Marine Communications Systems in Cape Verde

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Abstract - One of the major problems of conducting a radio link project in Cape Verde comes from the geographic location of the country (10 volcanic islands scattered in the Atlantic Ocean, 500 km from the West African Coast). Another problem is to discover the reasons that cause connection failure, to study them and to present the best possible solution for making a connection. Therefore, a connection project will be presented between two islands of the country and a solution for the project and the problems that cause connection failures will be presented too.

On the other hand, despite of the development of wireless mobile telecommunications technologies, fourth generation technology (4G) has not yet been introduced in Cape Verde and third generation technology (3G) is not a privilege of all the regions of the country. In this thesis, the propagation models for the 3G coverage and the current situation of this technology in the country will also be presented.

The use of communication technologies for the protection of individuals in emergency situations has become increasingly dynamic worldwide, so these technologies are one of the basic and fundamental tools for supporting protection and relief operations. The need to create an emergency and safety communication network has been studied and there is already a project implemented almost ready to go live. Therefore, the technology used, the benefits and the architecture of the project in question will be studied in this thesis.

Keywords - radio link, propagation models, 3G coverage, emergency and safety communication network, LTE-4G technology.

I. INTRODUCTION

In radio communication, for frequencies above 30 MHz, the ionosphere is no longer the determining factor in the establishment of connections, so it was necessary to create a narrow beam to confine most of the transmitted energy and to start using antennas each more directional, as the frequency increases, the wavelength is reduced.

In Cape Verde, according to the operator CVTELECOM, the radio waves are being used in an emergency, that is, when there is a cut in the optical fiber, since the old connections were almost all replaced by fiber optics, leaving only the survival. However, some radio-relay connections often fail during a long period of the year and the reasons have not yet been deepened.

Over the years and the evolution of technology, it has become necessary to create technologies that improve the quality of service (QoS) and cheaper for communications for short and long distances.

Despite the technological improvement in Cape Verde with the introduction of 3G technology in November 2011, the need to keep pace with global technological developments leads to the study to introduce 4G technology in the country by the end of the first half of 2019.

Due to increased insecurity in the last 12 years and taking into account that there is no emergency and safety communication network yet, a project funded by ANAC (National Communications Agency) has been developed to introduce the number 112 (with a video surveillance system) as the national emergency number and to create an emergency and safety communication network in order to respond to the current situation of the country.

The radio transmission system was almost entirely replaced by fiber optic networks, increasing the responsiveness in terms of bandwidth. At this moment, radio-relay beams are used only in an emergency, that is, if there is a cut in the optical fiber, where there is no ring, the system can be activated until the situation normalizes. This method of resolving an emergency becomes a major problem if there is a failure of fiber optic connection between the islands of Santiago and Fogo, especially since there is a loss of signal in the radio-beam systems over half the year (from February to November).

In this context, and in view of existing projects in the development of communications systems, this thesis aims to understand a radio link project and present a solution to solve the connection failure, to study the models used for the 3G coverage and the communication network emergency and security in Cape Verde, and to analyze the results obtained to conclude on its benefits.

In this way, a study is made on the radio link system and how to use it as an emergency system, mainly in the Santiago-Fogo circuit, a study also is presented on the propagation models of 3G network coverage and improvement which will be achieved with the 4G network for emergency communication and security.

II. RADIO LINKS

A. Connection by Radio Links

A simplified description of a radio relay link is a high-capacity bidirectional link in the 6 GHz band, thus, a typical long distance link, with a total length of 300 km. Terminal stations are connected to the centers of transmitter and receiver of traffic by frequency or time division multiple telephony systems, supported on coaxial cables or optical fibers, and they are located at high points in order to achieve line of sight (LoS).

In a connection between two stations, all the transmitters and receivers involved use the same directive antenna installed in a tower or a mast (spy tower), and they can be located in own building, at the base of the tower, when this is
a simple support structure, or near the antenna (at the top of the tower) on the larger premises. On the other hand, the connection of the transmitters and receivers to a single antenna (using filters) is done by coaxial cable or by waveguide when the frequency is equal to or greater than 2 GHz (using combinations of circulators and filters).

Radio spectrum is divided into frequency bands distributed on an international basis for uses such as fixed and mobile terrestrial communications, maritime communications, satellite communications, navigation aids, radio broadcasting, radio astronomy and amateur radio. This spectrum distribution is made according to the recommendations of the ITU-R (International Telecommunication Union - Radiocommunications).

B. Propagation Elements

A wave propagates in free space when the path experienced by it, between transmission and reception, is characterized by LoS, that is, a clean and unobstructed path. Theoretically, the term free space indicates the vacuum, however, it can be applied, at project level, in the characterization of wave propagation in unobstructed scenarios, provided that these scenarios meet the conditions to take the LoS.

