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An Innovative Graphical Viewer Analysis Applied in a Multipoint Transmission System

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ABSTRACT Transmission systems are the basis of the communication systems process. This paper on the operationalization of its stages is little or rarely updated. Currently, interests are focused on global discussions on topics such as 5G networks, different types of modulation, data transfer rates, and the possibility of services focused mainly on offering quality to the end user. As technology changes, operating companies invest hundreds of millions in infrastructure and equipment, but almost always, the entire operating system from previous generations remains operative for years and does not receive proper attention, development of technologies, or improvements in the control of its operational efficiency, mainly from the point of view of automation technology upgrades. Therefore, it is important to reassess and optimize this infrastructure and its modus operandi in order to guarantee an extension of the useful life and to provide an economy to the operators. The main aim of the paper is to discuss the main aspects of a multipoint transmission system through a graphic technique called leveling diagram. It was applied based on a real scenario, in the city of Curitiba, a metropolis with more than two million inhabitants located in the Southern region of Brazil. The combination of this graphical technique and numerical analysis resulted in new modeling. Therefore, the main contribution of this paper is to provide a new alternative of visual analysis for transmission systems.

INDEX TERMS Legislation, leveling diagram, noise, power levels, reliability, transmission system.

I. INTRODUCTION

Telecommunications have become an indispensable part of modern society, having produced an intense behavioral change that integrates and influences human relationships in virtual social networks, security issues, public services, commerce, financial system, among others. From telecommunication systems and the evolution of studies related to the propagation of electromagnetic waves and new techniques of data transmission, all these scenarios have become evolutionary. Thus, the constant need to supply the continuous changes caused by the dizzying evolution of technology, which increasingly demands services of high quality, high performance and reliability, emerged in the area of radio propagation. Nowadays, there is a certain difficulty in achieving high performance in reliability in transmission systems, considering that as new technologies emerge, more engineering efforts are required in this area and in safety.

In this situation, performance is characterized by the combination of three aspects: Spectral Occupation, Received Power, and Probability of Outage. Spectral Efficiency indicates how the bandwidth employed for transmission is being used, i.e., the greater the spectral efficiency, the greater the volume of information transmitted. Spectral Occupation can be expressed by the association of 1. Spectrum Efficiency in the use of a given frequency (services); and 2. The respective legislation in force, which permeates it. In addition, Received Power describes the influence that the elements that constitute the environment of propagation have on the transmission of a signal to the receptor [1]. Finally, Probability of Outage is associated with the limit of failures permitted for a system in operation. In order to assure satisfactory performance of the system, the dissociation of these three points is not recommended, since the simple idea of the conception of transmission system requires true comprehension of these three aspects and engineering analysis of the design methodology, as well as the acknowledgment of the current legislation [1], [2].

This study combines four stations in Curitiba, a large city in the Southern region of Brazil. It aims at offering a rigorous combination of these aspects in the process of conception of a multipoint and multichannel transmission system in absolute

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consonance with both Brazilian and international legislations. Another objective is to obtain, by means of consistent methodology, data describing the most relevant characteristics for transmission systems, considering the limits required by the Brazilian telecommunications regulatory agency for systems operating in the 3.5 GHz bandwith (currently in the standardization phase in Brazil), and also for 5 GHz and 8.5 GHz bandwidths. Moreover, all data obtained was summarized in the form of interactive graphics interface, in order to simplify the comprehension and analysis of the results obtained.

The innovative aspect of graphic analysis is its possibility to analyze more easily the parameters of systems and implement changes more accurately. The main idea behind the system design process is based on the equation of parameters integrating the aspects of geometry, frequency, power, interference (noise), and link reliability. The contribution of this paper is to provide a new alternative of visual analysis for transmission systems, based on the creation of a graphic interface called Leveling Diagram, which allows for the behavioral diagnosis of transmission systems.

A. SPECTRAL OCCUPATION

In order to achieve efficient and satisfactory spectral occupation related to the signal transmission, it is necessary not only to comply with a sequence of methodological procedures but also with a well-enforced application of the current legislation. Table 1 summarizes some of the main national and international legislations in force for the 3.5 GHz, 5 GHz, and 8.5 GHz frequencies, which will be used in this article [3]–[5].

TABLE 1. Main applied normalizations.

Main Propagation-Related Aspects	
Parameter	Recommendations
Free - Space Loss	ITU-R 525-2 and ITU-R 341-5
Attenuation due to Atmospheric Gases	ITU-R 676-3 and ITU-R 676-4
Earth Curvature Factor	ITU-R 453-6
Signal Liberation Criteria	ITU-R 530-8
Main Equipment-Related Aspects	
Parameter	Recommendation
Quality Indicators	ITU-R 557-4 and ITU-R 594-2
Transmitter and Receiver Equipment	ETSI TR 102 243-1
Types of Cables	ANATEL RESOLUTION 470
Main System-Related Aspects	
Parameter	Recommendation
Calculation related to Echo Noise	ITU-R P.372-8
Calculation related to Noise due to Cross and Parallel Polarizations	ITU-R P.372-8 and ITU-R P.1238-7
Unavailability of the System due to Equipment Failure	ANATEL RESOLUTION 542
Total Link Availability	ITU-T G.25 and ITU-T G.22

B. RECEIVED POWER

The licensed frequency bands comply to severe use and service conditions applied to them. Within the scope of this paper of designing a system that operates with licensed frequency bands, a synthesis of the main legislation for the specific use of the frequency bands of 3.5 GHz, 5 GHz and 8.5 GHz is presented in Table 2 [6]–[8].

TABLE 2. Summary of the main limitations related to the respective power for each frequency.

Frequency	Band of Operation	Transmitted Power	Threshold
3.5 GHz	3400 MHz to 3600 MHz	$P_r \leq 30$ W for systems with fixed stations	For BER $\leq 10^{-6}$ 4-PSK 4-QAM = - 87 dBm 16-QAM = - 84 dBm
	3400 MHz to 3550 MHz	$P_r \leq 5$ W for fixed or mobile systems	For BER $\leq 10^{-3}$ 4-PSK 4-QAM = - 84 dBm 16-QAM = - 81 dBm
	3550 MHz to 3600 MHz	$P_r \leq 2$ W for fixed or mobile systems	
5 GHz	4440 MHz to 5000 MHz	$P_r \leq 2$ W for fixed or mobile systems	For BER $\leq 10^{-3}$ 64-QAM = - 83 dBm For BER $\leq 10^{-6}$ 64-QAM= - 86 dBm
8.5 GHz	8275 MHz to 8500 MHz	$P_r \leq 1$ W for fixed or mobile systems	For BER $\leq 10^{-3}$ 4-PSK, 16-QAM = - 85 dBm For BER $\leq 10^{-6}$ 4-PSK, 16-QAM = - 89 dBm

C. PROBABILITY OF OUTAGE

The determination of link reliability affects the choice of the most appropriate equipment to meet the needs of the system [9] and [10]. In order to determine the probability of outage for systems, the following analyses are necessary [1] and [4]:

- *System Inoperation (k):* in this study, recommendation ITU-R P.530-14 was used. It is determined by the following equations:

$$dN_1 = X_m = d, \tag{1}$$
$$\Delta = -l_1 - l_2 = -4, 4, \tag{2}$$
$$\gamma = l_x x - c_n = -0, 0027, \tag{3}$$
$$k = 10^{\Delta - \gamma dN1}, \tag{4}$$

where:

dN_1 – Represents the statistical value of the refractive gradient, which can be obtained through ITU-R P.453-9 recommendation;

Δ – Represents the diffraction loss (ITU-R 526-5);

γ – Represents the variations in atmospheric refraction.

- *Probability of Total Inoperative Period in Minutes per Year:* is the sum of the probabilities of inoperability occurring due to non-selective and selective fading. Equations 5, 6, and 7 characterize this relation [in %]:

$$Pns = \frac{I_m}{10^2} - Ps\,[\%]\,, \tag{5}$$

$$Ps = Pns + \frac{I_m}{10^2}\,[\%]\,, \tag{6}$$

$$I_m = (Pns + Ps)\,10^2\,[\%]\,, \tag{7}$$

where:

P_{ns} – Represents the probability of inoperability due to non-selective fading [%];

P_s – Represents the probability of inoperability due to selective fading [%].

- *Percentage of Time with Equipment Failures*: represents the number of defects of terminal equipment during the year and depends basically on the operating conditions. ANATEL (Brazilian National Telecommunications Agency), through resolution 542, establishes the percentage of maximum time with equipment failure allowed - F, which is determined by:

$$F = x\left(\frac{A}{MTBF_r}\frac{B}{MTBF}\right) = \frac{xa}{MTBF_r}\frac{xb}{MTBF} \tag{8}$$

where:

x – Represents the number of days in a year;

A – Represents the number of transmitters in the section considered;

B – Represents the number of modems in the section considered;

MTBFr – Represents the mean time between TX and RX failures, in days;

MTBF – Represents the mean time between modem failures, in days.

- *Total System Availability*: can be expressed by:

$$I_{total} = \left(F\left|I_p\right|p + I_e + t\right)\% \tag{9}$$

where:

I_p – Represents the system unavailability due to propagation, according to ITU-T G821 recommendation. It should not exceed the value of Ip = 15.2 × 10-6% for radio links up to 10 GHz;

I_e – Represents the unavailability of the system due to equipment failure;

t – Represents the total interruption time due to equipment failure.

II. METHODOLOGY

The methodology used for the development of this study considers three approaches: 1. Research-action structure, which is based on the survey of the system constituent parameters, such as: transmitted and received power, reception threshold, fade margin, and interference fade margin. These parameters were then used in a real case study, with the aim of having an applicability scenario that allows for their analyses; 2. Implementation of the parameters in Microsoft VBA (Visual Basic for Application), which is the database that will feed the Leveling Diagram and the simulations in MatLab and Statistical System R softwares; 3. Graphical analysis of the Leveling Diagram through SVG (Scalable Vector Graphics) tool.

FIGURE 1. Map on the localization of the stations by using Matlab® software.

