon, this model presents the variations represented in Figure 1.

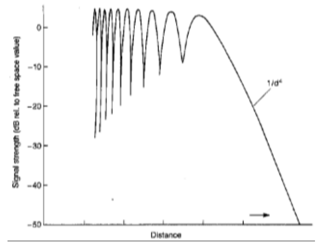

Figure 1 - Function of the electric field relative to free space propagation as a function of distance. [7]

The fluctuations in the value of the electric field as a result of the distance are derived from the sum of the direct signal and the reflected one, with the maximum consequent of the constructive sum and the minimum of the destructive contribution of the signals when opposed to the phase. [7]

C. *Cost 231 – Okumura-Hata*

The Okumura-Hata model was created based on measurements and is designed for an urban environment with flat terrain, with a frequency range between [150, 2000] MHz. Despite the existence of these requirements in the standard model, the addition of correction factors lends its use to many more scenarios in different environments. [6]

The equation nº4 represents the mathematical expression that allows the calculation of the average path attenuation through the model.

$$L_{p[dB]} = 69{,}55 + 26{,}16\log(f_{[MHz]}) - 13.82\log(h_{be[m]}) + [44{,}9 - 6{,}55\log(h_{be[m]})]\log(d_{[km]}) - H_{mu[dB]} - \sum CF \quad (4)$$

The height of the BS antenna is represented by h_{be}, CF the correction factor and H_{mu} the correction factor for the effective height of the mobile antenna, the latter being dependent on the coverage area.

D. *Walfisch – Bertoni*

Developed in 1988 and on a theoretical basis, the Walfisch-Bertoni model was designed to determine the attenuation and diffraction characteristics of the top of buildings in urban environments. [7]

By default, it is considered a regular urban structure, meaning that all streets and all buildings have the same height, with propagation perpendicular to the street, as shown in Figure 2.

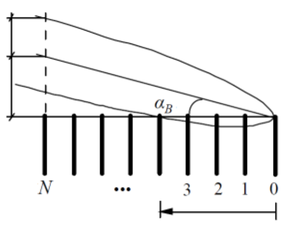

Figure 2 - Representation of the scenario for using the Walfisch-Bertoni model. [7]

The general expression of losses for this model is found in the equation nº5.

$$L_{p[dB]} = L_{0[dB]} + L_{rt[dB]} + L_{rm[dB]} \quad (5)$$

The factor L_0 represents the propagation in free space from the antenna to the interruption of the Fresnel ellipsoid by the roofs of the buildings, with the losses of this interruption being accounted for by the factor L_{rt}. Finally, the L_{rm} factor is responsible for losses due to diffraction at the tops of buildings. With the exception of attenuation in free space, these factors are strongly dependent on the angle of the Fresnel ellipsoid, the wavelength, the width of the street where the mobile is located in the case of L_{rt} and dependent on the height of the buildings, height of the mobile, angle from the mobile terminal with the top of the building and distance from the top of the building to the mobile in the case of L_{rm}. The expressions for calculating these two factors are represented in the equations 6 and 7, respectively. [7]

$$L_{rt[dB]} = -20\log(2{,}35\, g^{0{,}9}) \quad (6)$$

$$L_{rm[dB]} = -20\log\left[\frac{1}{\sqrt{\pi k \rho}}\left(\frac{1}{\psi} - \frac{1}{2\pi - \psi}\right)\right] \quad (7)$$

E. Cost 231 - Walfisch-Ikegami

The Walfisch-Ikegami model is designed for urban environments with the characteristics of the previous model (regular structures) by default and aims to account for diffraction losses in buildings, as well as reflections inside the street where the mobile is located, being therefore, the congregation of the Ikegami model with the Walfisch-Bertoni model. [7]

The propagation scenario suitable for the use of the default model is represented in the Figure 3.

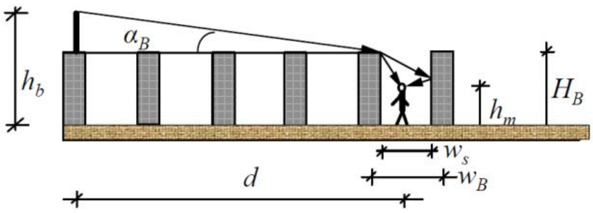

Figure 3 - Representation of the propagation scenario for using the Walfisch-Ikegami model. [7]

If the propagation is with a line of sight between the emitter and the receiver and with a distance greater than twenty meters, the equation Number 8 is used.

$$L_{p[dB]} = 42{,}6 + 26\log\left(d_{[km]}\right) + 20\log(f_{[MHz]}) \quad (8)$$

If the transmission is carried out in an environment where there is no line of sight, the path attenuation has as general expressions equations nº 9 and 10.

$$L_{p[dB]} = \begin{cases} L_{0[dB]} + L_{rt[dB]} + L_{rm[dB]} & if \quad L_{rt} + L_{rm} > 0 \quad (9) \\ L_{0[dB]} & if \quad L_{rt} + L_{rm} < 0 \quad (10) \end{cases}$$

The terms L_{rm} and L_{rt} correspond to the losses due to diffraction at the top of the buildings and the losses as a result of reflections inside the street(s), respectively.