In practice, most of the calculations performed on radio link systems projects use a version of the Friis formula where the intervening quantities are expressed in logarithmic units, with free space attenuation given by

\[ A_0 = 92.4 + 20 \log_{10}(d_{hm}) + 20 \log_{10}(\text{f}_{GHz}) \text{ [dB]} \]

The written expression is only valid if the antennas are sufficiently far apart, that is, there is a minimum distance \( d_{min} \) to be considered, where \( d_a \) is the largest opening size of any of the transmitting or receiving antennas

\[ d_{min} = \frac{2d_a^2}{\lambda} \text{ [m]} \]

The reflection is one of the most significant propagation mechanisms in fixed systems with wireless networks. The waves are reflected when they focus on large objects compared to the wavelength of the propagating signal. The interference of direct rays with rays reflected by the ground can greatly alter the signal received in the receiving antenna, in relation to the signal that would be received in conditions of propagation in the free space.

In fact, the approximation of the flat earth can only be used for very short distances. In general, it is indispensable to take into account not only the orography of the course, but also the sphericity of the Earth.

The expression of angle \( \Psi \) is given by

\[ \Psi \approx \tan^{-1}\left(\frac{h_1}{d_1}\right) = \tan^{-1}\left(\frac{h_2}{d_2}\right) \]

When \( h_1 = h - \frac{\lambda^2}{2a} \) and \( h_2 = h + \frac{\lambda^2}{2a} \). By doing \( h_1 d_2 = h_2 d_1 \) and given \( d = d_1 + d_2 \), we obtain a cubic equation in \( d_1 \) and finally a difference of trajectory between the direct and reflected rays

\[ d_1^3 - \frac{3}{2} d_1 + \left[ \frac{1}{2} d^2 - a(h_1 + h_2) \right] d_1 + h_1 \cdot d_1 = a \]

\[ \Delta_c \approx 2\frac{h_1 h_2}{d} \]

The degree of obstruction of a line of sight can be studied empirically, however it is possible to calculate path losses as a function of the obstructions if it can establish conditions in which propagation between the transmitting and receiving antennas can be considered as a free space. For this, you must understand a very important parameter: the Fresnel zone.

![Figure 2 – Fresnel zone](image)

Most of the energy of the transmitted signal is found in the first zone of Fresnel \((n = 1)\), hence, for the realization of projects, it is only important to consider this zone. The diameter of the first Fresnel ellipsoid is given by

\[ D_1 = \sqrt{\frac{4\lambda d_1 d_2}{d}} \]

Atmospheric gases, in particular oxygen, water vapor and carbon dioxide, fog and hydro meteorites (especially rain) are responsible for further attenuation in the pathways which develop, wholly or in part, in the atmosphere which constitutes an important propagation element.

The radio link systems usually use frequencies between 1 and 55 GHz, with lower frequencies being more favorable for longer paths and frequencies between 2 and 13 GHz, it is generally sufficient to consider the effect of rain (intense) which may be the determining factor in the design of the connection to the higher frequencies in the range concerned.

The attenuation suffered by the radio link is due to two mechanisms: losses in the water droplets that are heated and dispersion.

In the radio link on the troposphere, the experience shows that the received signal has fluctuations (sometimes of great amplitude) above and below its median value, which affects the quality of service achieved, incorporating the knowledge of its characteristics and the possibility of forecasting its effects. This phenomenon is called fading.

![Figure 1 – Equivalent heights](image)
ITU-R Recommendation P.530-8 describes two methods for predicting fast fading at any location.

It is not always possible to avoid the effects of fading economically or to increase the transmitted power and gains of the antennas, guaranteeing at the reception the desired power. However, there is an effective alternative solution that is called diversity.

The diversity is of order \( n \) when in a course the received signal is obtained from \( n \) different signals. On the one hand, if these signals come from reception with distinct antennas the diversity is classified as space. There are several reasons to prefer this type of diversity: it is more economical in the use of spectrum, it is also the lowest cost, except when using very large antennas, since it is only necessary to duplicate the receivers at each terminal. On the other hand, if the same antenna is used at reception for signals of different frequencies, we are dealing with the diversity of frequencies.

C. Analog Radio Links

The radio link can be used for both analog and digital signal transmission. What differs from one case to another are the characteristics of the modulators and demodulators, as well as the characteristics of the low frequency stages. However, the high frequency, frequency conversion and intermediate frequency stages are identical in one case as in the other.

The main characteristics of the analog signals are: simple telephony, frequency division multiple telephony, high-quality monophonic and stereo sound broadcasting and mono and polychromatic television.

D. Digital Radio Links

Nowadays, due to high binary rates and competitive costs, the use of radio link systems in digital systems is becoming increasingly widespread, particularly, for multiple telephony.

For transmission rates of 2, 8 and 34 Mbit/s, digital radio links are usually more advantageous than analog ones.

