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Design of an antenna for the MESH community wireless network of Mambita Police Inspectorate

[1]Fredys A. Simanca H., [2]Pablo E. Carreño H., [3]Fabián Blanco Garrido, [4]Patty Pedroza Barrios, [5]Paúl Sanmartín, [6]Freddy Guerra Alfonso

[1]*Universidad Libre, fredysa.simancah@unilibre.edu.co*
[2]*Universidad Libre, pabloe.carrenoh@unilibre.edu.co*
[3]*Universidad Libre, fabian.blancog@unilibre.edu.co*
[4]*Universidad Libre, patty.pedrozab@unilibre.edu.co*
[5]*Universidad Libre, paul.sanmartinm@unilibre.edu.co*
[6]*Universidad Libre, freddya-guerraa@unilibre.edu.co*

Abstract

Despite the technological advances made in recent years, plans and strategies of the Colombian Government and contributions of private enterprise, there are still many territories in Colombia without internet connection and specifically schools that continue to apply traditional methodologies in education. The Rural Educational Institution of Mambita, located in the Municipality of Ubalá - Cundinamarca, does not escape from this reality. In the context of the pandemic that began in 2020 and the quarantine strategy decreed by the Colombian government during 2020 and 2021, the need to have a network for the interconnection of its educational community became evident, including students, teachers, school administrators and parents. But due to the lack of economic resources available to the Universidad Libre, in the framework of a research project, the researchers faced the need to design wireless antennas that would allow the design of a MESH wireless network for the educational institution and that such design would allow to reduce costs, thereby seeking to benefit through innovations and contributions to the design and implementation of the MESH network to the Mambita Police inspection. Consequently, the antenna was designed using specific materials that significantly reduced costs and obtained an antenna that through the application of tests allowed to verify a range of 350 meters, which is quite significant, since in the market antennas are available with a range of no more than 300 meters.

Keywords: MESH network, wireless antenna, community networks.

1. INTRODUCTION

Due to the quarantine situation that was experienced in the Colombian territory since March 2020, the need to suspend classes arose, this made evident the shortcomings of our educational model exacerbating the existing inequalities, and although the government is working with virtual information systems, methodologies and technological means to continue with the educational training, this was not enough to solve these problems.

The Departmental Rural Educational Institution of Mambita has been affected by this problem, facing communication problems between teachers and students, since there is no connectivity in the village, affecting the educational population, made up of 292 students, 16 teachers and 5 administrative staff. This leads to a halt in the development of thematic content at all levels, as teachers have had to leave workshops in the village photocopier so that students can have access to educational texts, showing the shortcomings of the educational institution in terms of the insufficient use of ICT resources.

This is in addition to the geographical location of the Mambita police inspection, and the purchasing power of the community of this rural area to have access to technologies and communications that currently exist, although there are alternatives to achieve these accesses, there is the drawback that these technologies are very expensive to implement.

This is the reason that has motivated the Universidad Libre and specifically the researchers of the systems engineering program to design a technological solution based on a wireless network type MESH for the Mambita police inspection, and for this it was required the design and construction of at least five wireless antennas, seeking to reduce costs in the implementation of the network. With the design and implementation of the MESH type network, the goal is to achieve Wi-Fi network connectivity, so that each actor has the opportunity to access information and communication.

An antenna can work hand in hand with other tools for proper operation in the network environment as is the case of the Access Point, which is a wireless access point that consists of a wireless router and an antenna [1]. This allows connectivity of different technological devices in the same network. In the environment of the operation of MESH networks [2], it is important to take into account the operability of the antenna and its characteristics such as polarization, antenna gain, radiation, directionality, amplifier power, etc. For optimal functionality of MESH networks: The protocols designed for WMNs assume omnidirectional antennas that transmit radio signals and receive signals from all directions, taking into account that the Access Point will be able to receive signals from all directions [2], so the Access Point will provide connectivity to any other device across the network. In the case of directional antennas, only one antenna will be able to communicate with the other antennas if they are in the direction of transmission.

In Colombia, there are no companies capable of designing and building antennas for communication and network connectivity, even different entities resort to suppliers or design their own antennas capable of emitting certain gain, the wider the better, since there is an opportunity to develop specific antennas for certain use. This is possible thanks to the technology that is handled today, the possibilities of creating new innovative designs of antennas in Colombia are the result of wanting to improve the remote connection through wireless antennas that allow high gain [3].