The data used in this study were obtained by the generation of signals in three different frequencies. Criteria for their choice were based on the aim of working in bands of high frequencies (microwaves) in the range of SHF (Super High Frequency). Besides, factors related to service demands in relation to the number of users per channel and the technical possibility of building a point-to-multipoint system were considered to choose the frequencies. Thus, the frequencies selected were 3.5 GHz, 5 GHz, and 8.5 GHz. Fig. 1 presents the transmission system to be analyzed in this paper:

The fixed stations are named: CP – Polytechnic Center Station; M – Mercês Station; C – Colombo Station; SLP – São Luiz do Purunã Station. Fig. 1 presents a point-to-multipoint system covering six links with distances from 6 km to 48 km. The coverage areas contemplate part of the dense urban, urban, suburban, and rural areas of the city of Curitiba (state of Paraná, Brazil).

A. LEVELING DIAGRAM

After the points were established, data on each link were collected to feed the database. At this stage, Leveling Diagram consists of a physical and fixed structure with lines and arrows in the vertical and horizontal directions, which are identified according to the following conventions:

- ✓ Continuous lines in the horizontal direction represent the values of signal levels in [dBm] and noise levels in [dBm];
- ✓ Dotted lines in the horizontal direction represent the technical limits established by standards or recommendations that served as limit reference measures [dBm];
- ✓ Continuous arrows in the vertical direction represent the values indicative of the aspects related to the final reliability of the system;
- ✓ Dotted arrows in the vertical direction represent the signal values in [dB], attenuation in [dB], losses in [dB], system safety margins in [dB], and noise in [dB].

As aforementioned, this methodology, based on the Leveling Diagram, was implemented in the SVG tool. It is an XML-based application that vectorially describes two-dimensional drawings and graphs. Its physical structure, either static (fixed arrows and lines) or dynamic (arrows and lines follow changes in the information flow), are the basis to develop the prediction desired. This methodology is innovative as it provides a new alternative for visual analysis, which enables global visualization (the system as a whole), instead of visualization through separate parts, as it is traditionally performed. It is possible due to the following factors:

- ✓ Leveling diagram provides a detailed analysis of each link (end-to-end). It presents not only the most important parameters in the link, but also the current international standards for its operation, which allows for more precise adjustments and decision-making;
- ✓ At the end of the design process, all data obtained are tabulated; thus, they can be individually analyzed within the multipoint system. The process is concluded by the generation of a final report, in which the system operation is recorded as a whole. It is worth noting the importance of this report since it allows the verification of which link may have been operating in standards below the specified one as well as which parameter can be changed in order to obtain the operating levels;
- ✓ Leveling diagram enables checking and reporting each individual parameter that composes each link in blocks or windows, with the aim at solving any of level reference doubt as well as generating reports with answers in statistical standards for each individualized parameter.

III. ANALYSIS OF THE SYSTEM

In this study, it is assumed that multipoint transmission systems are characterized by the presence of a central access point interconnected with several other points in different environments, creating an efficient and broad network of data transmission controlled by a main station capable of transmitting in several channels [10] and [11]. Based on it, a survey was carried out on the current panorama of telecommunications services provided in this link in the city of Curitiba (state of Paraná, Brazil), as presented in Fig. 2. It will be considered during the design process.

Based on Fig. 2, an analysis on the number of channels assigned to each frequency and the possible services that could travel in it was performed in order to meet the demand of number of users, the amount of demand for services, as well as the application of these requirements in a multipoint system [12]. The result of this analysis is presented as the arithmetic mean performed for each frequency in Table 3:

Based on Table 3, 3.5 GHz, 5 GHz and 8.5 GHz frequencies presented higher service incidence and, consequently, higher pollution in the radio spectrum. Thus, the critetion for frequency bandwith choice is implicit. After this process, analysis on the main aspects related to transmission systems is performed based on geometric parameters [11].

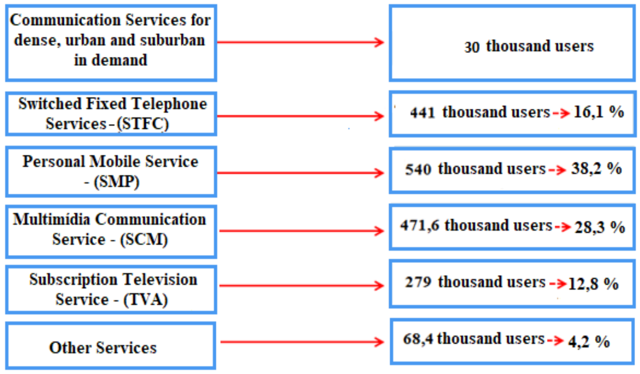


FIGURE 2. Multipoint–multichannel projected system for telecommunications services.

TABLE 3. Use of radio frequency spectrum in the metropolitan region of curitiba. Source: Anatel.

FREQUENCY UHF/SHF	AMOUNT OF CHANNELS	AVERAGE CHANNEL USER	AVERAGE DEMAND FOR SERVICES BY CHANNEL
2.5 GHz	6 channels	30 to 40 thousand users	X = 35 thousand users
3.5 GHz	40 channels	30 to 50 thousand users	X = 40 thousand users
4 GHz	6 channels	25 to 35 thousand users	X = 30 thousand users
5 GHz	7 channels	35 to 47 thousand users	X = 44 thousand users
8.5 GHz	12 channels	36 to 50 thousand users	X = 42 thousand users
11 GHz	14 channels	30 to 45 thousand users	X = 35 thousand users

- *Geometric Parameters:* is the characterization of the link physical structure. In other words, it means characterizing the morphology and topology of the covered area (height and type), choosing the radiant elements, determining the azimuth, elevations, the structuring of the cabling, the shelter, among others, in order to allow for the irradiated signal to achieve the receiving points. The main parts are described in Fig. 3

Once the latitude and longitude of the stations have been determined, the linear distance between the two points of different latitudes and longitudes is calculated, i.e., the actual distance between them is determined. This distance is known as orthodromic distance and is given by:

$$d = R\,\mathrm{arcs}(\{\mathrm{sen}(latA)\mathrm{sen}(latB) + \cos(latA)\cos(latB)\cos(longA - longB)\})[km] \quad (10)$$

$$\Delta = \mathrm{arcs}\{\mathrm{sen}(latA)\mathrm{sen}(latB)\cos(latA)\cos(latB) \times \cos(longA - longB)[\mathit{degrees}] \quad (11)$$

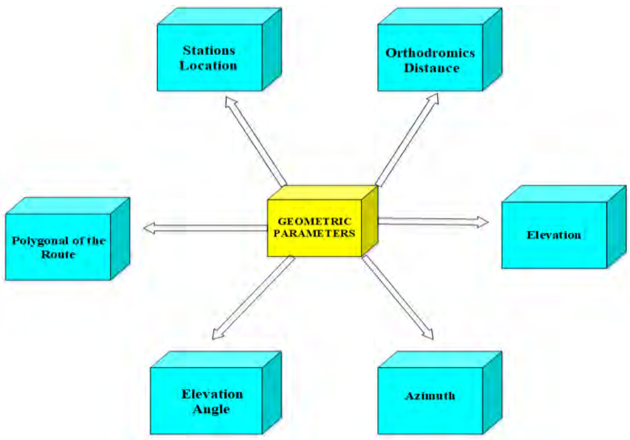


FIGURE 3. Geometric parameters.

TABLE 4. Link distance results.

		Link 1 (CP-M)	Link 2 (CP-C)	Link 3 (CP-SLP)	Link 4 (M-C)	Link 5 (M-SLP)	Link 6 (C-SLP)
Orthodromics Distance	Δ (degrees)	0.0574	0.1835	0.366595	0.1604	0.32048	0.42837
	D (km)	6.3901	20.427	40.79323	18.474	35.61375	47.6678

where:

Lat A and Long A – Represent the station geographic coordinates to the west;

Lat B and Long B – Represent the station geographic coordinates to the east;

Δ – Represents the orthodromic distance in degrees;

R – Represents the radius of the earth.

Table 4 summarizes the distances considered for the analysis.

To choose the irradiating system, ETSI TR 102 243-1 recommendation was used. It considers models of antenna with elements of the same nature, same direction, same performance class (which justifies the use of crossed polarization), similar gains, and angle discrimination to derivations that will be uniformly performed (indispensable for the calculation of the system noise). Based on this condition, a set of six antennas from Engineering & Energy Resource was chosen. Its characteristics are displayed in Table 5 [12] and [13].

Azimuth aims at aligning the antennas in the same transmission/reception direction of greater irradiated power [14]. For this purpose, it is necessary to calculate the angle between the north and the line-of-sight of the station of lower longitude. It is worth remembering that there is azimuth variation according to its geographic position. In other words, azimuth varies according to its position in relation to the north-south axis. Equations 12 and 13 allow the calculation of azimuth:

$$A_{zA} = \arccos\left\{\frac{\text{sen}\,(\text{latB}) - \cos(\Delta)\,\text{sen}\,(\text{latA})}{\text{sen}\,(\Delta)\cos(\text{latA})}\right\}, \quad (12)$$

$$A_{zB} = 360^\circ - \arccos\left\{\frac{\text{sen}\,(\text{latB}) - \cos(\Delta)\,\text{sen}\,(\text{latA})}{\text{sen}\,(\Delta)\cos(\text{latA})}\right\}, \quad (13)$$

TABLE 5. Equipment specifications.

