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Computational Tool for Rain Attenuation and Gaseous Absorption in Geostationary Satellite Links

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Abstract: - This paper presents a computational tool for the calculation of gaseous absorption and rain attenuation in satellite communication systems with a geostationary orbit (GEO). Th software designed, planned, and implemented is based on MVC architecture that separates the code of the stages obtaining a clear and efficient structure. The software has a flow divided into three parts to process the algorithm (model, views, and controller). The software uses some forms to interact with the user and present the results of the computations in a friendly way. Additionally, to this, the program gives some files pdf to show the results and can be updated in its earth stations and satellites database.

Key-Words: - Satellite communications, atmospheric losses, rain attenuation, gaseous absorption, MVC architecture, visual computing programming languages, source code, geostationary orbit.

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1 Introduction

Satellite links are affected by atmospheric attenuation because air, clouds, fog, ice, and rain are some of the most important sources of absorption of radiofrequency waves, [1], [2]. These phenomena take place in the troposphere, which is the lowest layer of the Earth's atmosphere, where a lot of clouds are found and almost all weather occurs within this layer. Rain absorption is the most important kind of atmospheric phenomenon that is necessary to consider because the presence of high precipitation can reduce the power of the carrier significantly, [3], [4], [5], [6].

In this paper, a calculation procedure and software for atmospheric impairments in satellite links is presented. This software was designed using the MVC (Model View and Controller) software architecture which uses three different layers to separate the code from each other. This architecture is very useful in web applications because it is compatible with large-size web applications, supports Asynchronous Method Invocation (AMI), is easily modifiable, and has easy planning and maintenance.

Atmospheric attenuation is one of the largest additional losses in digital satellite communications where rain attenuation is normally the main problem because the link could fail, [7], [8], [9], [10], [11]. In the software presented here, the rain attenuation model is especially detailed and some windows and forms were designed and built for its computation. The required parameters for the calculation are the slant ranges, the elevation angles, and the position of the earth stations; for both up-link and down-link

All the calculations are based on International Telecommunications Union (ITU) technical documents, especially in the radio-communication group recommendations (ITU-R or ITU Radiocommunication Sector) which is the United Nations (UN) specialized agency created for Communication Technologies, [6], [12], [13], [14], [15], [16].

The computational tool was implemented in Microsoft Visual Studio which supports multi-language support and it has coding tools.

The structure of the paper is divided into five sections: the first section is the introduction to the paper, section two is dedicated to explaining the architecture of the computational tool, section three is related to describing the atmospheric losses (gaseous and rain attenuation), in section four the main results of the paper are presented with an example; and, finally the conclusions of the article are presented in section five.

2 Software Architecture

As it was mentioned before the software architecture was planned to use the MVC approach. Figure 1 shows the Model View and Controller where the user interface, data, and logic are separated. The goal of this idea is to obtain flexibility in the computational tool.

The view is the block that gives interaction with the user. The user interface of the software allows the values of the parameters involved in the atmospheric attenuation calculation where some forms are employed, and data is validated. Besides, the results of the software are friendly illustrated in some windows (label 6).