There are specific protocols of Wi-Fi networks that allow to optimize the different ways of communication and connection in the network, allowing to use the network in specific environments, under routing and different forms of connectivity and communication. In the configuration of a network, antennas can change their behavior, adjusting their functionality in the most optimal way, in the case of MESH networks, 802.11n Wi-Fi antennas introduce several improvements to the 802.11 PHY (radio) and MAC layers that result in better throughput and reliability for wireless networks” [4].

The use of antennas is quite demanded in the connection of networks by Wi-Fi, several environments around the technology use them for certain communication and connection, in particular there is a degree of interest in the automotive industry to develop efficient antennas in vehicles, to provide unified services of traditional AM and FM systems and new services WiMAX, GPS, GPRS, digital terrestrial television, among others [5].

For the construction of an antenna, basic requirements must be taken into account in the environment where it will be implemented and under what circumstances its usefulness will benefit the network. In the case of vehicles, an optically transparent conductor with conductivity comparable to that of copper and transparency comparable to that of glass is required to manufacture this type of antenna [5]. Considering the appropriate materials for the construction of an antenna, not only functionality is guaranteed, but also failures and malfunctions are mitigated, and a good antenna design allows minimizing different types of losses, such as coupling losses, transmission, reception, mismatch, etc. [6].

For optimum performance of an antenna, the maximum utility must be supplied with the optimum energy, since the design of an antenna requires the maximum transmission of power to the load [7]. The maximum power transmission to the load is very important in the design of an antenna, as well as the measurements in the medium such as height, direction or inclination. These parameters will allow effectiveness and efficiency in the operation of the antenna.

The manufacture and use of these antennas is similar to the antennas that can be purchased, and the objective and implementation methodology is the same. The difference is based on cost and function, since it is more profitable to build the antennas than to buy these prefabricated ones, which is a benefit for the population of Mambita and for the MESH network project [8] [9].

The project also contributed to cost reduction by using inexpensive and accessible materials, without the need to opt for ready-made and much more expensive antennas. The design and construction of the antennas provided the MESH network with security, anti-interference and stable bandwidth.

Additionally, the antennas will allow to expand the network connection wirelessly as it has the dynamic increase of the network coverage. This will allow anyone who is allowed access to the network to use the network around the antenna within a radius of 250m to 350m. It should be noted that the implementation of the antennas is fast, simple and more accessible than industrial antennas, used for populations with wide coverage.

2. Materials and methods

The approach applied to the research process for the design of antennas for the MESH network of the Departmental Rural Educational Institution of Mambita, is based on the field of applied technological research. [10]The design also has a quantitative approach, adding the collection of data and variables that contribute in the construction of the processes. [11]. For which, the following set of activities is established as a modular reference of action.

2.1 Analysis stage

In this phase, the operation of a MESH network is studied and contextualized, as well as the operational work scenario, which in this case is the community lacking technology in the municipality of Mambita, located in the municipality of Ubalá in the department of Cundinamarca. The variables, processes, modifiers and the informational equivalence and characteristics of the technology available or expected to be able to implement and design the antennas are categorized.

This phase resulted in relevant information such as:

- What the school currently has in terms of connection.
- What is an antenna and how it operates with a MESH network?
- Identified what is expected with the implementation of the MESH network, in terms of network services.
- What tools are required to design MESH network antennas.
- Identification of the target population.

2.2 Design stage

After knowing "what is wanted" and "what is expected", the study proceeded to dimension the technological support and the functional logical infrastructure with which the semantic prototype of action is to be built. Then, it proceeded to dimension the technological support and the functional logical infrastructure, with which the semantic prototype of action has to be built. The prototype was created by means of software tools where the step-by-step model and the tools that allowed the design to be optimal were linked. The operations were resorted to characterize the services to be considered within the MESH solution, validating their level of adequacy, degree of reliability and associated economic level of use, i.e., this phase allowed to obtain the projected scheme that economically defines the solution. Results of this phase:

- Software tools for design.
- Antenna modeling in software.
- Topology, taking into account the functionality of the MESH network.
- Tools required for construction.

2.3 Construction stage

In this phase, the different alternatives were evaluated for implementing the software design, the level of technological complexity, the human talent required for its installation and configuration and the function of use among the community or group of users, in order to establish a parallel comparative table between what was thought, what was projected and what was possible. The development for the construction of the comparative modules, to then establish the relationships between the integrative modules and the technological base that will support the implementation of the defined services. Then, the step-by-step procedure was designed for its construction with plans, measurements and parameters.