As for the requirements for using the model, the frequency used should be between 800 and 2000 MHz, the distance between 20 meters and 5 kilometers, the antenna height between 4 and 50 meters and the mobile terminal between 1 and 3 meters. [7]

Use outside the required ranges does not fail to make sense, however, it is necessary to have the notion that the standard deviation of the result is greater, and in some cases can reach 7 dB, which makes the introduction of the power value in the BS a more complex, and unpredictable process. [6]

F. Complementary Attenuation Factors

Depending on the propagation medium, it is sometimes necessary to consider complementary attenuation factors, the existence of obstacles in a very favorable position for the occurrence of a considerably high attenuation, such as mountains or a building obstructing the Fresnel ellipsoid. We must also take into account the existence of vegetation, not only for its physical characteristics (they block the signal like any other obstacle), as well as for the chemical characteristics (they can be modeled as dielectrics). [7]

The Knife-Edge model is used when, during and between the transmission, obstacles with dimensions much larger than the wavelength are encountered, which are approached by an opaque semi-infinite screen (razor's edge), aligned with the edge of building diffraction. [9]

The simplifications for this model may seem unrealistic and somewhat exaggerated, however, it is a fact that the distant fields near the geometric shadows are little affected by the curvature of the obstacles. [6]

Equation nº11 allows to calculate the attenuation introduced by the obstacle using the Knife-Edge model.

$$L_{ke[dB]} = 6{,}4 + 20\log(\upsilon + \sqrt{\upsilon^2 + 1}) \qquad if \;\; \upsilon > -0{,}8 \quad (11)$$

The parameter υ is related to the height of the obstacle, the communication distance, the distance from the transmitter to the obstacle, the distance from the obstacle to the receiver and, finally, the operating frequency. The expression for the calculation of the parameter υ is represented in equation nº12.

$$\upsilon = h\sqrt{\frac{2d}{\lambda d_t d_r}} \quad (12)$$

When calculating this parameter, if the value obtained is less than or equal to -0.8, it is considered that there is no attenuation imposed by the obstacle, since it has a non-significant value and can therefore be excluded from the calculations. [10]

Although this model is suitable for the presence of obstacles, it is not correct to use it in urban areas, with a high density of buildings, since the mobile is in most cases in areas close to the obstacles, therefore not respecting the Fresnel region's limitations. [10]

Vegetation, commonly present in rural environments, is another mitigation factor that is also accounted for, as it has some weight in reducing signal strength, not only for its dielectric properties but also, and mainly for obstructing transmission. [7]

The equations that allow the calculation of losses due to vegetation are presented below.

$$L_{v[dB]} = \begin{cases} 0{,}063\, f_{[MHz]}^{0{,}284} d_{v[m]} & if \;\; 0 \le d_{v[m]} \le 14 \quad (13) \\ 0{,}187\, f_{[MHz]}^{0{,}284}\, d_{v[m]}^{0{,}588} & if \;\; 14 \le d_{v[m]} \le 400 \quad (14) \end{cases}$$

The term d_v corresponds to the effective distance, that is, the distance from which the first tree interrupts the Fresnel ellipsoid to the mobile terminal, as shown in the Figure 4.

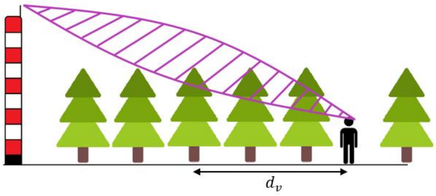

Figure 4 - Representation of propagation with vegetation.

Through the analysis of the equations and the figure, it appears that with the increase in frequency the losses are greater, which would be expected, since, the shorter the wavelength, the narrower and more direct is the Fresnel ellipsoid, therefore a greater percentage of the ellipsoid is interrupted.

G. *Indoor Coverage*

The widespread use of mobile phones led to the need to investigate the propagation in indoor environments as well as to account for the attenuation introduced by the walls in radiation coming from outside, namely from base stations. The propagation models studied until then, do not account for this attenuation. There are two ways of accounting for losses in indoor coverage - semi-deterministic models or by statistical models. [6]

The semi-deterministic models take into consideration the characteristics of the building materials, number of crossed walls and various other paramenters. [7]

In the case of statistical models, the additional attenuation is taken as a function of the percentage of indoor places to be covered, while considering the general characteristics of a building. [7]

When we are dealing with a case of propagation in an indoor environment, the following equation is considered.

$$L_{pTotal[dB]} = L_{poutd[dB]} + L_{pind[dB]} \quad (15)$$

It appears that when accounting for total attenuation, with the mobile terminal in an indoor environment, the two types of attenuation are accounted for. [7]

Figure 3 shows the attenuation occurring in both types of environment in greater detail.

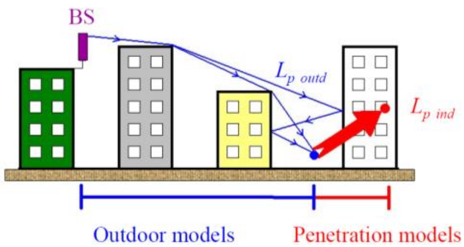

Figure 5 - Representation of the spread from the BS to the interior of the building. [7]

The transmitted signal then suffers several types of attenuation, essentially the reflection on the outside, and refraction when passing from the outside environment to the inside, through the walls of the buildings. [7]

A statistical model that accounts for the attenuation introduced in the penetration of building walls was developed based on measurements made in Lisbon, with the values shown in the table below. This model follows a Log-Normal distribution. [7]

Table 1 shows the average attenuation value and respective standard deviation introduced by each of the bands used in mobile communications.