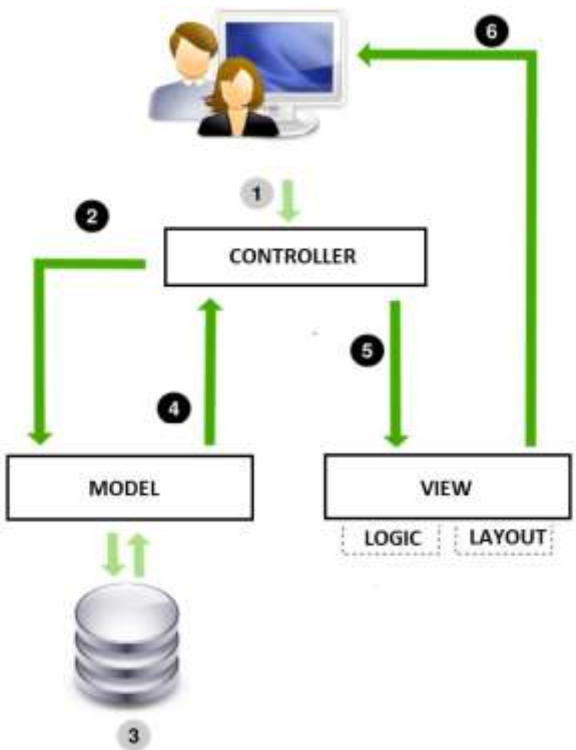

Fig. 1: Model, View, and Controller Layout.

The controller is the block dedicated to processing the accessed data (label 1) and it has to calculate the atmospheric losses. Additionally, this stage takes logical decisions and manages the errors that could occur during the computation process. The controller sends and receives information to and from the model (labels 2 and 4). The controller also processes and sends the data to the view (label 5).

The model is the block that has the following tasks: storage and manipulation of the data. In this part of the architecture, a lot of information is obtained in the software running.

The software was designed with the sequence that is shown in Figure 2, where the view is in the first and last stages, the controller processes and calculates a lot of information and, the model is in the stage where data are loaded and saved for other calculations.

The left column is related to the user interface, where the selection of the earth stations (origin and destination) and geostationary satellites takes place. The database of the satellites and earth/ground stations can be updated by the user.

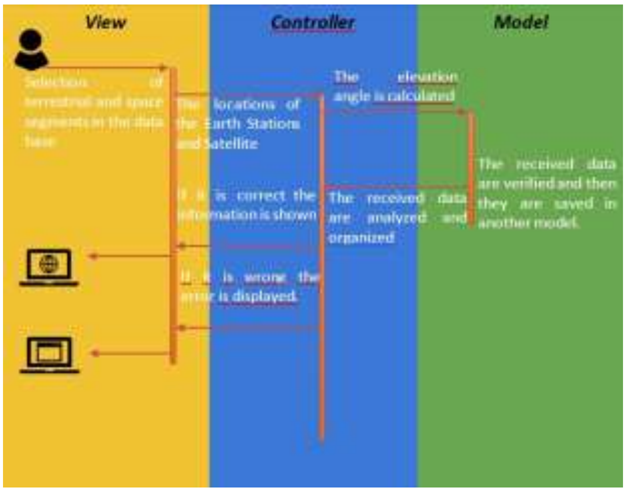

Fig. 2: Diagram sequence of the computational tool.

3 Atmospheric Losses in Satellite Links

The software uses the layout shown in Figure 3, where we have one satellite in the space segment and two stations in the user or ground segment (origin and destination), [1], [2], [3].

In this work, the control segment is not mentioned because this part of the satellite system is not involved in the communication link. As illustrated in Figure 3, there are two links (up-link and down-link) the software calculates the atmospheric attenuation for both, [11], [17].

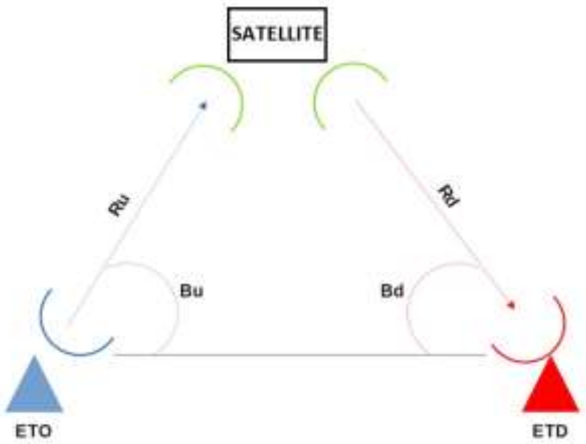

Fig. 3: Uplink and downlink in a satellite system.