The following results were obtained:

- Identification of other MESH network solutions in operation.
- Technical human talent for the installation of the proposed network design.
- Human talent for network configuration.
- Identification of the elements to be purchased for the implementation of the network.
- Purchase requisition documents for the required elements.

2.4 Functionality testing stage.

At this stage, the operation of the antennas was validated, and the corresponding maintenance was evaluated for the operation of the hardware and software in the short, medium and long term.

3. Results

The idea was to create an antenna with the characteristics of Table 1, based on the idea that the antenna should have a range between one and two kilometers.

Table 1. *Antenna parameters*

Parameter	Value
Profit	10 dBi
Impedance	50 Ω
Connector	SMA Female
GHz	2.4

It was also estimated that the antenna to be built should have a gain of 10 dBi, equivalent to 2.4 kilometers, considering that the obstacles in the propagation medium present losses in the gain. The 50ohm is intended to be used to carry voltage and power. Also, the antenna was to handle the 2.4 GHz range.

A process of analysis, verification and validation of the antenna architecture sketch was carried out. For this purpose, different constructions and choice of materials were reviewed, using different tutorials and research from various entities.

3.1 Antenna structure design

The study proceeded to design the antenna by means of the Antenna Toolbox software, which allows modeling and simulating the utility of an antenna. The application can design independent antennas and build antenna arrays using predefined elements with parameterized geometry, arbitrary planar structures or customized 3D structures described with STL files [12].

Figure 1 shows the dimensional characteristics of the antenna design.

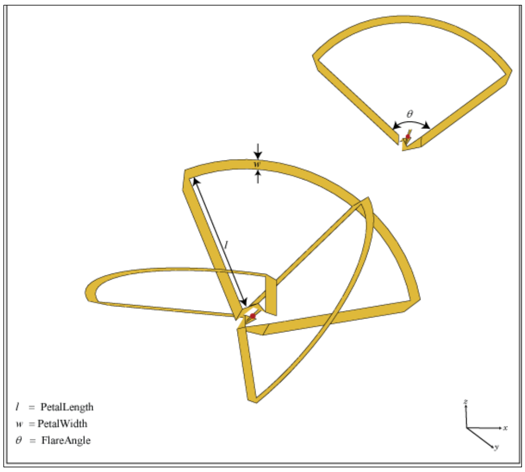

Figure 1. *Antenna dimensions [13].*

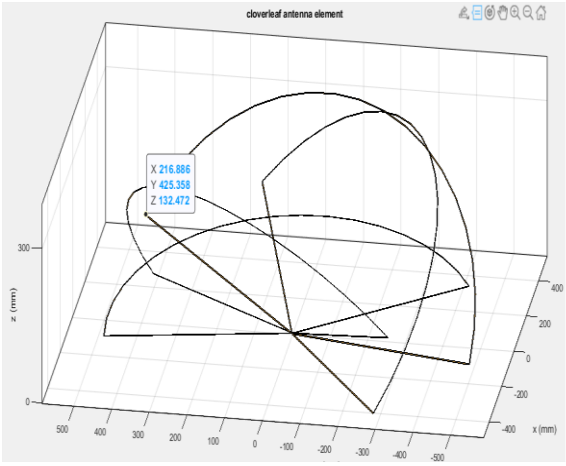

Figure 2. *Exact dimensions of the optimized antenna*

3.2 Antenna Logic Design

The antenna was physically dimensioned and the exact position and measurements of the antenna at the points of a vector were detailed (See Figure 2).

To find the straight length of each of the petals, the formula for the distance between two points was used, since the total distance of the petal is known, but not its parts:

$$d = \sqrt{(\boldsymbol{Xb} - \boldsymbol{Xa})^2 + (\boldsymbol{Yb} - \boldsymbol{Ya})^2 + (\boldsymbol{Zb} - \boldsymbol{Za})^2}$$

$$= \sqrt{\left(\mathbf{0} - (-\mathbf{94.892})\right)^2 + \left(\mathbf{0} - (-\mathbf{486.264})\right)^2 + \left(\mathbf{0} - (-\mathbf{0.001})\right)^2} =$$

$$= \sqrt{(\mathbf{94.892})^2 + (\mathbf{486.264})^2 + (\mathbf{0.001})^2} = \quad (1)$$

$$= \sqrt{\mathbf{9004.491664} + \mathbf{236452.677696} + \mathbf{0.000001}} =$$

$$= \sqrt{\mathbf{245457.169361}} = \frac{\sqrt{\mathbf{245457.169361}}}{\mathbf{1000}} \approx \mathbf{495.4363423902207}$$

This process was performed with each point of the petals finding exactly the length of each one of them discarding the length of the curvature, since the excess of the extension will be the distance of the curve of the petal.