Table 1 - Attenuation introduced by buildings per band according to the Lisbon model.

Band [Mhz]	Averaged Value [dB]	Standard Deviation [dB]
800	2,6	9,2
900	3,7	9,9
1800	10,2	13,8
2100	11,6	14,7
2600	13,6	15,9

The values presented above cannot be taken for granted for each and every case, because it is only an average, based on several measurements made. The attenuation value introduced is always essentially dependent on the width of the wall and the construction material. [6]

III. SIMULATION AND ANALYSIS

This chapter presents the mobile power measurements corresponding to a real mobile coverage situation for current network in various locations and scenarios on the island of Madeira, presenting a coverage improvement solution based on software simulations and calculations using the equations described in the propagation models section.

Table 1 shows the reference values for a qualitative analysis of the quality of the levels of radioelectric coverage in GSM, UMTS and LTE.

Table 2 - Levels of radio coverage in GSM, UMTS and LTE. *[11]*

Coverage	GSM [dBm]	UMTS [dBm]	LTE [dBm]
Good	RxLev ≥ -85	CPICH RSCP ≥ -95	RSRP ≥-105
Acceptable	-95 ≤ RxLev < -85	-105 ≤ CPICH RSCP < -95	-115 ≤ RSRP < -105
Bad	-110 ≤ RxLev < -95	-115 ≤ CPICH RSCP < -105	-125 ≤ RSRP < -115
Nonexistent	RxLev < -110	CPICH RSCP < -115	RSRP < -125

For the study carried out, the quality reference values for the LTE presented in the table will be taken.

A. *Measurement and Simulation Tools*

To carry out the simulations, the well-known engineering software, Matlab, was used. The Longley-Rice model provided in the software was used, however, as this is a general model of telecommunications simulation, the characteristic parameters of an antenna used in mobile networks were added to the program, in order to approximate as much as possible the simulated results, to reality.

Propagation models for mobile communications were also used, such as the Okumura-Hata model or the Walfisch-Bertoni model.

This work used two different simulation methods in an effort to achieve a higher critical analysis, with a greater amount of data, facilitating the decision-making process in the creation or alteration of the characteristics of the access networks in order to improve them from the point of view, radio propagation and coverage.

B. *Case Study - Estrada dos Esmeraldos*

On the Estrada dos Esmeraldos in Ponta do Sol there is a problem with coverage in all technologies, which hinders not only data transmission but also voice calls or SMS. Despite the numerous complaints from locals, there has been no improvement, and the operator MEO responded by correspondence that it would be impossible to improve coverage in the location in question.

The base station to which the mobile terminals connect in the 4G network is located in the municipality of Ribeira Brava, where, due to the topographic conditions represented in Figure 6, the difficulty of propagating electromagnetic waves to the study area is intelligible.

Figure 6 - Identification of the study area and topographic conditions.

The tower in which the antennas are inserted has a height of approximately 20 meters and is located in the middle of the Serra d'Água valley, with the adjacent mountains approximately 500 meters high. In addition to the neighboring mountain, there are three more mountains with relatively high heights that obviously disturb the coverage, introducing attenuation.

Another issue that further complicates the coverage guarantee is the fact that this section is right next to the mountain, which is practically a shadowed area.

During the measurements, it was noticed that although in 4G technology the mobile terminal connects to the base station of the Fajã site, Ribeira Brava, in the 2G technology it connects to the Tabúa site, however, this fact does not mean that 2G coverage is much better than 4G. In fact, 2G in this area is also quite problematic, because the locals, being in an indoor environment, can only make voice calls or send SMS's by the windows of their houses, since the attenuation introduced by the glass is much less than that of the walls.

Figure 7 shows the illustration of the actual connection of the mobile terminals present in the study area.

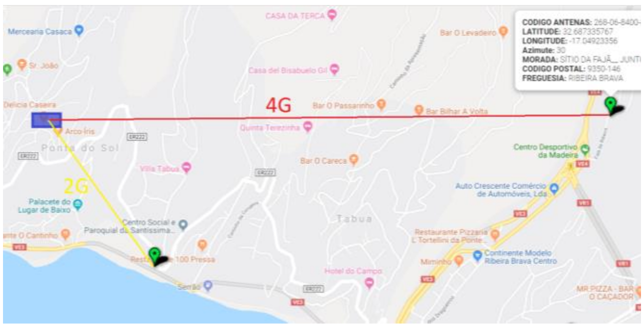

Figure 7 - Illustration of the connection of the mobile terminal to 4G and 2G technology.

With this analysis, it turns out that the big problem in this zone is that it is in a shadowed area, otherwise the 2G coverage would be good, which is not true.

Figure 8 shows the terrain profile between the base station (LTE) and the mobile terminal.