The digital systems, due to their ability to provide much higher transmission rates (in the tens of Gbit/s), compete with optical fiber communications systems, but a physical connection between the terminals is required. On the other hand, the radio links have a much faster installation and are less conditioned by the accessibility and characteristics of the path.

E. Radio Link Project

A bidirectional connection by radio link between the localities of Monte Tchota (MT - Santiago Island) and Cova Figueira (CF - Fogo Island) is now being carried out, since it is a connection with serious problems at a certain time of the year and it having been deactivated by the operator responsible for it.

The project will be scaled to achieve a solution that solves connection failures, meeting the requirements established by ITU-R standards and ANAC.

According to the ANAC documentation, the frequencies most commonly used for the radio link are \{2, 7, 13 and 15\} GHz. However, through Feixer it is possible to perform a frequency scanning in the range \{2; 16\} GHz with an increase of 2 GHz.

Regarding the type of modulation to be used, it is assumed that the values of \( m \geq 64 \) require a rather high signal-to-noise ratio and, not considering frequency and bandwidth combinations that require such a number of modulation levels, calculations are performed for the various combinations for the connection, based on the ANAC rate simulator.

Knowing that the distance corresponding to a direct radius between the two locations with terminal antennas is 74 km and considering that the cost does not vary much for very short distances, the best solutions for the different frequency bands and type of modulation are tabulated below

<table>
<thead>
<tr>
<th>( f [\text{GHz}] )</th>
<th>( ID )</th>
<th>( LB [\text{MHz}] )</th>
<th>Modulation</th>
<th>( m )</th>
<th>Cost [ECV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>7.4</td>
<td>14</td>
<td>16-PSK</td>
<td>16</td>
<td>337 200</td>
</tr>
<tr>
<td>13</td>
<td>13.3</td>
<td>14</td>
<td>16-PSK</td>
<td>16</td>
<td>337 200</td>
</tr>
<tr>
<td>15</td>
<td>15.3</td>
<td>14</td>
<td>16-PSK</td>
<td>16</td>
<td>337 200</td>
</tr>
</tbody>
</table>

Table 1 - Rental cost of frequencies, bandwidth and modulation

From Table 1, it can be concluded that the maximum level of modulation to be considered in this project is 16, taking into account the electronic complexity of necessary equipment and corresponding need for a higher signal-to-noise ratio.

For the calculation of unavailability in the connection the following expression is used and we considered an Average Repair Time value (MTTR) of equipment problems of 4 hours.

\[
I(\%) = 0.3 \times \left( \frac{\text{max}(76 \text{ km}, 280 \text{ km})}{2500} \right) = 0.0336
\]

Given typical atmospheric conditions in Cape Verde, it is possible to estimate the following parameters, whenever possible (and worst case), for Feixer simulation.
Atmospheric pressure: 1013 milibar
Average Atmosphere Temperature: 30 °C (wet season)
Relative humidity: 80% (wet season)
Water Vapor Density: \( \rho = 24,255 \text{ g/m}^3 \)

According to ITU Recommendation P.837-7 and given islands characteristics with terminal antennas, the mean intensity of precipitation is \( R_i = 15 \text{ mm/h} \), value exceeded 0.01% of the time.

Considering that the unavailability resulting from rainfall corresponds to 10% of the total unavailability calculated previously, we have \( I(\%) = 10\% \times 0.0336 = 0.00336\% \).

The design is dimensioned for vertical polarization, since for horizontal polarization, there is more attenuation due to the raindrops being elliptical and flattened vertically.

Typically, in this type of systems, the use of elliptical waveguides is considered, the length of the guides corresponding to the sum of the heights of the masts (emitter / receiver) and the clearance - designed for 10 m.

The existence of the signal multipathing phenomenon in the link under analysis gives rise to the phenomenon of fast fading, with coexistence of pathways being experienced for short time intervals, thus obtaining the geo-climatic factor, according ITU-R Recommendation P.530-8 for fast fading calculation, which corresponds to the method 2 in the Feixer tool

- Project coordinates: \( C_{\text{Lat}} = 0 \) and \( C_{\text{Long}} = 3 \)
- Receiving antenna located between \( h = [400; 700] \) m leads to \( C_n = 6 \)
- The total distance of the connection is 73.948 km which leads to the classification of the route as "terrestrial"
- Average Refractivity gradient in the lower 100 m of the atmosphere is less than -100 N/km in 30% of the time (ITU-R Recommendation P.453-6)

Based on ITU-T Recommendations ITU-R and ITU-T Recommendations P.530-8 and F.1189-1, the following table values are considered

<table>
<thead>
<tr>
<th>( I ) [KB/s]</th>
<th>SESR</th>
<th>BBER</th>
<th>ESR</th>
<th>( \beta_{\text{ESR}} )</th>
<th>( N_B ) [bit/s]</th>
<th>( N_B ) [bit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>1.6 \times 10^{-4}</td>
<td>1.6 \times 10^{-5}</td>
<td>6 \times 10^{-3}</td>
<td>6.5 \times 10^{-5}</td>
<td>8000</td>
<td>6120</td>
</tr>
</tbody>
</table>