TECHNICAL SPECIFICATIONS	
Electrical Specifications for 3.5 GHz Frequency	
Frequency Range	3550 MHz – 3555 MHz
Model of Antenna JRB – 25 e JRB – 19 (RF – Engineering & Energy Resource)	
$Gain_{TX}$, dBi	26
$Gain_{RX}$, dBi	27
$VSWR_{TX}$	1.5
$VSWR_{RX}$	1.3
Rej. In Cross Polarization for 0°, (for VHP6)	40°
Rej. In Cross Polarization for 120°, (for VHP6)	45°
Rej. In Cross Polarization for 0°, (for VHP8)	30°
Rej. In Cross Polarization for 120°, (for VHP8)	45°
Angular Discrimination, dB (for VHP6)	31
Angular Discrimination, dB (for VHP8)	42
Polarization for VHP6	H
Polarization for VHP8	H/V
Electrical Specifications for 5 GHz Frequency	
Frequency Range	4430 MHz – 4730 MHz
Model of Antenna JC – 219 e JC – 221 (RF – Engineering & Energy Resource)	
$Gain_{TX}$, dBi	28
$Gain_{RX}$, dBi	29
$VSWR_{TX}$	1.09
$VSWR_{RX}$	1.06
Rej. In Cross Polarization for 0°, (for VHP6)	32.1°
Rej. In Cross Polarization for 120°, (for VHP6)	45°
Rej. In Cross Polarization for 0°, (for VHP8)	30°
Rej. In Cross Polarization for 120°, (for VHP8)	45.8°
Angular Discrimination, dB (for VHP6)	33
Angular Discrimination, dB (for VHP8)	35
Polarization for VHP6	H
Polarization for VHP8	H/V
Electrical Specifications for 8.5 GHz frequency	
Frequency Range	8286 MHz – 8412 MHz
Model of Antenna JR – 75 e JR – 72 (RF – Engineering & Energy Resource)	
$Gain_{TX}$, dBi	29.5
$Gain_{RX}$, dBi	30.8
$VSWR_{TX}$	1.3
$VSWR_{RX}$	1.7
Rej. In Cross Polarization for 0°, (for VHP6)	30°
Rej. In Cross Polarization for 120°, (for VHP6)	44.5°
Rej. In Cross Polarization for 0°, (for VHP8)	33°
Rej. In Cross Polarization for 120°, (for VHP8)	45.5°
Angular Discrimination, dB (for VHP6)	33
Angular Discrimination, dB (for VHP8)	43
Polarization for VHP6	H
Polarization for VHP8	H/V

where:

A_{zA} – Represents the azimuth of station A;

A_{zB} – Represents the azimuth of station B.

TABLE 6. Link azimuth results.

		Link 1 (CP-M)	Link 2 (CP-C)	Link 3 (CP-SLP)	Link 4 (M-C)	Link 5 (M-SLP)	Link 6 (C-SLP)
Azimuth (degrees)	B → A	119.58	3.00115	86.5988	21.0458	80.97046	61.4030
	A → B	239.55	182.996	266.4245	201.017	260.8201	241.224

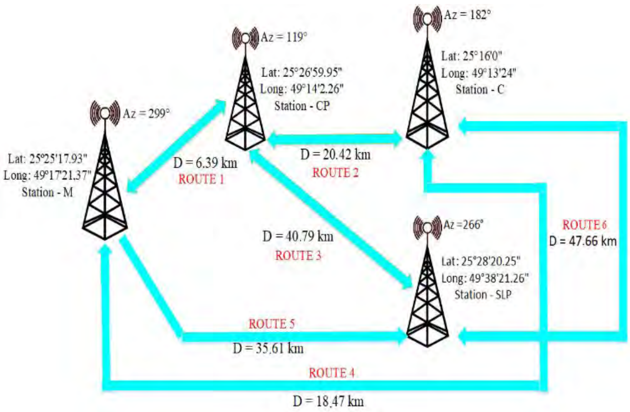


FIGURE 4. Polygonal of the route with all base stations.

TABLE 7. Link up and down tilt results.

		Link 1 (CP-M)	Link 2 (CP-C)	Link 3 (CP-SLP)	Link 4 (M-C)	Link 5 (M-SLP)	Link 6 (C-SLP)
Elevation Angle (º)	Δ	0.0574	0.18357	0.366595	0.16604	0.320048	0.42837
	AE (degrees)	- 0.071	- 0.0229	- 0.04582	- 0.0207	- 0.04001	- 0.0554

Based on the locations of the system stations, azimuth results are presented in Table 6.

The definition of the polygonal route is an indispensable condition required by ANATEL. Its main objective is to align the azimuth of all stations that are part of the link, which is a preponderant factor when efficiency and quality of the system are desired [14]. The polygonal of the route that contains all stations is displayed in Fig. 4.

In order to improve the alignment between transmission and receiving antennas, the elevation angle is determined. This angle indicates the slope required for the antenna in relation to the horizontal plane and is given by:

$$AE = \tan^{-1}\left[\frac{\left(\cos\frac{\Delta}{4} - 1\right)}{\left(\mathrm{sen}\frac{\Delta}{4}\right)}\right] \tag{14}$$

Table 7 summarizes the up and down tilt values considered for the analysis.

Choosing the type of cable to be used in the design is very important as the cable may be responsible for some of the possible losses that may occur in the link [15]. The calculation of the loss in the cable is obtained by the following equations:

$$A_c = \frac{1,4110^3\left(\frac{ki}{2a} + \frac{k_a}{2}b\right)\sqrt{f} + 100pf\sqrt{\varepsilon_r}}{z_0}, \tag{15}$$

$$z_0 = \frac{138.16}{\sqrt{\varepsilon_r}}\log\frac{bk_a}{ak}, \tag{16}$$

$$A_c\ \text{meters} = \left(\frac{A_c\ \text{tower height}}{100}\right), \tag{17}$$

where:

a – Represents the internal conductor radius [mm];

b – Represents the external conductor radius [mm];

ki – Represents the correction factor for the internal conductor binding;

k_a – Represents the correction factor for the conductor type of construction;

f – Represents the operating frequency [GHz];

p – Represents the tangent of losses;

Z0 – Represents the impedance of the cable [Ω];

ε_r – Represents the dielectric constant [F/m].

- *Frequency and Propagation Parameters*: The frequencies used in the links were primarily determined according to the type of service in which it would be used [16]. Based on the choice of frequency, it was possible to determine the antenna tower heights, losses due to atmospheric gasses, rainfall losses, cable losses, signature area, and dispersive fade margin for each link. as shown in the Fig. 5.

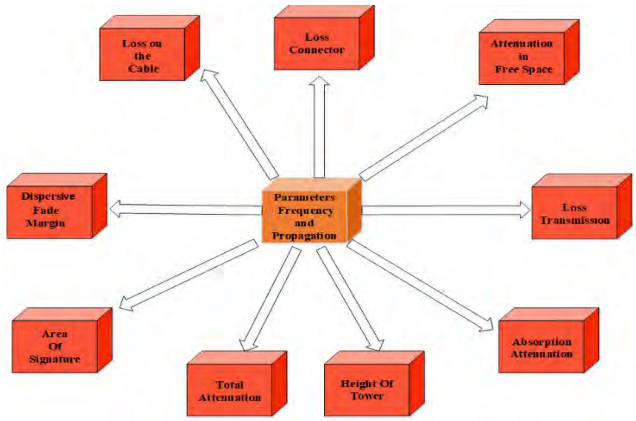


FIGURE 5. Frequency and propagation parameters.

As the focus of this paper is presenting a graphical analysis proposal, in this first moment, only the propagation in free space was considered as a system prediction model. Therefore, in order to better understand the process used to find link loss values, a detailed description of the criteria imposed on the system was performed. Table 8 shows the results for frequency and propagation parameters obtained at 3.5 GHz frequency.

Based on the data from Table 8, some conclusions that similarly apply to the other two frequencies used in this study can be drawn from the 3.5 GHz frequency.

TABLE 8. Results for frequency and propagation parameters at 3.5 GHz frequency.

	Link CP-M	Link CP-C	Link CP-SLP	Link M-C	Link M-SLP	Link C-SLP
Tower Height for k = 4/3	66.80 m	70.34 m	75.22 m	48.6 m	72.89 m	112.45 m
Tower Height for k = 2/3	63.23 m	65.93 m	72.80 m	39 m	68.77 m	96.32 m
Free Space Loss	119 dB	113 dB	130 dB	119 dB	129 dB	128 dB
Transmission Loss	61 dB	60 dB	62 dB	66 dB	68 dB	67 dB
Cable Loss for k = 2/3	3.0 dB	4.5 dB	4.8 dB	4.5 dB	4.8 dB	5 dB
Connector Loss	0.25 dB	0.27 dB	0.28 dB	0.35 dB	0.38 dB	0.42 dB
Rainfall Loss	0.7553 dB	0.6448 dB	0.5745 dB	0.44 dB	0.6906 dB	0.6049 dB
Atmospheric Absorption Loss	0.021 dB	0.032 dB	0.028 dB	0.027 dB	0.025 dB	0.035 dB
Signature Area	3.18^{-9} n/s	3.11^{-9} n/s	3.19^{-9} n/s	3.15^{-9} n/s	3.16^{-9} n/s	3.28^{-9} n/s
Dispersive Fade Margin	19.16 dB	21.11 dB	25.36 dB	24.2 dB	23.25 dB	28.36 dB
Total Attenuation for k = 2/3	64.27 dB	64.75 dB	67.15 dB	70.8 dB	74.12 dB	73.39 dB

The first step in this process was calculating the free-space attenuation, cable losses, waveguides, connectors, and visibility criterion, which considers the release of 100% of Fresnel zone when the earth curvature factor is k = 4/3, or 60% when the curvature factor is k = 2/3. Then, the position or height of the antenna in the tower was calculated. ITU-R530-09 is recommended for designs in which the height of antennas in the towers is higher than 30 m and shorter than 82 m [17] and [18]. Based on this recommendation, the most critical visibility scenario (k = 2/3) was considered in the calculations.