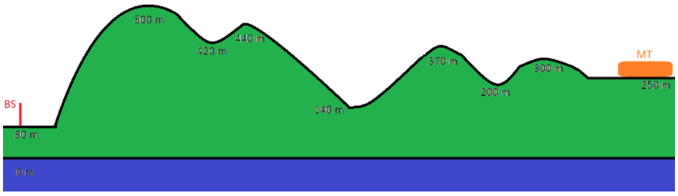

Figure 8 - Representation of the terrain profile with elevations.

When looking at the image the ability to guarantee coverage in the area where the mobile terminal is located is certainly a challenge given the topography.

Next, the measurements and simulations performed in both outdoor and indoor environments are presented.

Power measurement was performed on the mobile phone in the center of the Estrada dos Esmeraldos path and the received signal was -115 dBm as shown in Figure 9.

Figure 9 - Measurement outdoors on Estrada dos Esmeraldos.

For an outdoor environment, the signal is really too low, falling into the "acceptable" category, although at the border with the "bad" category. The truth is that, from the user's point of view, the connection is unstable and very little especially effective in sending data with relatively high badwidth requirements, such as videos or high definition images.

In the previous image it is also seen that the mobile terminal receives signal from neighboring cells, values that even approach the received signal, however, the RSRQ value indicates the impossibility of the problem being interference with neighboring cells, for this to be the case it would have to be higher.

In order to try to understand the problem and try to improve it, a simulation was performed in the matlab, paired with the calculations through the propagation models for mobile communications in order to analize the results obtained and to investigate which on better solves the problem in question.

Before the simulation, and despite the refusal to supply any type of data by the operator MEO, a personal visit to where the tower is located led to the conclusion that it is approximately 20 meters.

The set of possible physical data to be observed as well as the data prediction according to the simulated results are shown in Table 3.

Table 3 - Technical parameters considered in the simulations for transmission in the 800 MHz band.

Technical Parameters	
Frequency	800 MHz
Tower Height	20 m
Emission Power	60 W / 40 W

Bandwidth	20 MHz
Mobile Terminal Gain	2 dBi
Mobile Terminal Noise Figure	7 dB
Mobile Terminal Height	1,8 m
Mobile Terminal Noise Power	-93,98 dB
Receiver Sensitivity	-129,34 dB

The table shows that for the emission power parameter there are two power values. The placement of the two values comes from the results obtained in the simulation using the Longley-Rice model and from the simulation using the propagation models for mobile communications, with these values being a mere forecast, making it impossible to know their value for sure.

Using the Longley-Rice model, the following coverage map was obtained, represented in Figure 10.

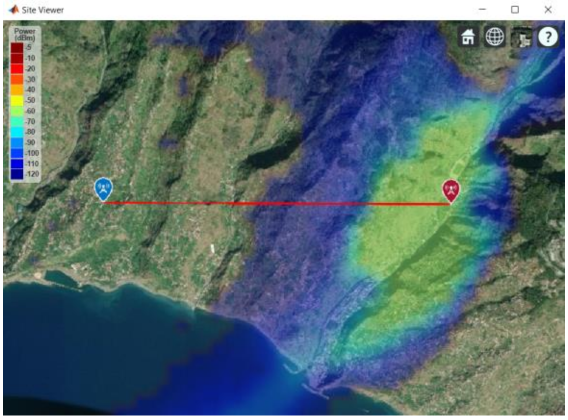

Figure 10 - Simulation of the power coverage map.

It was found that through this simulation, even using the best angle, that is, the angle at which the highest level of reception power was reached, the coverage of the study area is practically null. Through this analysis, it can be checked that the propagation over the mountains is practically impossible, in a process that would obviously be justified by diffractive processes.

The value obtained at reception was -122.87 dBm, which, despite not deviating much from the actual measured value, owes much to the power value considered in the emission, always having the uncertainty of it and the low probability of using the value maximum power. The value falls under the category of "bad coverage", corresponding to reports by residents of the area.

Regarding the simulation by the models of propagation of mobile communications, it was decided to use the Okumura-Hata model, with the necessary corrections. It started by making an estimate of the effective height of the ground Δh for later use in the model equations, having defined the value of 328 meters. This value was obtained considering 80% of the difference between maximum and minimum height of the mountains. In addition to this parameter, only a power of 40 W was considered, corresponding to approximately 16,02 dB.

With all the necessary parameters obtained, the attenuation was calculated using equation number 4.

$$L_p = 163{,}28\ dB$$

At this moment, we have all the necessary terms for the calculation of the power received on the mobile terminal, having been calculated through the expression number 1.

$$P_r = 16{,}02 - 163{,}28 + 5 + 2 - 3 = -113{,}26\ dBm$$

In order to analyze and criticize the results obtained, the values of the measurement and the simulations performed were grouped, in Table 4.

Table 4 - Presentation of the received power values measured and in the simulations.

	Measurement	**Propagation Model**	**Matlab Simulation**
$P_{r[dBm]}$	-115	-113,26	-122,87

It should be noted that the value obtained in the simulation by the Okumura-Hata model is closer to the real value, however, for a value greater than -115 dbm, according to ANACOM, "acceptable" coverage is already considered, which does not correspond to reality. From this point of view, the matlab simulation, based on the Longley-Rice model, although more pessimistic, seems to be much more realistic.

In addition to the coverage problems existing in the outdoor environment, a data survey was also carried out for the indoor environment, not least because it is in this environment that residents usually base most of their complaints.