3.1 Gaseous Absorption

The gaseous absorption is calculated using an empirical procedure described in the ITU-R P.676 recommendation and is determined by the following equations, where *Frequency* is the lineal frequency of the carrier, Hz.

$$f_1 = \frac{Frecuency}{20} \tag{1}$$

$$f_2 = \frac{Frecuency}{22} \tag{2}$$

$$f_3 = \frac{Frecuency}{55} \tag{3}$$

$$f_4 = \frac{Frecuency}{59} \tag{4}$$

$$f_5 = \frac{Frecuency}{60} \tag{5}$$

After this calculation, a logarithmic representation is obtained using the following equations, where D is the slant range of the link (up-link or down-link).

$$Log1 = 10\log\left(1 + \frac{D^2}{f_1{}^2}\right) \tag{6}$$

$$Log2 = 10\log\left(1 + \frac{D^2}{f_2{}^2}\right) \tag{7}$$

$$Log3 = 10\log\left(1 + \frac{D^2}{f_3{}^2}\right) \tag{8}$$

$$Log4 = 10\log\left(1 + \frac{D^2}{f_4{}^2}\right) \tag{9}$$

$$Log5 = 10\log\left(1 + \frac{D^2}{f_5{}^2}\right) \tag{10}$$

Finally, the gaseous absorption is obtained using the equation (11).

$$[L_g] = Log1 + Log2 + Log3 + Log4 + Log5 \tag{11}$$

3.2 Rain Attenuation

In the calculation of rain attenuation is necessary to complete the following steps: (a). Selection of the Precipitation Region, (b). Determination of the rainfall rate, (c). Calculation of the geometric distance of the rain, (d) Correction to the distance, (e). Determination of the regression coefficients, and (f). Calculation of the rain attenuation, [12], [13], [14], [15], [16].

Taking into consideration the ITU-R recommendations, the software uses a modified worldwide map of the regions with different typical precipitation rates, that is shown to the user in a window, see Figure 4.

The colors of the map indicate typical rainfall rates depending on the location of an earth or ground station. The location of the earth station is specified by its longitude and latitude angular coordinates. The software has a database with earth stations around the world.

Table 1 shows the typical regions in columns (capital letters from A to Q) and typical average availability percentages of the link yearly.

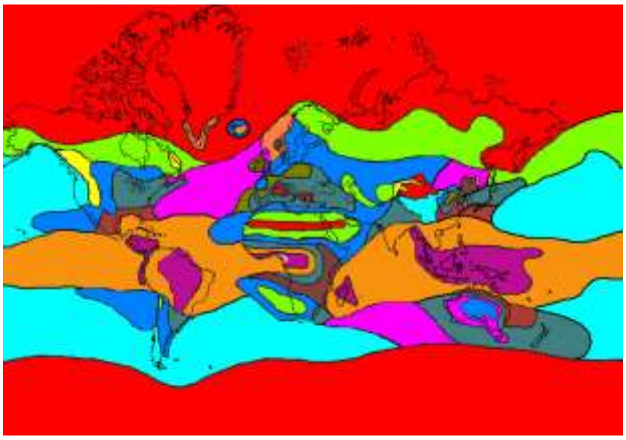

Fig. 4: Rain Precipitation Regions.

Analysis based on similar information illustrated in Table 1 has been obtained and published by researcher's groups along the time, [7], [8], [9], [10].

Table 1. Rainfall rate regions

	Rainfall rate(mm/hr)														
(%)	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
1.0	<0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24
0.3	0.8	2	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

The geometric distance is obtained in ideal conditions that are plotted in Figure 5, where L_0 is the geometric distance, km; L_g is the ground distance, km; H_0 is the height of zero degree level, km; H_g is the height above the sea level, km; and, b is the elevation angle, degree.