Table 2 - Values of the parameters considered in the project

The minimum safety margin defined for this project is given by the following relationship

\[
\frac{C}{N_{\text{condições ideais}}} - \frac{C}{N_{\text{min recomendado ITU}}} \geq 3 \text{ dB}
\]

Knowing that the modulations considered at the experimental level in this project have order \( m \leq 16 \), and because no equalizers are used in the connection, the selective margin is calculated by Feixer method 1, which corresponds to ITU-R Recommendation F.1093-1.

The viability study of the connection is done without recourse to any repeater and the following values are taken for analysis

- \( d_{\text{link}}: 74 \text{ km} \)
- \( h_{\text{transmitter}}: 27 \text{ m} \)
- \( h_{\text{receiver}}: 35 \text{ m} \)
- \( \text{diamantennas}: 3 \text{ m} \)
- \( \eta_{\text{antennas}}: 55\% \)

From the above figure, it can be noted that the orography is lower than the transmitter and receiving antennas, hence no repeater is required.

In order to comply with the ITU recommendations for error clauses observed with the Feixer tool and to minimize fading effects frequency diversity is considered by placing a diversity antenna within 10 m of the main antenna and obtaining the following results.

<table>
<thead>
<tr>
<th>Critical Margins</th>
<th>ESR</th>
<th>SESR</th>
<th>BBER</th>
<th>ESR (Raın)</th>
<th>SESR (Raın)</th>
<th>BBER (Raın)</th>
<th>Unavailability (Rain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Diversity</td>
<td>( \leq 12 \text{ GHz} )</td>
<td>( \leq 4 \text{ GHz} )</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>( \leq 15 \text{ GHz} )</td>
</tr>
<tr>
<td>With Diversity</td>
<td>( \leq 14 \text{ GHz} )</td>
<td>( \leq 12 \text{ GHz} )</td>
<td>( \leq 9 \text{ GHz} )</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>( \leq 15 \text{ GHz} )</td>
</tr>
</tbody>
</table>

Table 4 - Results obtained in Feixer regarding error clauses

According to ANAC, the operator responsible for the projects for radio frequency bands (CVTELECOM) uses the 2 GHz band for these links, which leads us to conclude that for this frequency and using diversity, the norms for the error clauses of the ITU are fulfilled in the project simulation with Feixer.

The geographical coordinates of the equipment installation, the angle of inclination and the locations azimuth values of the connection between the two locations are presented according to [7]

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation</th>
<th>Azimuth</th>
<th>Angle of Inclinação</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monte Tchota</td>
<td>15º02'13.38&quot;N</td>
<td>23º37'22.52&quot;O</td>
<td>1062 m</td>
<td>257.576°</td>
<td>-0.781°</td>
</tr>
<tr>
<td>Cova Figueira</td>
<td>14º53'32.71&quot;N</td>
<td>24º17'36.11&quot;O</td>
<td>483 m</td>
<td>77.402°</td>
<td>0.117°</td>
</tr>
</tbody>
</table>

Table 5 - Coordinates of equipment installation and link angle and azimuth

In spite of concluding the viability of the connection with the Feixer tool, according to CVTELECOM, the signal
received in the locality of Cova Figueira had a lot of interference during most of the year which led to the deactivation of this connection, which leads us to the study of a solution, since it is one of the places with the biggest signal failures in Cape Verde.

A solution for the project would be to design a metal mesh in order to absorb the reflections due to the mirror of water that exists in front of the Cova Figueira. For this, calculations will be made so that the first Fresnel ellipsoid is not prevented.

We start by analyzing the following figure, where \( H_a = \cot \alpha + h_{ant} = 1062 + 27 = 1089 \text{ m}, \quad H_r = \cot \alpha + h_{ant} = 483 + 35 = 518 \text{ m}, \quad d_1 \theta d_2 \) are, respectively, the distances from the specular point to the transmitting and receiving antennas.

\[
\tan \Psi = \frac{H_a + H_r}{d} = \frac{H_a}{d_2}
\]

and we have \( \tan \Psi = 0.0217 \), so \( \Psi = 0.0217 \text{ rad} = 1.24^\circ \), \( d_2 = 50.18 \text{ km} \) and then \( d = d_1 + d_2 \), we have \( d_2 = 27.77 \text{ km} \).