It is a fact that the walls introduce considerable attenuation due to their thickness consisting almost entirely of cement, they are basically obstacles. A factor that further complicates the situation is the case of the mobile terminal being in the center of the property, because the probability of radiation having more walls (obstacles) is higher the greater the property, or the more floors it has.

Figure 11 shows the measurement made inside a 3-storey house, performed exactly in the center of the house.

Figure 11 - Measurement inside a house on Estrada dos Esmeraldos.

Compared to the measurement performed outdoors, it presents, as expected, a lower received power value, specifically -11 dBm. The value obtained then falls under the category of "Nonexistent" despite being very close to the border value with the category "Bad".

Really, inside the house it is very complicated to receive or send data on the 4G network, forcing users to position themselves close to the windows in order to have less attenuation, since the attenuation caused by the glass is lower than that of the walls, which, despite many times improving the signal quality, does not always solve the problem, mainly due to the inconvenience.

According to the propagation models studied, the difference in the presence of the mobile terminal in the interior translates into the addition of a complementary attenuation, in this case, since we are in the 800 MHz band, the increase would be 2,6 dB, resulting in a value of power received within -117,6 dBm.

Table 5 - Presentation of the measured and simulated value for indoor environment.

	Measurement	*Indoor Propagation Model*
$P_{r[dBm]}$	-126,00	-117,60

It appears that, according to ANACOM, the measured value falls into the category of “Non-existent Coverage” while the simulated value is in the category of “Bad Coverage”.

In order to solve this case, and to at least improve the signal quality in the area, there are two solutions, some with higher cost than others.

One would be the creation of a root base station, probably in the southernmost part of the valley, with the antenna having a negative slope, that is, pointing practically upwards in the north direction, in order to cover all the houses from the bottom of the the valley to the top of the adjacent peaks. However, this solution would only be viable if the signal was non-existent, or even if there was no tower in the vicinity, which does not correspond to reality. In addition, the cost of creating and installing a base station is obviously high, not only because of the bureaucratic part but also the expenses on material, labor and the payment of a license and/or space rental.

In Figure 12 we have the representation of coverage on the site through this solution, considering the Longley-Rice model.

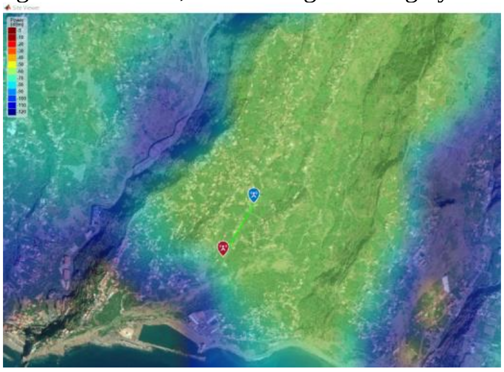

Figure 12 - Solution for creating a base station.

As can be seen, the coverage is really guaranteed in this way, because the value of power received at the site would most likely be between -40 dBm and -30 dBm, which in fact is an excellent sign, however, this solution it is doubtful even by exposure to radiation. In this case, the tower is 8 meters long and the emission power is 10W, however, the fact that there are a considerable number of houses close by probably makes the solution not advisable.

In addition to the solutions already presented, there is also the solution of the peak or femto cells.

The pico and femto correspond to small cells, normally placed inside, which aim to provide cover in the small environment around them.

Figure 5.12 shows the illustration as an example of a peak or femto cell in an office environment.

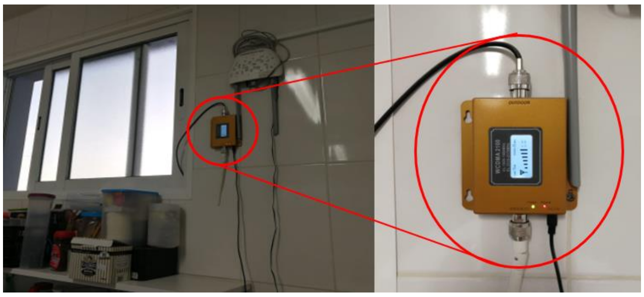

Figure 13 - Demonstration of a peak or femto cell.

This solution, in addition to being cheap, has the great advantage of solving the user’s problem almost instantly, because it is a practical solution, since it is effective and does not need to put the customer waiting for the operator to decide to place a station in the vicinity.

The creation of femto and pico cells is carried out by choosing a location for fixing the micro repeater, having an output antenna connected at one end. At the other end of the micro repeater module, there is an input where a cable is connected to the input antenna, which is located outside, far from the attenuation introduced by the walls.

The imperceptible procedure that occurs in these devices is, in the case of the downlink, the reception of the signal from a BS in the input antenna of the module, with the signal being amplified and later radiated inside the housing by the output antenna. In the case of the uplink, what happens is precisely the same, but in the opposite direction.

For this study area, the most suitable solution seems to point towards the use of micro repeaters, creating the peak or femto cells inside the houses.

C. *Case Study – AVASAD Funchal*

AVASAD, is a health treatment company with technicians from the Medical Sciences of Work and Sport, located in Funchal, more precisely on Rua dos Aranhas.

This place has a waiting room and in addition, due to the fact that it is a center for physiotherapy and other treatments, internet access is undoubtedly a form of comfort and occupation for service users, especially in longer treatments.