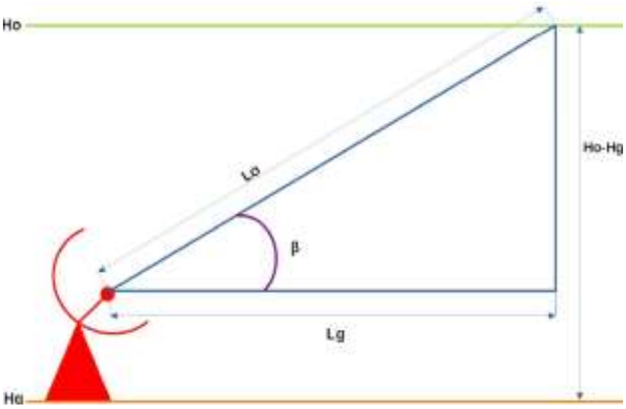

Fig. 5: Geometric path of the rain.

The regression coefficients that are normally in the logarithmic model obtained by experimental measurements are estimated in Table 2.

Table 2. Regression coefficients.

Frequency (GHz)	*a*		*b*	
	R_p <=30	R_p>30	R_p <=30	R_p>30mm
10	0.0117	0.0114	1.178	1.189
12	0.0186	0.0196	1.162	1.150
15	0.0321	0.0347	1.142	1.119
20	0.0626	0.0709	1.119	1.083
25	0.105	0.132	1.094	1.029
30	0.162	0.226	1.061	0.964
35	0.232	0.345	1.022	0.907

The regression coefficients, the rainfall average rate R_p, and geometric distance are used in the equation (12), where $[L_r]$ is the rain attenuation, dB; *a* and *b* are the regression coefficients; and L_0 is the geometric distance. This equation can be employed in an average rainfall rate of less than 6.2 mm/hr.

$$[L_r] = a\left(R_p{}^b\right)L_0 \tag{12}$$

In satellite links where the average rainfall is severe (higher than 6.2 mm/hr), the rain attenuation can be computed using the equation (13). In this procedure, the geometric distance of the link is corrected.

$$[L_r] = \frac{a\left(R_p{}^b\right)L_0}{1 + \frac{L_0\left(R_p - 6.2\right)}{2636}} \tag{13}$$

4 Results

In this, the main results of the software are presented using an example.

The link involves piles of earth stations located in Buenos Aires, Argentina (36.3ºS, 60°W) and La Paz, Bolivia (16.2°S, 68.1ºW). The geostationary satellite is the SATMEX-5 (116.8ºW) see Figure 6.

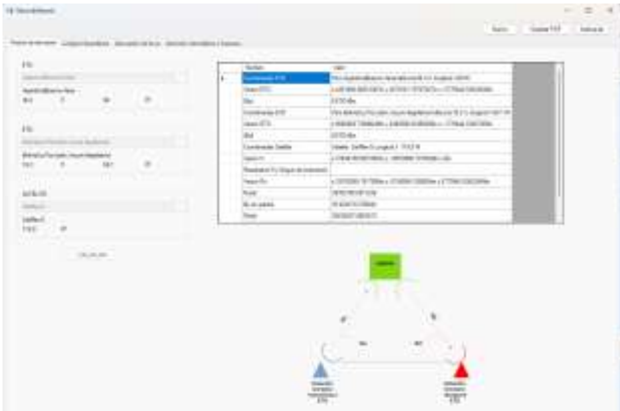

Fig. 6: Form for the selection of the Earth and space station.

Figure 7 shows the elevation angle calculation. The software uses the inner product of the position vectors of the stations and assumes a spherical Earth to calculate geometric considerations. The elevation angles corresponding to uplink and downlink are 35.62º and 50.28°.