The diameter of the first Fresnel ellipsoid will be given by

\[
D_1 = \frac{4 \lambda d_1 d_2}{d}
\]

Since the working frequency is 2 GHz, we have \( \lambda = 15 \text{ cm} \), and consequently \( D_1 = 106.33 \text{ m} \). The first Fresnel zone clearance will be given by the criterion of "clearance" \( \tilde{x} \)

\[
\tilde{x} = \frac{H_a d_1 + H_r d_2}{d} = 760.46 \text{ m}
\]

Considering now that if you want to put the metal mesh at \( \rho_{rede} = 10 \text{ m} \), from the main antenna and knowing that the antenna at Cova Figueira is 0.117° inclined upwards, we have \( \Psi = 1.24^\circ + 0.117^\circ = 1.36^\circ \), as if you can see in the following figure

and we obtain \( \Delta = 0.24 \text{ m} = 24 \text{ cm} \), and the height to put the metal mesh will be

\[
H_{m,rede} = h_r - \Delta - h_{rede} = 23.76 \text{ m}
\]

where \( h_r = 27 \text{ m} \) is the height of the receiver antenna and \( h_{rede} = 3 \text{ m} \) is the height of the metal mesh.

The metal mesh to be designed will be such that \( d_{rede} = 0.1\lambda = 1.5 \text{ cm} \) and \( h_{rede} = 3 \text{ m} \).

Figure 8 shows the schematic of the proposed solution and Figure 9 shows an image of a metal mesh with \( d_{rede} = 5 \text{ cm} \).

Since the first Fresnel ellipsoid is not prevented, we concluded that this is an optimal solution for this connection design.

Figure 8 - Schematic of the proposed solution

Figure 9 - Metal mesh

III. 3G COVERAGE

A. Propagation Models

Mobile communications networks planning require a design methodology based on the need to estimate the coverage radius in a cell through the characteristics of the transmitter, the receiver and the wave path.

For these situations, propagation models and mathematical models that describe the signal losses along the path (attenuation) which predict the coverage area are used. These models are divided into two main groups: theoretical models and empirical models.

A well-known theoretical model is Ray-tracing, which is based on the electromagnetic wave propagation theory and collected data that describes in detail the characteristics of the environment. However, this type of model does not have great advantage at the project level, since it represents only the propagation characteristics of a specific environment and requires great computational effort.

There is a theoretical model \([\text{Walfisch-Ikegami} - \text{COST231}, 1999]\), well known for propagation in urban environments (European cities), with diffraction and refraction in buildings. This model is a combination of two models: [Ikegami et al., 1984] and [Walfisch and Bertoni, 1988] which was later improved by [Maciel et al., 1993]. The model takes the same assumptions of the previous models, concerning the urban structure.
The path loss in free space propagation is

\[ L_{0[\text{dB}]} = 32.44 + 20 \log_{10}(d_{[\text{km}]/1000}) + 20 \log_{10}(f_{[\text{MHz}]}) \]

For LoS propagation in a street \((\phi = 0)\), the path loss is given by

\[ L_{p[\text{dB}]} = 42.6 + 26 \log_{10}(d_{[\text{km}]}) + 20 \log_{10}(f_{[\text{MHz}]}) \text{, } d > 0.02 \text{ km} \]

in all other cases, one has

\[ L_{p[\text{dB}]} = \begin{cases} L_{0[\text{dB}]} + L_{\text{rm}[dB]}, & L_{\text{rt}} + L_{\text{rm}} > 0 \\ L_{0[\text{dB}]}, & L_{\text{rt}} + L_{\text{rm}} \leq 0 \end{cases} \]

where the parameters of the equations are given by the characteristics of the problem (e.g.: frequency, distance, antenna and building height, street width and distance between buildings) and the model is valid for

- \( f \in [800,2000] \text{ MHz} \)
- \( d \in [0.02,5] \text{ km} \)
- \( h_b \in [4,50] \text{ m} \)
- \( h_m \in [1,3] \text{ m} \)
- standard deviation \( \in [4,7] \text{dB} \)
- the error increases when \( h_b \) decreases relative to \( H_B \)

Measurement of the signal magnitude for the evaluation of the average value requires the filtering of fast fading, and the resulting power after filtering the fast fading is compared with the one from the model and then the average and the standard deviation of the difference between the two being calculated.

In the following figures, the mean value of losses (in dB) as a function of distance (in km) and frequency (in MHz) for propagation in LoS \((\phi = 0)\) and for propagation without line of sight - NLoS, with \( \phi = 90^\circ \).

On the other hand, the empirical models are based on the realization of several observations and measurements in real propagation environments. To efficiently represent losses in a given environment, an equation is created that best fits the measured data, taking into account its parameters derived from the characteristics of the environments studied and linked to the frequency of operation and effective heights of the antennas used for the transmission and reception of the signal.