Figure 14 shows the location of the base stations closest to the treatment center, as well as some characteristics of the study area.

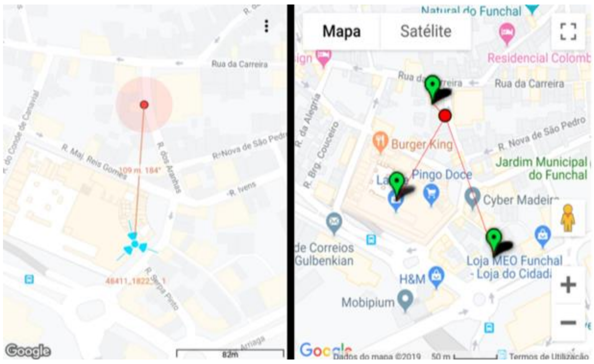

Figure 14 - Identification of the BS location and characteristics of the study area.

Through a visit to the site, a search was made of some characteristics of the nearest BS, having been noticed that all three represented in the previous figure are on top of buildings.

Performing a quick and simple analysis to the right of Figure 14, it would be logical to say that the mobile terminals in the AVASAD area would certainly be connected to the nearest base station, however, according to the application “Cell Tower Locator” the mobile terminal connects to the base station located above the La Vie shopping center or to the one next to the MEO store, on the Calçada de São Lourenço. This evidence led to the verification of the BS type of the nearest BS, having been noticed that it has only one sector being it directed in the opposite direction to the study site. At BS next to the MEO store, a similar case occurs, in this case with the existence of two sectors, but none directed to the place of study.

Other measurements were carried out at exactly the same location at a different time and it was found that the mobile terminal was, this time, connected to the enode-B 6409, which is located next to the MEO store, on the Rua de São Lourenço as shown in Figure 15.

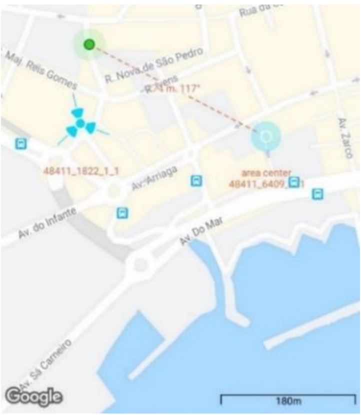

Figure 15 - Identification of the location of the connected BS.

Knowing the problem and some of its characteristics, we proceeded to the analysis in outdoor and indoor environment.

In the measurement performed in the center of Rua dos Aranhas, the result shown in Figure 16 was obtained.

Figure 16 - Measurement performed close to AVASAD in an outdoor environment.

It was found that in this case, the connection is very good and is well above the value considered "Good" by ANACOM. It was also found that this zone has a high tendency for handovers to occur, varying widely between cell 1822 and 6409, however the power values received from one and the other are very similar.

After looking at the two base stations, an estimate was made of some of the most influential parameters in terms of coverage. Tab shows the estimated parameters of cell number 6409.

Table 6 - Technical parameters estimated in cell 6409 and 1822.

Technical Parameters	CID 6409	CID 1822
Frequency	2100 MHz	2100 MHz
Tower Height	8 m	13 m
Emission Power	10 W	10 W
Bandwidth	20 MHz	20 MHz
Mobile Terminal Gain	2 dBi	2 dBi
Mobile Terminal Noise Figure	7 dB	7 dB
Mobile Terminal Height	1,8 m	1,8 m
Mobile Terminal Noise Power	-93,98 dB	-93,98 dB
Receiver Sensitivity	-129,34 dB	-129,34 dB

In order to obtain some proposals for solving the problem, some simulations were carried out.

Initially it was simulated in Matlab based on the Longley-Rice model, in this way we tried to create the real scenario, considering eNodeB 6409 with the characteristics presented in Table 6. Figure 17 shows the representation of the radiated power distribution on the map.

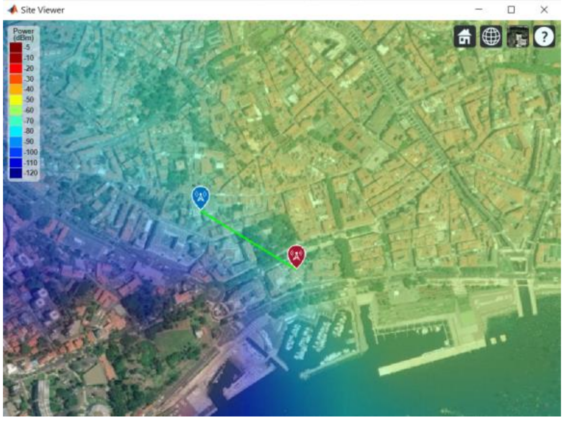

Figure 17 - Representation of the radiated power on the map.

In addition to the characteristics mentioned in the table, a 35º angle for the antenna was also considered. The reason why this angle was considered and not the maximizing angle of the received power was the high discrepancy between the real and the simulated values. With the 35º angle, a received power value of -72.86 dBm was obtained, which in fact is very similar to the measured value.