To calculate cable and connector losses, an acceptable loss limit of up to 4.5 dB, which meets the ITU criteria, was adopted for towers up to 55 meters in height in the frequencies of 3 GHz to 10 GHz. Even though there were small divergences in dB, above the critical limit established by the standard, these results were regarded as non-ideal but acceptable, considering the theoretical basis that acknowledges that every designer admits a margin of tolerance within the system, which covers precisely these types of setbacks. This margin is estimated to be up to 1 dB above the recommended value. ITU-R P.837-6 recommendation was used to calculate losses due to rainfall $A_{0,01}$, as demonstrated by:

$$A_{0,01} = \gamma_r d_{ef}, \tag{18}$$

$$d_{ef} = (dr), \tag{19}$$

$$r = \frac{1}{0,477 d^{0.633} R_{0.01}^{0.073a} f^{0.123} - 10.579(1 - e^{-0,.24d})}, \tag{20}$$

where:

$R_{0.01}$– Represents the rainfall rate exceeded by 0.01% (average per year);

d_{ef} – Represents the link segment in which there is higher rainfall incidence;

r – Represents the effective link length in [km];

Based on it, the rainfall losses presented values below 2 dB. To determine losses due to absorption of atmospheric gases A_{ab}, the following equations were used:

$$A_{ab} = (A_{as} + A_{au})\, d, \tag{21}$$

$$A_{as} = \left(7.1910^{-3} + \frac{6.09}{f^2 0.227} + \frac{4.81}{(f-57)^2 + 1.50}\right) f^2 10^{-3}, \tag{22}$$

$$A_{au} = (0.050 + 0.0021p + \frac{3.6}{(f-22.2)^2 + 8.5} + \frac{10.6}{(f-183.3)^2 + 9} + \frac{8.9}{(f-325.4)^2 + 26.3}) p f^2, \tag{23}$$

where:

A_{as} – Represents the specific attenuation of dry air/oxygen in [dB/km];

A_{au} – Represents the specific attenuation of wet air/water vapor in [dB / km];

p – Represents the density of water vapor in gram/m^3 (the standard recommends using p = 7.5 g/m^3.

The results obtained provide the signal absorption due to gases present in the atmosphere. As the values were lower than 0.2 dB, they were discarded of the calculation of the link total attenuation. Regarding the determination of the signature area (which is responsible for quantifying the equipment robustness in relation to the distortions caused by selective fade), the smaller the signature area, the more sensitive and reliable the reception equipment. According to ETSI TR 102 243-1, this value should be around 10^{-8}. The values found were around 10^{-9} for all study links. To determine the signature area S_W, the following equations were used:

$$S_w = \frac{(S_m + S_{nm})}{2}, \tag{24}$$

$$S_m = \frac{(\lambda_m B_s 10^{-3})}{\tau_r}, \tag{25}$$

$$S_{nm} = \frac{(\lambda_{nm} B_s 10^{-3})}{\tau_r}, \tag{26}$$

where:

S_m – Represents the signature area for minimum phase;

S_{nm} – Represents the signature area for non-minimal phase;

TABLE 9. Results for frequency and propagation parameters at 5 GHz frequency.

	Link CP-M	Link CP-C	Link CP-SLP	Link M-C	Link M-SLP	Link C-SLP
Tower Height for k = 4/3	75.05 m	77.8 m	85.22 m	62.1 m	75.77 m	121.55 m
Tower Height for k = 2/3	69.21 m	67.1 m	76.94 m	56 m	72.33 m	97.12 m
Free Space Loss	122 dB	132 dB	138 dB	131 dB	137 dB	139 dB
Transmission Loss	68 dB	78 dB	84 dB	77 dB	83 dB	85 dB
Cable Loss for k = 2/3	4.0 dB	4.5 dB	3.8 dB	4.6 dB	4.2 dB	4.9 dB
Connector Loss	0.22 dB	0.23 dB	0.29 dB	0.31 dB	0.33 dB	0.40 dB
Rainfall Loss	1.8048 dB	1.595 dB	1.4615 dB	1.18 dB	1.4101 dB	1.5223 dB
Atmospheric Absorption Loss	0.0017 dB	0.002 dB	0.0028 dB	0.003 dB	0.0039 dB	0.0032 dB
Signature Area	6.94^{-9} n/s	6.96^{-9} n/s	7.43^{-9} n/s	6.97^{-9} n/s	7.99^{-9} n/s	7.82^{-9} n/s
Dispersive Fade Margin	23.18 dB	24.33 dB	26.79 dB	22.25 dB	28.33 dB	30.14 dB
Total Attenuation for k = 2/3	65.32 dB	66.7 dB	68.15 dB	71.2 dB	78.12 dB	79.39 dB

λ_m – Represents the mean depth for minimum phase;

Bs – Represents the bandwidth of the signature areas in [MHz];

τ_r – Represents the reference delay at 6.3 in [ns].

As important as the determination of the equipment signature area is the calculation of the dispersive fade margin (MDF), which is an indicative aspect of the system state in relation to the inoperative. ANATEL RESOLUTION 492 is recommended as reference, as it indicates MDF operating below 25 dB for frequencies from 3 GHz to 12 GHz at a distance of up to 20 km as guarantee of the equipment quality. In this case, for instance, CP-SLP and C-SLP links presented values slightly above the critical limit recommended. This situation occurs since, for these two scenarios, the distances between the links were superior to 20 km, causing more errors due to distortions in the signal, basically caused by multipath, and making the equipment susceptible to greater interference probability. MDF calculation was determined by:

$$MDF = 17,6 - 10\ln\frac{S_w}{158,4} \tag{27}$$

Regarding the attenuation in free space, the conceptual basis that frequency and distance are directly proportional, i.e., the higher the frequency and distance, the greater the signal attenuation, must be acknowledged, considering the best propagation scenario, which is direct line-of-sight (LOS) [19]. Based on it, the values found corroborate with the ones expected. Table 9 shows the results for frequency and propagation parameters obtained at 5 GHz frequency.

Table 10 shows the results for frequency and propagation parameters obtained at 8.5 GHz frequency.

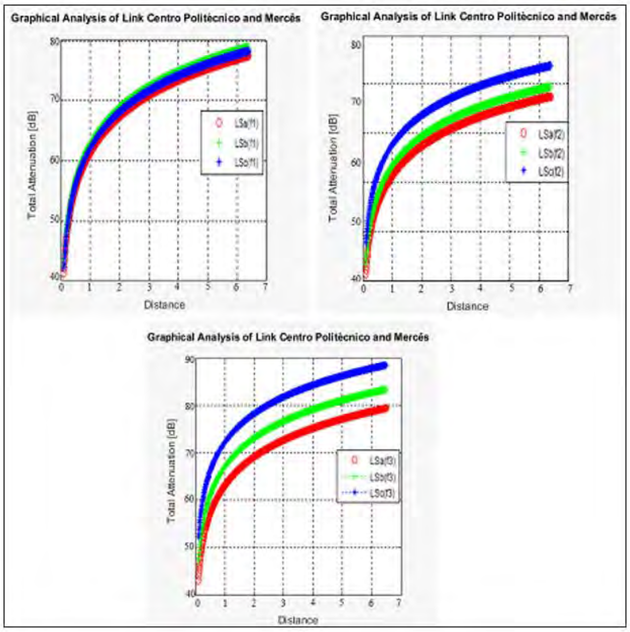
TABLE 10. Results for frequency and propagation parameters at 8.5 GHz frequency.

	Link CP_M	Link CP_C	Link CP_SLP	Link M_C	Link M_SLP	Link C_SLP
Tower Height for k = 4/3	78.81 m	86.94 m	88.82 m	60.49 m	66.89 m	125.71 m
Tower Height for k = 2/3	70.11 m	80.68 m	87.61 m	55.94 m	60.20 m	97.96 m
Free Space Loss	127 dB	120 dB	134 dB	126 dB	125 dB	118 dB
Transmission Loss	66 dB	64 dB	67 dB	62 dB	67 dB	69 dB
Cable Loss for k = 2/3	3.8 dB	3.6 dB	4.4 dB	3.5 dB	4.6 dB	5.2 dB
Connector Loss	0.32 dB	0.34 dB	0.38 dB	0.37 dB	0.40 dB	0.42 dB
Rainfall Loss	1.47 dB	1.6939 dB	1.9621 dB	1.768 dB	1.9819 dB	1.9829 dB
Atmospheric Absorption Loss	0.003 dB	0.0038 dB	0.022 dB	0.0026 dB	0.0021 dB	0.0032 dB
Signature Area	7.97^{-9} n/s	7.98^{-9} n/s	7.8^{-9} n/s	8.7^{-9} n/s	8.9^{-9} n/s	8.39^{-9} n/s
Dispersive Fade Margin	24.08 dB	24.42 dB	27.85 dB	24.56 dB	26.62 dB	31.37 dB
Total Attenuation for k = 2/3	69.27 dB	71.75 dB	68.14 dB	70.45 dB	62.22 dB	75.69 dB

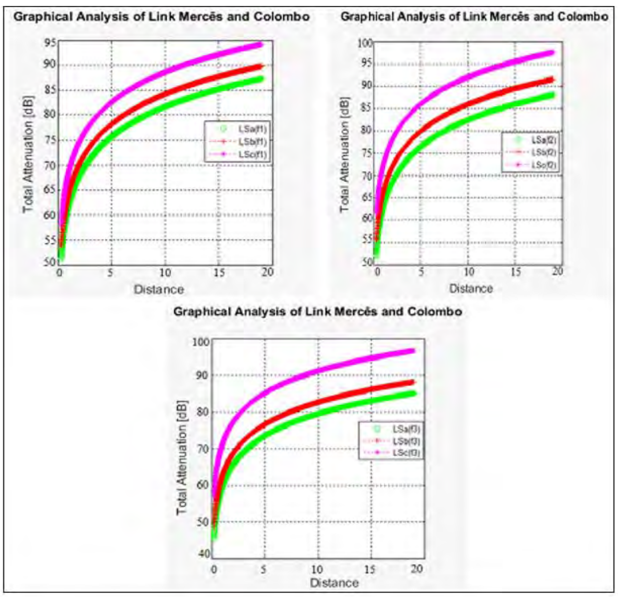
Moreover, determining the system total attenuation is very important. Thus, each link studied was implemented in Matlab software and can be then analyzed. It is noteworthy that, for the purpose of simulating the link total attenuation, tower heights were considered for k = 2/3. To organize the article, only the graphs referring to CP-M, M-C and C-SLP links will be presented, since their visualization includes two distinct scenarios (dense urban and urban areas of Curitiba).