The Okumura-Hata model is used in the of mobile networks planning, being one of the main references in the study of projects in this area, which makes it very well known. This model is a combination of measurement results obtained by [Okumura et al., 1968] and [Hata, 1980] and the model is valid for

- \( f \in [150,1500] \text{ MHz} \)
- \( d \in [1,20] \text{ km} \)
- \( h_{be} \in [30,200] \text{ m} \)
- \( h_m \in [1,10] \text{ m} \)

The resulting model requires a study of environments. Typically, there are three distinct categories of environments: rural (or open area - there are no obstacles in the region, between 300 and 400 m, in front of the mobile terminal), suburban (some obstacles, but the region ahead of TM is not very dense) and urban (very dense area with very tall buildings). The classification of these environments depends on parameters such as: terrain ripple, vegetation density, density and height of buildings, density of open areas and density of areas with water.

The parameter proposed to quantify the density of the buildings is known as Terrain Occupation Coefficient (Remington et al., 1988), given by

\[ C_{to} = \frac{\text{building total surface area}}{\text{building terrain occupation area}} \]

Typically, we have \( C_{to} > 1 \) for urban environments, \( C_{to} \approx 0.4 \) for suburban environments and \( C_{to} < 0.1 \) for rural environments. The loss path is given by

\[ L_{p[\text{dB}]} = 69.5 + 26.16 \log_{10}(f_{[\text{MHz}]}) - 13.82 \log_{10}(h_{be}[\text{m}]) + 
\left[ 44.90 - 6.55 \log_{10}(h_{be}[\text{m}]) \right] \log_{10}(d_{[\text{km}]}) 
- H_{\text{mut}[dB]}(h_m,f) - 2 \text{ correction factors} \]

where the parameters of the equation above are given by the characteristics of the problem and environments (e.g.: frequency, distance, antennas height, terrain undulation,
mixed paths, isolated hill, across and along streets, average slope, open area or quasi open area and suburban areas.

The graph obtained for the losses (in dB) as a function of the distance (in km) for the frequency of 900 MHz is shown below for the different environments.

![Graph showing losses vs distance for different environments.]

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![Graph showing losses vs distance for different environments.]

In order to include the frequency range such that \( f \in [1.5,2.0]\) GHz, the model [COST 231, 1999] is presented as an extension to the Okumura-Hata model.

Some changes have been made in the calculations and you start by calculating the effective height of the base station as

\[
h_{\text{be}} = \begin{cases} 
  h_b + h_{ob} - h_m, & h_{ob} > h_m \\
  h_b, & h_{ob} \leq h_m
\end{cases}
\]

And the path loss is given by

\[
L_p[\text{dB}] = 46.30 + 33.90\log_{10}(f[\text{MHz}]) - 13.82\log_{10}(h_{\text{be}}[\text{m}])
+ \left[44.90 - 6.55\log_{10}(h_{\text{be}}[\text{m}])\right] \log_{10}(d[\text{km}])
- H_{\text{mul}}[\text{dB}](h_m,f) + C_m[\text{dB}] - \Sigma \text{correction factors}
\]

where the parameter \( C_m = 0 \) for the small cities and \( C_m = 3 \) for the urban centres. And the other parameters depend on the characteristics of the problem and environment.

The following figure shows the average value of losses (in dB) as a function of distance (in km) and frequency (in MHz), for dense urban environments.

![Graph showing average losses vs distance and frequency for dense urban environments.]

B. Coverage Estimation

The estimation of the percentage of base station (BS) coverage area is essential for the QoS evaluation. By taking into account slow fading, the signal is described by the Log-Normal distribution with the mean power at the receiver, \( P_r \), and standard deviation in the environment, \( \sigma_e \).

Given the possibility of calculating the percentage of cells, \( P_{\text{circ}}(P_{\text{r min}}, R) \), at a given distance, \( R \), of BS with a power greater than the minimum sensitivity, \( P_{\text{r min}} \), it will be possible to estimate the percentage of the coverage area through the following relationship:

\[
P_{\text{area}} = \frac{1}{S_{\text{area}}} \int P_{\text{circ}} dS_{\text{area}}
\]

where

\[
P_{\text{circ}}(P_{\text{r min}}, R) = \text{Prob}(P_{r,R} > P_{\text{r min}}) = \frac{1 + \text{erf}\left(\frac{\Delta P_{[\text{dB}]}^*}{\sqrt{2}\sigma_e[\text{dB}]^*}\right)}{2}
\]

with

\[
\Delta P_{[\text{dB}]}^* = P_{r,R} - P_{\text{r min}}
\]

And taking a circle of radius R, the percentage of the coverage area will be given by

\[
P_{\text{area}} = \frac{1 + \text{erf}(a) + e^{(2ab+1)/b^2}[1 - \text{erf}(\frac{ab+1}{b})]}{2}
\]

where

\[
a = \frac{\Delta P_{[\text{dB}]}^*}{\sqrt{2}\sigma_e[\text{dB}]^*} \quad \text{and} \quad b = \frac{10a_{pd}\log_{10}(\epsilon)}{\sqrt{2}\sigma_e[\text{dB}]^*}
\]

The Figure 11 shows the percentage of coverage area as a function of the power variation (in dB), \( \Delta P \), and the standard deviation of the scenario (in dB), \( \sigma_e \).