Simulation was also carried out using specific propagation models for mobile communications. In a first phase, it was decided to use the Walfisch-Ikegami model because it is a scenario of presence inside a street in an urban area as well as due to the proximity to the redundant BS, therefore there is the probability that most of the attenuation occurs due to the presence of buildings, as well as reflections resulting from their location on the street. Subsequently, the calculations for the simulation using the Okumura-Hata model were performed, even because it is specific to urban environments, as is the case of this scenario in the center of Funchal.

Starting by Walfisch-Ikegami model, with all the necessary parameters obtained, the attenuation was calculated using equation number 8.

$$L_p = 68{,}87\ dB$$

Having the path loss value calculated, it is now possible to calculate the power received on the mobile terminal, having been calculated through the expression number 1.

$$P_r = 40 - 68{,}87 + 5 + 2 - 3 = -24{,}87\ dBm$$

It is of some importance to point out that this model was used outside its usage requirements, specifically in terms of frequency. In the propagation models chapter, the requirements are more complete, however, the Walfisch-Ikegami model has a frequency range between 800 and 2000 MHz, which makes the frequency value used outside the parameters.

Although the model was used outside the requirements, its result is not disposable. In fact, the value is only considered to have some extra associated error, even though it is reduced since the disparity is only 100 MHz.

Then, the simulation was performed using the Okumura-Hata model, not least because it was created specifically for urban environments.

Using Okumura-Hata model, with all the necessary parameters obtained, the attenuation was calculated using equation number 4.

$$L_p = 126{,}69\ dB$$

Having the path loss value calculated, its now possible to calculate the power received on the mobile terminal, having been calculated through the expression number 1.

$$P_r = 40 + 5 - 126{,}69 + 2 - 3 = -82{,}69\ dBm$$

In this case, it must also be taken into account that the model was used outside the parameters. This is because the frequency considered is 2100 MHz and the model is designed for a frequency range between 150 MHz and 2000 MHz.

The measurements and simulations were performed, for the purpose of critical analysis, and the values collected in Table 7 were grouped.

Table 7 - Presentation of the received power values measured and in the simulations.

	Measurement	Walfisch-Ikegami	Okumura-Hata	Matlab
$P_{r[dBm]}$	-76,00	-24,87	-82,69	-72,86

Of all the simulations carried out, the one that most resembled the measurement was the one carried out on the matlab using the Longley-Rice model, however, once again it is stated that the angle used in the simulation was not the ideal angle between the BS antenna and the mobile terminal, even because in this condition the value was much more optimistic than the simulations or even the measurement itself. However, the value presented in this simulation has no value, not least because the true angle is unknown and observed by the naked eye, but also because the BS under consideration has no antenna facing the location of the mobile terminal when measuring. On the other hand, the result obtained by the Walfisch-Ikegami model was extremely optimistic and completely different from the measurement or from the other models, most likely due to the fact that the buildings present in the transmission path do not have similar dimensions.

In an indoor environment the result is completely different, measurements were taken in the center of the building and there is really a problem with the 4G network coverage.

Figure 18 shows two measurements taken in the central part of the building's interior, when connected to the eNB 6409.

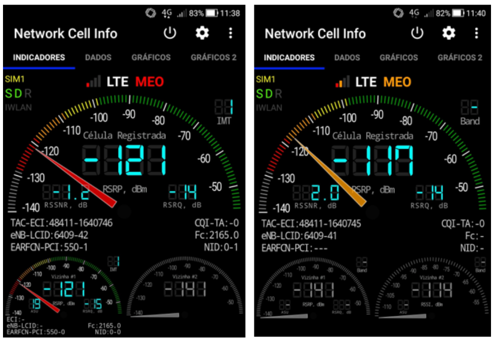

Figure 18 - Measurements performed in an indoor environment with the mobile terminal connected to the eNB 6409.

It was noticed that there are many variations of the value received on the mobile terminal, however, from the user's point of view, internet traffic is zero, since it is impossible to send or receive data.

In addition to the variation in value, there was also a high occurrence of technology exchange between the LTE network and the UMTS network, because when the value of power received on the mobile terminal in 4G is reduced to the point of being less than the sensitivity, from this, switching over to the 3G network takes place.

As in the outdoor environment, namely, in the center of Rua dos Aranhas, there was a high occurrence of handovers for the enB 1822. In Figure 19 two measurements taken in an indoor environment are shown, exactly in the same location as the 2 measurements shown in the previous figure.

Figure 19 - Measurements performed in an indoor environment with the mobile terminal connected to the eNB 1822.

Again, the measured value is very low and makes data transfer over the network impossible. It was also found that by being connected to enB 1822 it is possible to capture a signal from neighboring cells. Carrying out a more careful analysis of Figure 19, it appears that in one of the cells in the neighborhood the frequency of the signal captured is in the 800 MHz band, which may translate into a good solution for solving the problem, as described in the following subchapter.

The high occurrence of handovers between the cells could lead one to think that signal interference would be occurring, however, the values of RSRP and RSRQ are reduced for all measured cases, which makes the probability of the existence of interference very low.

A simulation was also carried out using the Lisbon model for indoor propagation and the attenuation introduced by the presence in an indoor environment would be similar to 11.6 dB with a standard deviation of 14.7 dB, because in this case the operating frequency is the 2100 MHz band.

The power value obtained inside was calculated by subtracting the value shown above from the power value measured in the center of Rua dos Aranhas, having obtained the value of -90,7 dBm of power received on the mobile terminal.