Results on the total attenuation of the system for CP-M stations are presented in Graph 1.

The distance variation from 2 to 6 km in the frequency of 3.5 GHz decreases the link net attenuation by up to 23 dB. Similarly, for the frequency of 5 GHz, this attenuation drops by up to 18 dB. For the frequency of 8.5 GHz, the attenuation drops by approximately 14 dB. Therefore, the shorter the distance and frequency, the lesser the loss that the system will suffer.



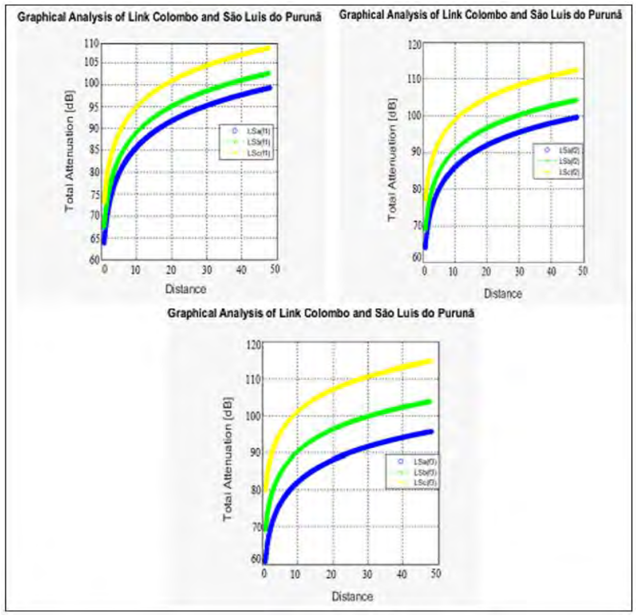
GRAPH 1. Link Total Attenuation (CP–M) for the three frequencies considered in this study.



GRAPH 2. Link Total Attenuation (M–C) for the three frequencies considered in this study.

Results related to the total attenuation of the system for M-C stations are presented in Graph 2.

The distance variation from 10 to 19 km in the frequency of 3.5 GHz decreases the link net attenuation to 8 dB, whereas for the frequencies of 5 GHz and 8.5 GHz, this value is around 4 and 5 dB, respectively. Therefore, for the urban area of Curitiba, one of the appropriate solutions to improve this result is increasing the gain of the antennas involved in the system, as well as using cables with lesser loss or even using repeaters at critical points of the stretch.



GRAPH 3. Link Total Attenuation (C-SLP) for the three frequencies considered in this study.

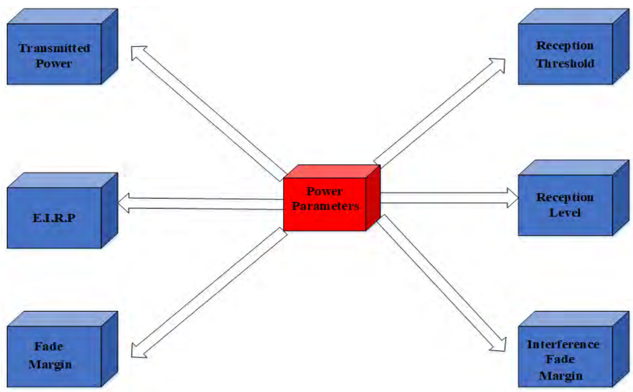


FIGURE 6. Power parameters.

Results related to the total attenuation of the system for C-SLP stations are presented in Graph 3.

The distances from 25 to 48 km in the frequencies of 3.5 GHz, 5 GHz and 8.5 GHz decrease the link net attenuation in 4 dB for the three cases. When the link is designed for long distances (rural), it is practically mandatory to install repeaters in order to improve the performance of the system regarding losses (mainly due to free-space attenuations).

- *Power Parameters:* Once the link has been dimensioned, the levels of the received signal that will act directly in the final calculation of the system reliability are verified. The main aspects covered in this section are described in Fig. 6.

As important as determining the system total attenuation is calculating everything that impacts on the received power [20], starting at the calculation of the E.I.R.P value, which represents a mechanism for verifying the actual power that the antenna is transmitting. According to ITU-R 557-4 and ANATEL resolution 609, the E.I.R.P value recommended for frequencies from 3 to 7 GHz is up to 55 dBm. However, this condition is valid only if the transmitted power of the equipment does not exceed the limit of 33 dBm. Meanwhile, for frequencies of 8 to 12 GHz the EIRP value recommended is limited to 53 dBm if the transmitted power is maximum of 30 dBm [21].

Another important parameter is the threshold, which represents the limit value of the lowest permissible signal level at the receiver input, in order to preserve high reliability for the BER (Bit Error Rate). BER is the verification parameter for errors introduced in the channel and determines the integrity of the received signal. In a very simplistic way, it can be defined BER = number of wrong received bits/ number of transmitted bits. Besides, it provides an ideal mean for analyzing the quality of signal reception since it analyzes the link as a whole: transmitter, environment and receiver [21]. Based on it, Table 11 shows the results for power parameters obtained at 3.5 GHz frequency.

TABLE 11. Results for power parameters at 3.5 GHz frequency.

	Link CP-M	Link CP-C	Link CP-SLP	Link M-C	Link M-SLP	Link C-SLP
Transmitted Power	28 dBm	28 dBm	28 dBm	28 dBm	28 dBm	28 dBm
Received Power	- 52.5 dBm	- 61 dBm	- 65 dBm	- 63 dBm	- 59 dBm	- 65 dBm
Threshold	- 84 dBm	- 84 dBm	- 84 dBm	- 84 dBm	- 84 dBm	- 84 dBm
BER	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
E.I.R.P	42.12 dBm	46.1 dBm	43.35 dBm	42.8 dBm	42.88 dBm	40.08 dBm
MD	28 dB	27 dB	25 dB	23 dB	26 dB	25 dB
MDI	29 dB	28 dB	26 dB	24 dB	27 dB	26 dB

Table 12 shows the results for power parameters obtained at 5 GHz frequency.

Table 13 shows the results for power parameters obtained at 8.5 GHz frequency.

Based on Tables 11, 12 and 13, the results obtained are within the limits for all scenarios under analysis. The values obtained through the MD (Fade Margin) calculation aim at providing an indicative of the system performance system, i.e., they represent a safety measure. According to some technical recommendations, references to indicative standards of MD quality for urban regions are usually made as: Excellent, when the system MD exceeds 28 dB; Normal, for scenarios where the margin varies from 15 dB to 25 dB (the system is considered as non-linear and probably will not be stable at all times of its operation); and Inappropriate, when the link

TABLE 12. Results for power parameters at 5 GHz frequency.

	Link CP-M	Link CP-C	Link CP-SLP	Link M-C	Link M-SLP	Link C-SLP
Transmitted Power	30 dBm	30 dBm	30 dBm	30 dBm	30 dBm	30 dBm
Received Power	- 50.43 dBm	- 55 dBm	- 59.22 dBm	- 52 dBm	- 55.56 dBm	- 56.92 dBm
Threshold	- 83 dBm	- 83 dBm	- 83 dBm	- 83 dBm	- 83 dBm	- 83 dBm
BER	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
E.I.R.P	49.07 dBm	50. 5 dBm	48.55 dBm	47.8 dBm	47.38 dBm	45.24 dBm
MD	30 dB	29 dB	27 dB	26 dB	22 dB	24 dB
MDI	31 dB	28 dB	26 dB	27 dB	23 dB	25 dB

TABLE 13. Results for power parameters at 8.5 GHz frequency.

	Link CP-M	Link CP-C	Link CP-SLP	Link M-C	Link M-SLP	Link C-SLP
Transmitted Power	30 dBm	30 dBm	30 dBm	30 dBm	30 dBm	30 dBm
Received Power	- 50.5 dBm	- 61 dBm	- 62 dBm	- 65 dBm	- 67 dBm	- 66 dBm
Threshold	- 89 dBm	- 89 dBm	- 89 dBm	- 89 dBm	- 89 dBm	- 89 dBm
BER	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
E.I.R.P	52.12 dBm	51.6 dBm	48.31 dBm	49.4 dBm	49.14 dBm	48.48 dBm
MD	29 dB	27 dB	26 dB	29 dB	28 dB	30 dB
MDI	30 dB	28 dB	25 dB	30 dB	29 dB	31 dB

has MD below 15 dB. Therefore, the results obtained have satisfactory MD for all cases.

- *Noise Parameters:* Noise represents any undesired signal that interferes with a system transmission process. It can have different sources, either natural or artificial. In a transmission system, noise level must be as low as possible; thus, the link performance does not decay. In this study, the most common noises in transmission systems were investigated. Besides, their levels were determined based on calculations on thermal noise contribution for 100%, 50% and 80% of time, echo noise, and interfering noise due to parallel and cross polarizations [21].

Thermal noise represents the noise generated inside equipment and circuits due to agitation of the atoms that compose them or to electromagnetic interactions, i.e., it is an inherent factor in any system. Thus, the calculation for its operation at 100% of time (most restrictive condition) is given by:

$$RT = 174 + 10\log B + FR \tag{28}$$

FR noise figure of 3 dB and a LB bandwidth corresponding to each operating frequency (e.g.: for a frequency of 3.5 GHz, B = 5 MHz) were considered. The noise contributions at 50% and 80% of time represent values indicative of possible situations that may occur in the equipment operation. For these cases, the following equations were used:

$$\frac{S}{NTh_{50\%}} = VS - (P_t + P_r)\,[dB]\,, \tag{29}$$

$$\frac{S}{NTh_{80\%}} = \frac{S}{NTh_{50\%}} - 2[dB], \tag{30}$$

where:

VS – Represents the ideal value of the signal-to-noise ratio at the transmitter output, which would be obtained in the case of a lossless transceiver connection.