![Graph showing percentage of coverage area vs \( \Delta P \) and \( \sigma_e \).]

C. Final Considerations

According to ANAC, the 3G network is a reality in all the islands of Cape Verde, with a total coverage area of 35.05% and a population coverage of 91.07%, operating in the 2.1 GHz band: 1900-1920 MHz (unpaired band), 1920-1980 MHz (uplink) and 2110-2170 MHz (downlink). These data refer to the month of December 2017.

With the advancement of the Internet and the need to simultaneously provide users with multimedia services based on mobile broadband such as Multimedia Messaging Service (MMS), video chat, mobile TV, HDTV (High-Definition Television), DVB Digital Video Broadcasting), basic services such as voice and data, always in the concept of use anywhere and at any time with the necessary quality, has developed the 4G network that will operate in the 800 MHz (790-862 MHz) range.
IV. EMERGENCY AND SAFETY COMMUNICATION

A. Communications in Emergency and Safety Scenarios

In a world characterized by a very complex environment marked by permanent change, by multiple threats and risks and even by the difficulty of predicting them, security is an inalienable right and duty, increasingly threatened in globalized societies.

The media flexibility and reliability in the use of communications networks are particularly relevant when implementing emergency and safety management solutions to combat natural disasters and other types of incidents.

The management of these means of communication has to be done at a horizontal and private level (security forces and civil protection, medical emergency, environmental protection, food safety, criminal, etc.), as well as at the geographical and vertical level (local, national and international).

In Cape Verde, the authority responsible for the project that implements and configures the Emergency and Security Communications Systematization Program is ANAC (in partnership with the Ministry of Internal Administration), which is also responsible for financing the project. The main objective of this project is the institutionalization of telephone network number 112 as a national emergency number (112 Cape Verde or CV-112) integrated in a CCTV system to include in a single emergency system various structures like national police, fire brigades, hospital and civil protection services in order to ensure that any user of a telephone from fixed network or mobile network, in a situation of emergency or catastrophe to have a safe and efficient emergency service, wherever it may be.

B. Technologies Used and Their Services and Facilities

In order to improve the network structure used in Portugal, LTE technology has been introduced to allow police officers access to high-quality videos anywhere.

LTE technology is a standard for high-speed wireless communication for mobile devices and data terminals based on GSM / EDGE (Global System for Mobile Communication / Enhanced Data Rates for GSM Evolution), and UMTS / HSPA (Universal Mobile Telecommunications System / High Speed Packet Access).

We can now cite some services and facilities of LTE technology:

- Fast call setup
- Excellent voice quality
- Emergency call
- Geolocation
- Status messages
- Short messages
- Easy Internet access
- Video calls
- Internet connection stability
- Streaming videos

C. LTE Advantages and Disadvantages

Main advantages of LTE technology:

- The 4G-LTE network is very fast. It is 10 times faster than the 3G network and offers extremely high voice quality, is very fast when downloading huge files over a wireless network, very good and clear with streaming videos, listen to music and watch online videos, music, watch TV online, among others streaming
- The main benefit in using LTE for public safety is the large-scale implementation of LTE and a large ecosystem, which allows less expensive equipment based on unified standards. These standards can be adopted by all public safety agencies and organizations around the world, thus sharing the scale with LTE’s non-public security applications
- LTE also offers an all-IP system architecture and flexible air interface with low latency and improved performance and efficiency, supporting flexible carriers and bandwidths from 5 MHz to 20 MHz, allowing a wide range of ecosystem support and regional flexibility for the operators
- The LTE system offers great flexibility to support a wide variety of deployment scenarios and carrier needs

Main disadvantages of LTE technology:

- The 4G network needs complex hardware, 4G technology is still limited to certain carriers and specific regions, but the number of cities that have 4G coverage is increasing every day, it will take some time for this network to be available on all major cities of the world
- 4G technology requires expensive infrastructure for operation. This is incorporated into eNodeB (access points) and mainly EPC (Evolved Packet Core) as gateways or routers. The 4G network is ideal for data rates, but not necessarily the best for voice services, some of these services are downloaded to Wi-Fi or 3G / GSM cellular technologies on the user's phone
- It is easier to get information from people illegally, because 4G technology involves the possibility of some interference but not much, but there is a possibility of being attacked (interference frequencies) which increases the invasion of privacy

D. Implementation of the Emergency and Safety Network

According to ANAC, the CV-112 project began to be implemented in the city of Praia, capital of the country, in 2015 and the equipment has already been implemented, waiting only for the interface to communication between the 112 and the CCTV and the introduction of technology 4G, since the Government of Cape Verde wants to introduce the CV-112 project with CCTV to complement the country's security system and what has been implemented serves to complement the video surveillance system that is done via optical fiber (all cameras are connected in fiber optic), taking advantage of the introduction of a modern network based on 4G technology.