Table 8 - Presentation of the measured and simulated value for indoor environment.

	Measurement	Indoor Propagation Model
$P_{r[dBm]}$	-121,00	-90,7

The power value obtained in the interior simulation falls, according to ANACOM, in the category of “Good Coverage”, which in fact is totally beside the reality of the measurement and the point of view of the network users.

The big difference between the power values at the reception on the outside and inside most likely arises due to the type of construction material of the building, together with the fact that it has several sections inside, that is, several walls, which are no less than obstacles, causing attenuation by refraction through penetration or reflection.

The most logical solution for this coverage problem would certainly be to increase the transmission power, however, and especially in urban environments, it is necessary to be very careful in this parameter, even due to the presence of more cells and with these various sectors, being, therefore, preferable to limit the area with power radiated in order to avoid various problems such as interference or even exposure to electromagnetic energy.

A simulation was performed on the matlab using the Longley-Rice model in which the antenna was kept at the site of the enB 6409 and simply changed the frequency band to 800 MHz as well as the emission power value for 15W instead 10W. Keeping the angle and all other parameters, the power value obtained in the center of Rua dos Aranhas was -70,99 dBm, which translates into an improvement compared to the -72,86 dBm previously obtained in the simulation.

Although the received power value has improved, it is a relatively uncertain solution, because the difference in values is not very high, however, it is a solution most likely considered cheap and, therefore, a candidate to be tested.

Another solution is to introduce another sector, directing it to the problematic zone.

In order to verify the improvement in coverage, a simulation was performed again by the Longley-Rice model, having obtained the result shown in Figure 20.

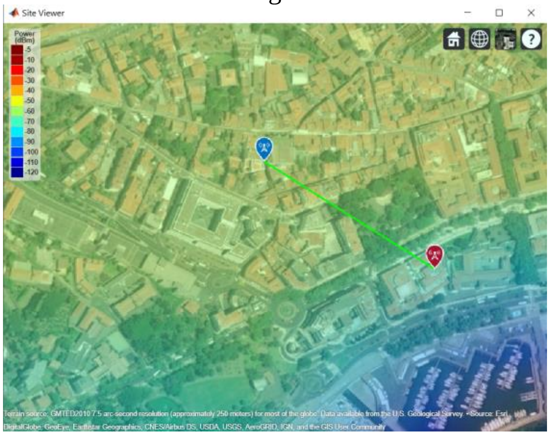

Figure 20 - Coverage map with the addition of the sector directed to the problematic zone.

In these conditions, a power of -40.59 dBm was obtained at the reception, which is an excellent value.

From the user's point of view, it can be said that this is a completely effective solution, however, this change in parameters is a solution that at the level of outside coverage would not be justified, because the real problem lies inside the building, therefore, it is a solution that is not economically viable. This solution could be implemented at any of the base stations surrounding the problem area, as they are all relatively close to the site and none have an antenna oriented to it.

Bearing in mind that there is a good value of power received in the center of Rua dos Aranhas, the solution that again seems to be the most viable would be the placement of a repeater, the same system described in the previous case studies in which it would be installed an outdoor antenna, for receiving the signal coming from the enB, passing it through the amplifier and later being radiated through the indoor antenna, thus reaching the mobile terminal for receiving the data. The sending of data by the user has the exact opposite direction to that described.

The communication system through a micro repeater, in addition to guaranteeing the interior coverage, is a system with a relatively cheap purchase cost, as well as food expenses, because this system does not require a large amount of power in its supply .

IV. CONCLUSION

This work concluded that one of the biggest problems on the island of Madeira is its difficult orography. As it is an island with mountainous terrain, many areas of shade are created, which greatly complicates the task of operators to ensure coverage for the entire population.

Although the propagation models are very useful in cell planning, this process is characterized by its high complexity due to the high sensitivity required in planning. It is not enough to check if the result of the simulation by the propagation models is positive, not least because the models were created in a specific scenario, forcing some corrections to be made in other places. There will never be a single model or equation that is infallible for all environments, not least because they are constantly changing, whether due to the construction of buildings, the movement of cars in urban and suburban areas or even due to the growth of vegetation in the areas rural areas.

The choice of the frequency used in each scenario is extremely important. It was seen that lower frequencies are easier to get around obstacles through diffraction. Higher frequencies almost require a line of sight between transmitters, on the other hand ensuring greater availability of bandwidth.

From the users' point of view, the selection of an operator should not only involve choosing the one with the lowest cost tariffs. A simple check of the signal level and comparison with the other operators is probably the most important parameter, not only because most tariffs have a two-year loyalty period, but also because the area where the user lives and works in principle are the places where they spend most of their time.

In addition to the problem areas identified, there are many deficiencies in coverage in indoor environments, making it difficult for companies to function properly or affecting the comfort of personal users, forcing them to move near the windows or even outside their homes to establish communications, so the most viable solution found is the placement of micro repeaters.

The realization of the practical part of this work was somewhat difficult due to the lack of access to the real information of the network installed in Madeira, more specifically, by not providing any type of information on the technical parameters of the base stations in the region, such as the number of sectors, the angle of the antennas, emission power and height of the towers. At first it was possible to consult a website page with the location of all base stations, which was discontinued in early December 2019.

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