The expression that characterizes this relation in [dB] is given by:

$$VS = P_t - FR - 10\log\frac{KT}{1\times10^{-3}} + 20\log\frac{\Delta f_{ef}}{f_0} + 139 + cp, \tag{31}$$

where:

K – Represents Boltzmann constant = 1.38×10^{-23} [J/°K];

T – Represents the ambient temperature in [°K];

cp – Represents the psofometric factor, considered as 2.5 dB in this study;

Δfef – Represents the channel bandwidth in [MHz];

f_0 – Represents the channel center frequency in [MHz].

The most likely environment to cause interference due to echo noise occurs in urban areas (mainly in the dense area), due to the number of concurrent users on adjacent channels. Other probable reasons are related to mismatching in the waveguide system (e.g.: antenna steady-wave ratio – VSWR, or even signal speed in the cables). The equations used to determine echo noise are:

$$\frac{S}{R_E} = 18,6 + PR_a + PR_b + 2A_c + X, \tag{32}$$

$$PR = 20\log\frac{VSWR+1}{VSWR-1}, \tag{33}$$

$$FC_{bb} = -15\log N, \tag{34}$$

$$m = \frac{\Delta f_{ef} 10^{\frac{FC_{bb}}{20}}}{f_m}, \tag{35}$$

$$\tau = \frac{2L_{cable}}{v_t c}, \tag{36}$$

$$\Delta\emptyset = 10\log\left(f_m + \tau\right), \tag{37}$$

where:

N – Represents the number of channels considered;

X – Represents the induction attenuation within the channel considered in [dB];

Δ fef – Represents the channel bandwidth in [MHz];

f_m – Represents the link operating frequency of the [GHz];

τ – Represents the traffic signal velocity in the cable in [m/s];

c – Represents the speed of light in [m/s].

Moreover, interfering noises due to cross and parallel polarizations are considerably important. Determining interfering noises due to parallel polarization is a preventive measure in the case when the transmitting links share the same operating range and use antennas with the same sense of polarization (either vertical or horizontal). The equations used are:

$$\frac{S}{NI_{\emptyset}} = 20\,dB + P_r - Y - RI_{\emptyset}, \tag{38}$$

$$RI_{\emptyset} = P_t + G_A + G_B - A_e - P_{alim\ a} - P_{alim\ b} - D_{\emptyset}, \tag{39}$$

As the need to design high performance transmission systems and differentiated services increases, the use of antennas with alternating polarizations is adopted as a technique. Consequently, the system ensures greater capacity at the cost of increasing vulnerability regarding the interference between links. The determination of interfering noises due to cross polarization is calculated through the following equations:

$$\frac{S}{NI_{PC}} = 20\,dB + P_r - Y - RI_{PC}, \tag{40}$$

$$RI_{PC} = RI_{\emptyset} - R_{PC}, \tag{41}$$

where:

$RI_{\emptyset}$ and RI_{pc} – Represent parallel and cross polarizations, respectively, in [dB];

AT – Represents attenuation in [dB];

$P_{alim\ a}$ – Represents the loss in feeders of transmitting station A in [dB];

$P_{alim\ b}$ – Represents the loss in feeders of transmitting station B in [dB];

DØ – Represents the antenna angular discrimination in [dB].

Finally, the values corresponding to the sum of the noise in each link were determined by checking whether or not the results obtained were within an acceptable limit (the values obtained for noise contribution at 50% and 80% of time should be greater than the noise contribution that operates at 100% of time).

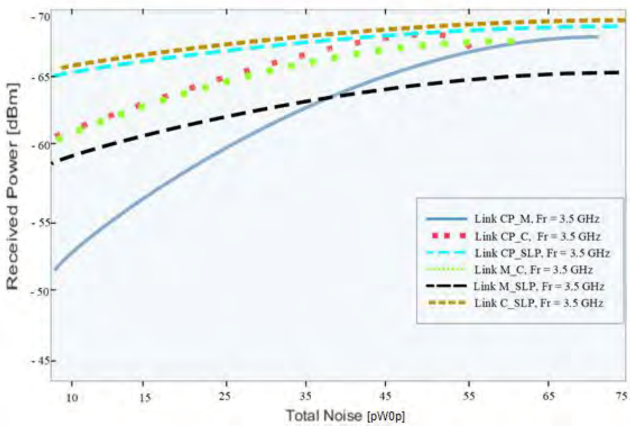
Table 14 shows the results for noise parameters obtained at 3.5 GHz frequency.

The results obtained for the system total noise represent the sum in *p*W0*p* of all noises considered relevant in the links [22]. ITU-R 395-1 resolution imposes that the noise level of a transmission system must not exceed the limit of 2*d* -100, regardless of the number of stations (where *d* represents the link distance in kilometers). It should not exceed the total limit of 60 *p*W0*p* (25 dB in average) for links up to 40 km. In addition, it should be noted that this weighting was performed for all frequencies under study. To sum up, results referring to the total noise of the frequencies studied can be observed in Graphs 4, 5 and 6, which present the total noise for 80% of time in Pw0P:

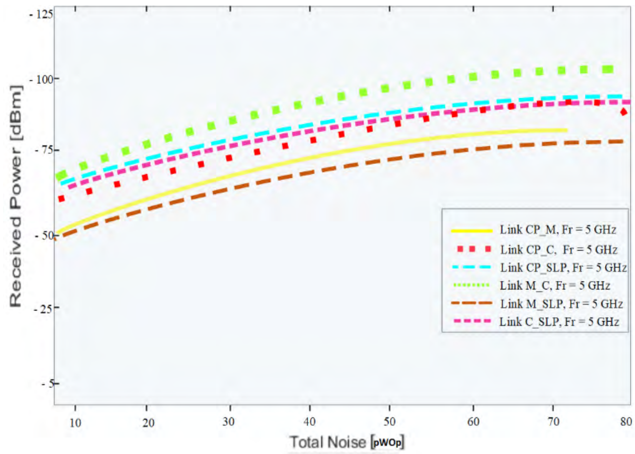
These graphs present values corresponding to the sum of the existing noises in each link, considering its performance when the period of activity (equipment operating time) is equivalent to 80% of time. The noise intensifies significantly

TABLE 14. Results for noise parameters at 3.5 GHz frequency.

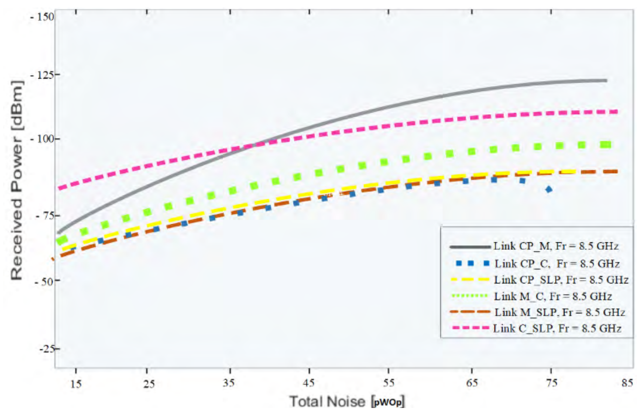
	Link CP_M	Link CP_C	Link CP_SLP	Link M_C	Link M_SLP	Link C_SLP
Noise Figure	3 dB	3 dB	3 dB	3 dB	3 dB	3 dB
SNR	39.67 dB	40.02 dB	40.69 dB	40.36 dB	41.16 dB	41.27 dB
System Value	70.83 dB	70.65 dB	71.22 dB	71.34 dB	71.83 dB	72.25 dB
System Equivalent Temperature	290 º	290º	290º	290º	290º	290º
Echo Noise	45 dB	49.23 dB	51.22 dB	53.67 dB	55.87 dB	61.33 dB
Thermal Noise	- 105 dBm	- 105 dBm	- 105 dBm	- 105 dBm	- 105 dBm	- 105 dBm
RPP	72 dB	74 dB	71 dB	80 dB	78 dB	81 dB
RPC	67 dB	66 dB	68 dB	65 dB	70 dB	72 dB
Thermal Noise for 50% of Time	16.2 dB	12.23 dB	18.64 dB	22.18 dB	26.54 dB	28.09 dB
Thermal Noise for 80% of Time	14.2 dB	9.23 dB	13.64 dB	19.18 dB	23.54 dB	26.09 Db



GRAPH 4. Total noise x received power for 3.5 GHz frequency.



GRAPH 5. Total noise x received power for 5 GHz frequency.



GRAPH 6. Total noise x received power for 8.5 GHz frequency.

(over 60 pW0p) in the frequency of 8.5 GHz for CP-SLP, M-SLP M-C, and C-SLP. It is noteworthy that, for the other stretches and frequencies, the noise level was within acceptable limits.

- *Reliability Parameters:* The reliability of a transmitting link is defined as the capacity in which a system performs its functions within a certain amount of time. Several factors hinder the determination of this reliability, such as the equipment tolerance limits in relation to the operating conditions. In practice, it is only possible to statistically express reliability through the failure probability that occurs within a certain amount of time. The main aspects discussed in this section are described in Fig. 7.

Determining the link reliability impacts on the choice of the most appropriate equipment to meet the needs of the system [23]–[25]. Graphs 7 e 8 show the values obtained for the system final reliability.

ITU-T G. 821 recommendation and ANATEL resolution 368 affirm that a system must operate correctly over a complete time interval to be considered as efficient. Usually, the system operation percentage higher than 95% is used as the reference parameter. Based on it, only C-SLP link in the frequencies of 5 and 8.5 GHz presented reliability rate slightly below 95%. It should be emphasized that analyzing the link final reliability also represents an indispensable factor in the system evaluation.

IV. FRAMEWORK GRAPHICAL ANALYSIS

This section represents the third part of the methodology proposed. The authors [21], [26]–[28] have already proposed results in transmission system by graphical analysis.