Currently in Cape Verde there are several emergency numbers of according to the type of occurrence.
There are also emergency numbers of regional/local access that do not always follow a logic so that the citizen, in an emergency situation, remember them. In addition, some of these numbers are not operational, forcing the user to pay the call. It should also be noted that not all municipalities have all the services, which makes it urgent to implement a single number for the whole country.

The CV-112 project dispatch center is composed of a set of qualified human resources and specialists, compatible equipment and technological means and a set of procedures to facilitate the decision process that leads to the overcoming of an anomalous situation that affects the safety of an individual, community or region. Taking into account the structural problems of the country, the project was developed in three phases.

The communications and information center must have an automatic exchange with sufficient capacity to manage fixed and mobile telephone lines, fax, and a data communication platform that allows secure connection to the Internet and secure exchange of information with the different entities.

In order for the emergency dispatch and coordination center to function safely, it is necessary to create a dedicated emergency communications network, since public networks in case of emergency tend to fail because they are affected or for congestion reasons.

On the other hand, the command and control unit is essential for the success of operations in emergency situations, as a single, integrated network connecting all relief agencies is a determining factor in the success of operations.

Thus, the Emergency Communications and Security Communications Network (RCES) project was created, which consists in the implementation of a network in each island and then interconnects them with each other and has as main objectives: to connect the SNPC with the different entities, in a way to ensure coordination and unity of command and control; interconnect the emergency coordination center with the relief agencies in order to ensure, in any type of incident, speed and efficiency in the response to calls made to 112 and to make fluid communication between emergency response entities, such as evacuation and search and rescue operations throughout the national territory.

The project architecture is shown in the figure below. Users call the number 112 to a Call Center where the type of emergency is filtered (firemen, police, hospital services, etc.) and then the command center, in turn, communicates with the local service stations depending on the type of emergency. This is a common structural scheme in all existing command centers.

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Figure 16 - Organization Chart of Communication and Information Center

Figure 17 - Architecture of the project CV-112

V. CONCLUSIONS

This thesis addressed three important points about the current problems of telecommunications in Cape Verde.

The first is a broad study of the radio links and the presentation of a project of a radio link between the two islands with the greatest signal loss. In the simulation made with the Feixer tool, it was concluded that the connection is viable, however in the design carried out in this project the propagation in oceans is not taken into account, and this is the main problem of this connection. Therefore, this work consisted in the study of this problem in search of a cheap and efficient solution.

It has been concluded that it is possible to put a metal mesh of a certain measure at a certain height within 100 m of the receiver antenna, since the ground remains more or less flat for about 150 m.

Then, the most widely used propagation models were presented in the 3G network coverage design. 3G technology has been expanding in Cape Verde and, although it is not a reality in all the localities of the country, it currently has a population coverage of 91.07% and a total coverage area of 35.05%, according to ANAC data of December 2017.

The biggest problem when it comes to telecommunications in Cape Verde is the lack of an emergency and safety net in a complex environment marked by permanent change, multiple threats and risks, and the difficulty of predicting them, and the security that constitutes a right and an inalienable duty that has been increasingly threatened in Cape Verdean society with the globalization of society.

This work was careful to research and study the current situation and obtain important information about the project under study to mitigate these problems. ANAC, in partnership with the Ministry of Internal Administration, created a project

Table 6 - National access numbers

<table>
<thead>
<tr>
<th>Entity</th>
<th>Phone Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital</td>
<td>130</td>
</tr>
<tr>
<td>Firefighters</td>
<td>131</td>
</tr>
<tr>
<td>National Police</td>
<td>132</td>
</tr>
<tr>
<td>Judiciary Police</td>
<td>800 11 34</td>
</tr>
<tr>
<td>Civil Protection</td>
<td>800 11 12</td>
</tr>
</tbody>
</table>
for the emergency and safety net that until then, there was nothing concrete about the matter, and as the country does not have a simple telephone number to be used in case emergency, ANAC created the CV-112 project to institutionalize the telephone network number 112 as the national emergency number and to complement the security situation, this project is implemented in conjunction with a CCTV system in order to assist police and civil protection services.

The project has been implemented for more than a year, waiting only for the interface for communication between number 112 and CCTV to arrive. This delay is due to the fact that the interface is being developed by different international suppliers.

In this work, a study was also presented on the implementation of CV-112 project and RCES. The architecture of the CV-112 project is a common structural scheme in all existing command centers and the RCES is very similar to the RNES, with the difference that it will be based on TETRA and LTE technologies, while the RNES is based only on the TETRA technology. The benefits of the LTE network and its use in new emergency and safety network projects around the world were crucial for ANAC to choose that technology.

REFERENCES