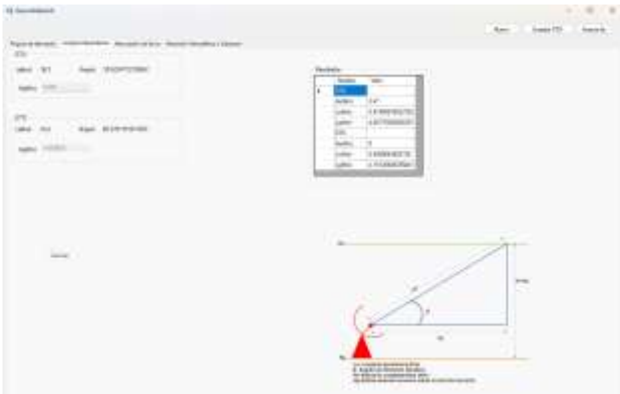

Fig. 7: Calculation of the geometric path of the rain.

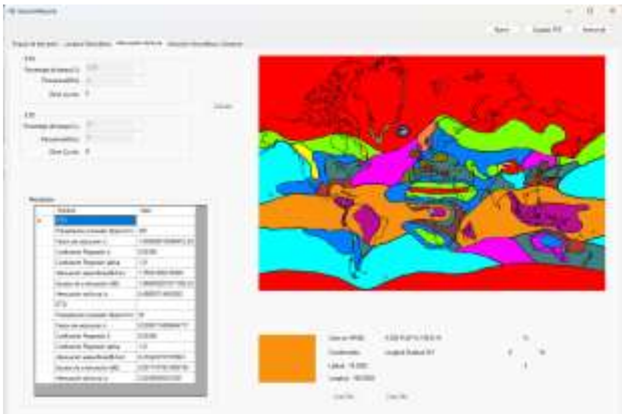

Fig. 8: Selection of the precipitation region using the location of the earth stations.

The regions selected are illustrated in Figure 8, where Buenos Aires is in a P Region and La Paz is in an N region. The results obtained with this information are plotted in the left section, below the region selection.

Finally, the results of the atmospheric losses are summarized in Figure 8 and Figure 9. The attenuation results are 8.498 dB and 2.524 dB (uplink and downlink respectively).

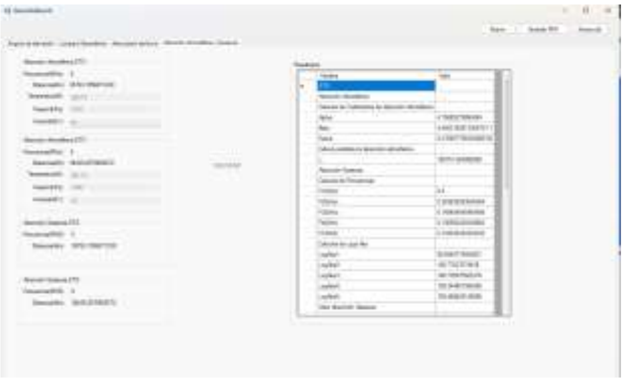

Fig. 9: Summary of the link.

4 Conclusion

In this paper, a computational tool for the calculation of atmospheric losses in satellite communications was presented. The losses generated by gaseous absorption and rainfall are computed with an algorithm that is based mainly on the recommendations.

The architecture of the software has a Model, View, and Controller structure because this approach has several advantages for the separation of the source code.

The Microsoft Visual platform was employed to build the tool which gives a standard application that can be used in a lot of computers. Because of these features the computational tool can be used in both undergraduate courses and research work in space and digital direct broadcasting satellite communications and Personal Communications Systems (PCS) by satellite, where the link is usually limited by the down-link budget.

The software is currently updated to improve the Earth's and satellite databases and the user interface. In addition to this, the model employed in the computational tool is also updated with recent works based on empirical considerations, theoretical advances, and experimental results, [18], [19], [20], [21].

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- Mario Reyes-Ayala: Conceptualization, investigation formal analysis, writing, review and editing
- Edgar Alejandro Andrade-Gonzalez: Project administration, resources, review, validation
- Sandra Chavez-Sanchez: Visualization, review validation
- Hilario Terres-Peña: Supervision, validation, review
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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.