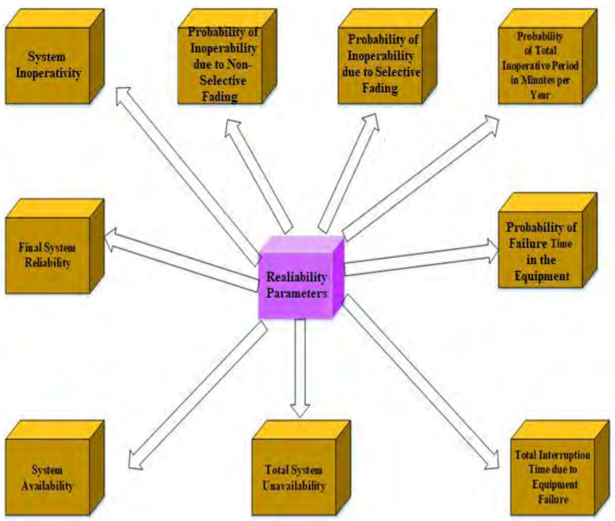
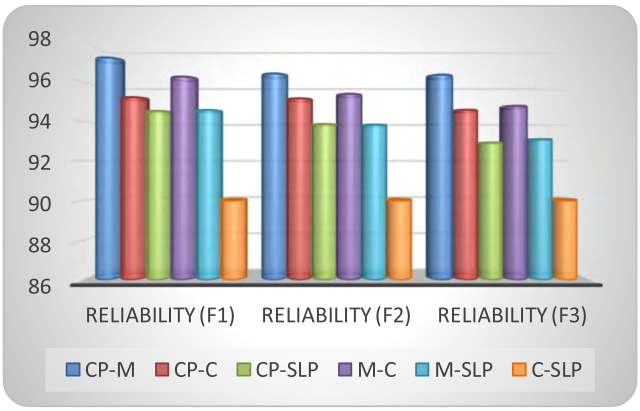
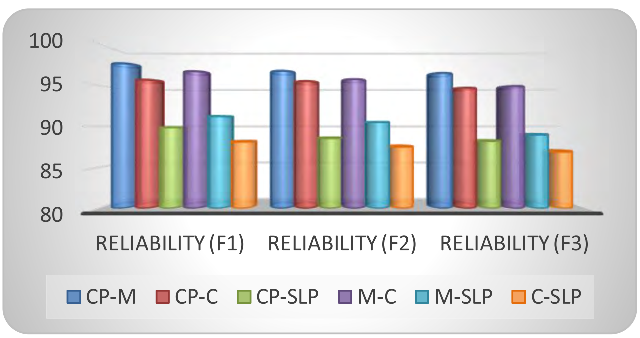


FIGURE 7. Reliability parameters.



GRAPH 7. Final system reliability for k = 4/3.



GRAPH 8. Final system reliability for k = 2/3.

However, this study proposes the elaboration of a dynamic signal level diagram. This proposition represents the solidification of the methodological proposal of this study, which consist of contributing in the process of conception of transmission systems.

The dynamic diagram proposed in this study is translated as a useful and sufficiently simplified tool since it schematically and visually offers the designer a simplified understanding of the process steps, and its results as a consequence. Information on the attenuation that the signal suffers along the path can serve as a point of discussion to establish criteria that improve (if necessary) the losses in the system and, as such, propose solutions related to the insertion of cables with fewer losses, antennas with higher gain, or even the addition of repeaters for long distances.

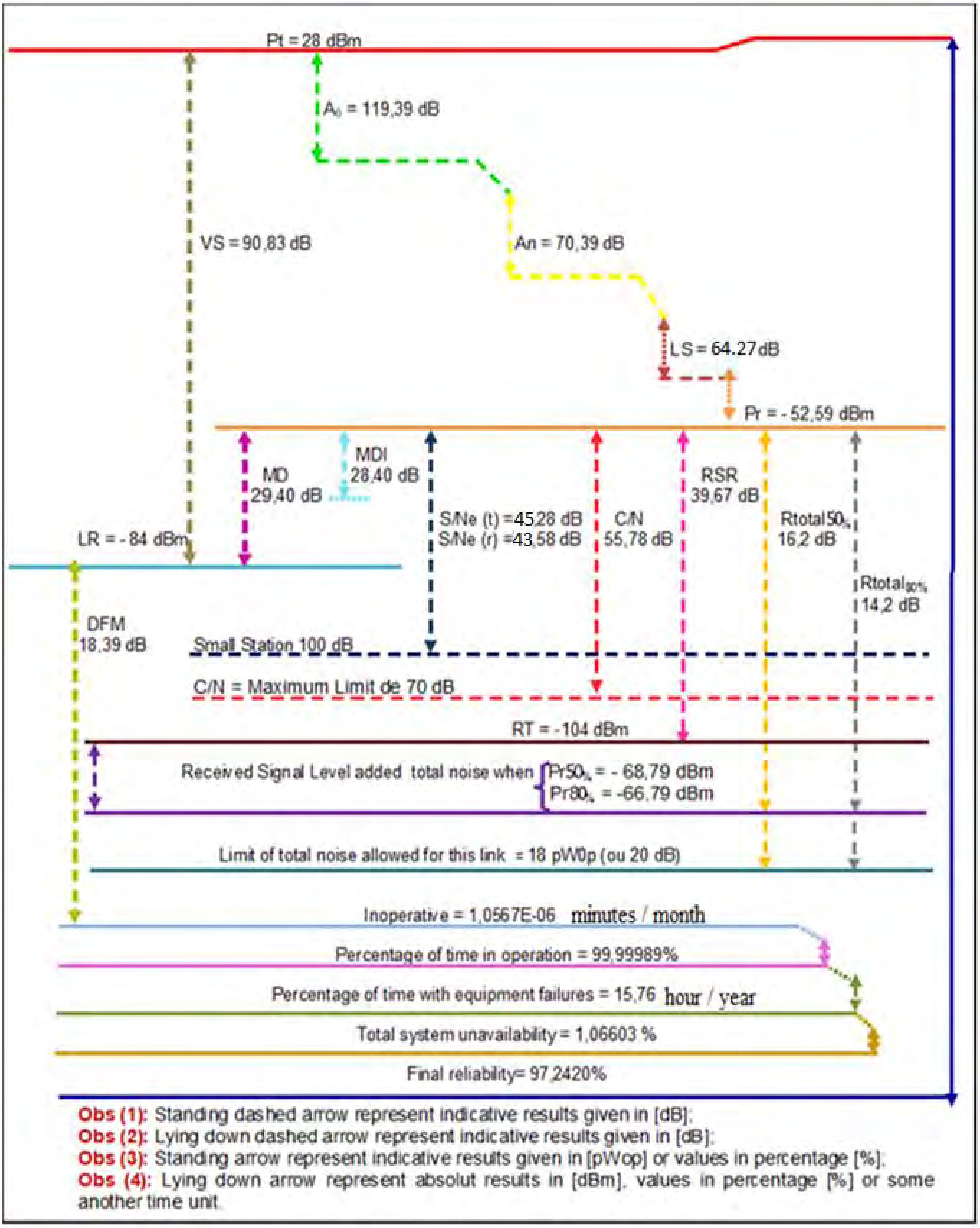
In addition, this information helps the designer regarding the interpretation of the losses that occur in the system, such as signal and noise levels, which are also possible issues to be discussed through the diagram.

Furthermore, it is possible to evaluate the received signal level in relation to the threshold due to the total noises (thermal noise, echo noise, noise due to parallel and cross polarizations, signal-to-noise ratio) generated within that system, as well as checking the fade margin that gives to the designer a sense of its operation. It should be noted that aspects related to system reliability can also be evaluated in the diagram as well as many other analyzes. Graphs 9, 10 and 11 on the link CP-M (dense urban area) show one example of this graphical analysis for the three frequencies studied.

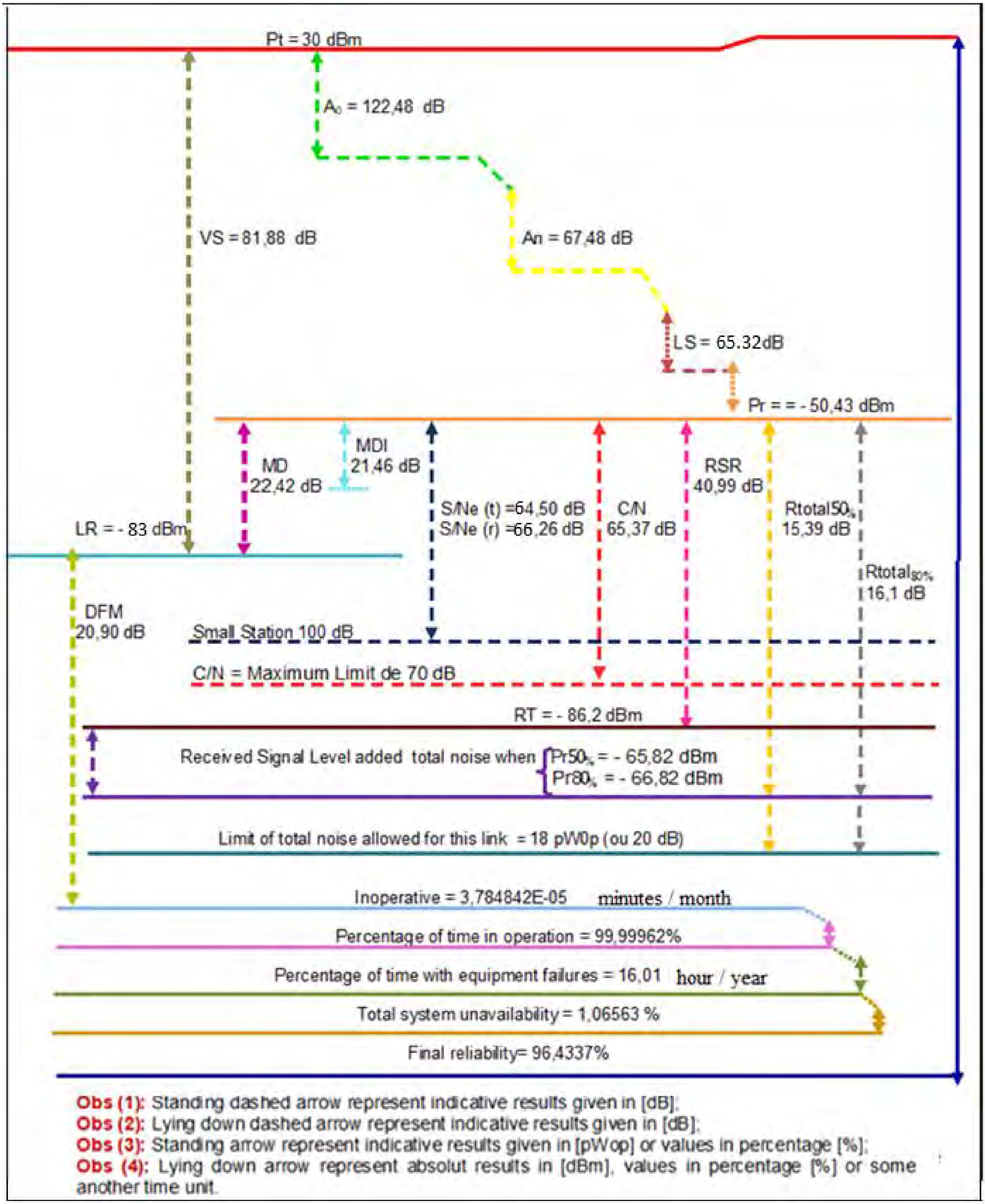
V. DISCUSSIONS OF THE RESULTS OBTAINED BY THE LEVELING DIAGRAM

It was possible to describe and visualize the behavior of a link operating at 3.5 GHz frequency through the signal leveling diagram shown in Graph 9, as it represents the behavior of a multipoint system that must support services for a large number of people. Thus, for a signal transmitted at a power of 28 dBm, the link presents a total attenuation of 80.59 dB (considering the distance of 6.39 km). By analyzing only the contribution of common factors and inherent propagation, atenuation (cable losses, rainfall losses, losses due to atmospheric gases, among others) considered in this transmission system, a reception power of -52.59 dBm was obtained (for a reception threshold of - 84 dBm assigned to this equipment) [29].

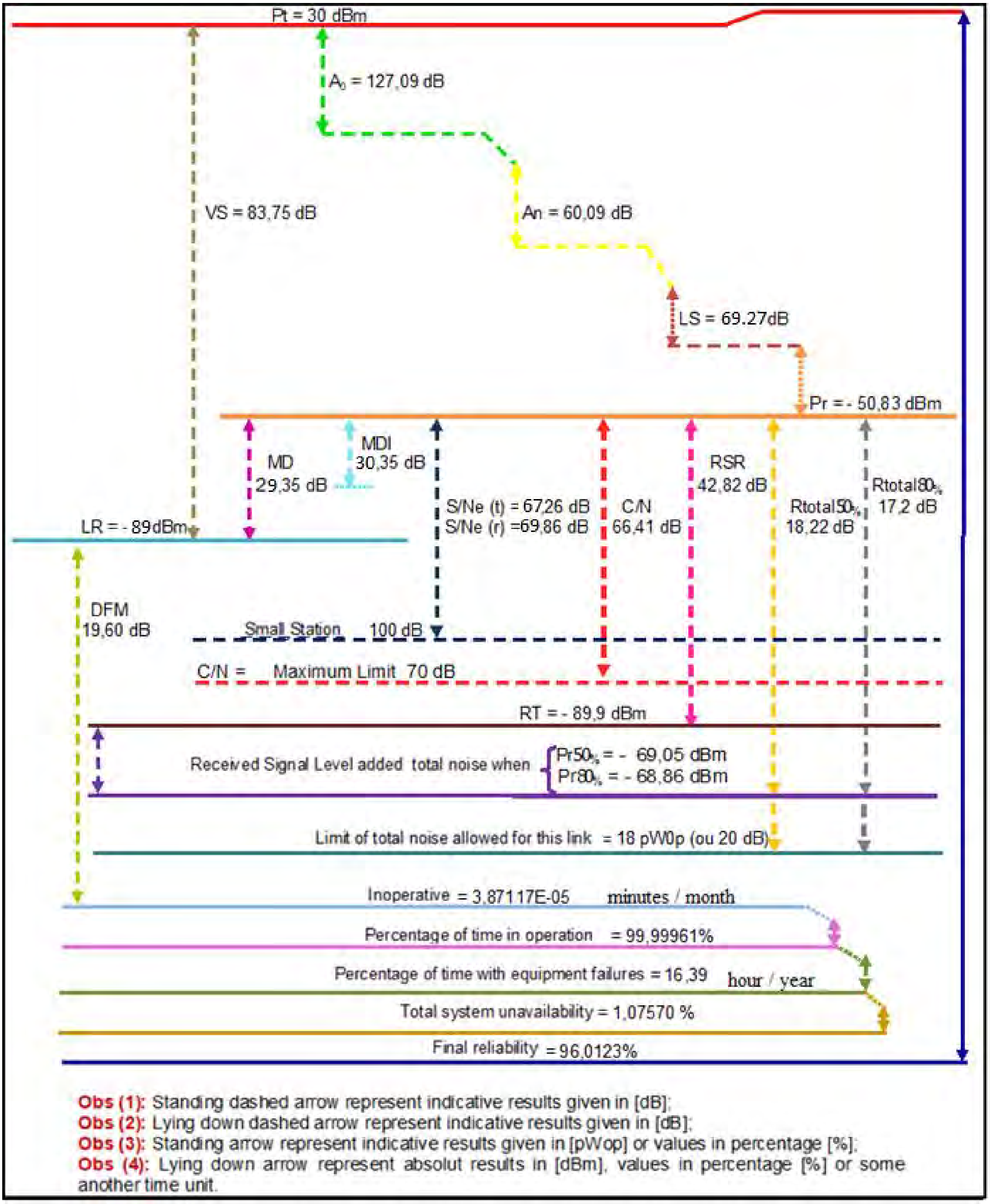
The fade margin (MD) presented a result of 29 dB for this link, considering the indicative standards described in ITU-T G.22 and G25. It corresponds to a high reliability link, being ideal for applications (services) that require high performance. Analyzing the Interference Fade Margin (MDI), considering 1 dB (value commonly taken as reference for links under direct line-of-sight – LOS), their contribution to the system results in the value of 28 dB. Contrarily, the signal-to-noise ratio (R/S) for this link was around 39.63 dB, and the carrier-noise ratio (C/N) presented the result of 55.78 dB. In this case, the link is considered as satisfactory since the results obtained (for R/S and C/N) are above 40 dB in relation to possible signal degradation. The total noise calculated for this system represents the sum in pW0p of all noises considered as relevant that incisively act in the link. In this analysis, it was considered: echo noise, thermal noise, noise contribution to 50% and 80% of time, and noise due to crossed and parallel polarizations.



GRAPH 9. **Graphical analysis of the link CP01-M02 in relation to 3.5 GHz frequency.**



GRAPH 10. **Graphical analysis of the link CP01-M02 in relation to 5 GHz frequency.**



GRAPH 11. Graphical analysis of the link CP01-M02 in relation to 8.5 GHz frequency.

Based on it, as recommended by [22] (the noise level should be around 60 pW0p or 25 dB for links operating between 3 GHz and 10 GHz at distances up to 50 km), Rtotal50% and Rtotal80% showed results within expectations since their values varied according to the limit recommended, as well as shown and analyzed in two perspectives, as demonstrated in the diagram.

According to the analysis process of the final reliability of transmission systems, it was considered: analysis of system inoperability; inoperability due to selective and non-selective fade; estimation of the probability of the inoperative period in minutes per year; percentage of time in operation; percentage of equipment failures; total system unavailability; and final reliability and probability of outage. According to ITU-T G.821 and ANATEL resolution 368, a system must operate correctly over a certain period of time to be considered as efficient. Systems operating at a percentage greater than 95% of time is commonly used as a benchmark. Based on it, this link presented a reliability rate above 97% in relation to the operating frequency of 3.5 GHz, as presented in the leveling diagram.

It is worth mentioning that the parameters considered for this frequency and the analysis scheme used in relation to it was adopted as reference for the other frequencies (5 GHz and 8.5 GHz). Therefore, it was not necessary to describe the same considerations assigned to the diagrams presented in the Graphical 10 and Graphical 11.

VI. CONCLUSION

Transmission systems have been under-described in the specialized literature. The aim of this study was to present an original, iterative and dynamic methodology for the analysis of results obtained in the conception process of a multipoint transmission system, in contrast to what exists in the literature. For the real system presented in this paper to have the advantages from being dynamically analyzed, a new analysis methodology, the Leveling Diagram, was developed. Therefore, throughout this study, we have tried to evidence the advantages in using this technique in comparison to what currently exists in the specialized literature and applications. For this purpose, the main steps of the system conception were presented. Each result obtained within the conception process was inserted in the diagram.

The motivation of this study was mainly proving that, at the end of the process, it is possible to obtain an overall view of the System, which combines the parameters related to geometry, attenuation, power, noise, and reliability in an interconnected and arranged way and presented as an interface visual. Moreover, as relevant as this combination of results, the main current legislations that limit or restrict the operation of a System are included in the Leveling Diagram, in aspects such as: limitations related to the choice of power level, limitations in the indicative references regarding the maximum noise tolerated, and limitations due to various multichannel interference problems. Therefore, changes in the link can be made. The results of these changes can be dynamically felt throughout the link, which enables a quick decision-making on the system being studied. Finally, besides being original, the methodology adopted in this study allows for the analysis of the power of the link as a whole (end-to-end), and no longer as separate parts, as typically found in all System prediction softwares. Thus, this situation makes the Leveling Diagram an indispensable tool to be used in conception processes.

This study is limited as the methodology proposed only applies to point-to-multipoint transmission systems, i.e., the diagram must undergo adaptations for mobile communication scenarios. For future studies, it is aimed to develop automatic diagrams (lines and arrows moving according to the data flow in the system) to analyze different propagation models. Therefore, the contribution of this study was providing a new graphical and interactive possibility of analysis of transmission systems.

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