To plot the radiation efficiency of the antenna, the following code was used, where the antenna and the space to be evaluated are specified, in which case it is the frequency range and impedance. In the vector from 0 to 1, it is understood that 1 is the highest value and 0 the lowest (Figure 3).

```
>> efficiency(cloverleaf_antennaDesigner,linspace(2.2e9,2.7e9,50))
```

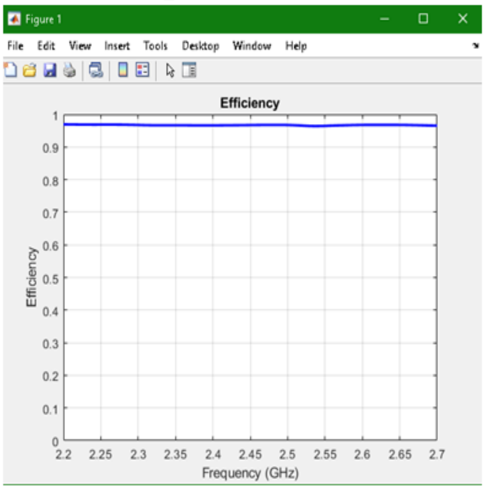

Figure 3. *Radiation efficiency of the optimized antenna*

Subsequently, the relationship between the antenna magnitude with respect to the antenna frequency was dimensioned in a graph to calculate the return loss. This allows detailing that the power emitted by the antenna has a loss of less than 3.8 dB with respect to the power with which the antenna is fed (Figure 4).

```
>> figure;returnLoss(cloverleaf_antennaDesigner,freq);
```

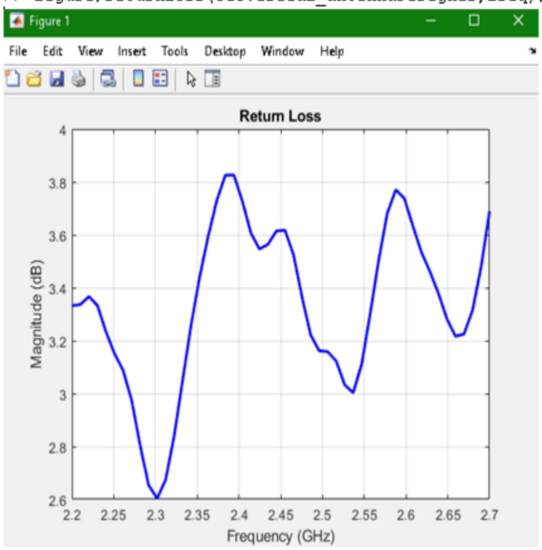

Figure 4. *Optimized antenna magnitude*

The load distribution allowed detailing the load value on the antenna surface at the 2.4 GHz frequency. This distribution is in the range of 5 to 55 nC/m, according to the diagram the highest loading is at the vertex and the lowest loading on the sides of the dipole (Figure 5).

```
>> charge(cloverleaf_antennaDesigner,2.4e9)
```

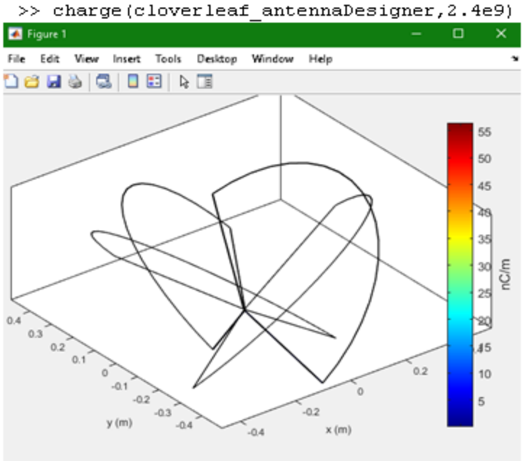

Figure 5. *Optimized antenna load distribution*

As well as the load distribution, the current distribution allowed detailing the current value on the antenna surface at the 2.4Gz frequency. This distribution is in the range of 1 to 10 A/m, according to the diagram, the highest load is at the vertex and the lowest load on the sides of the dipole (Figure 6).

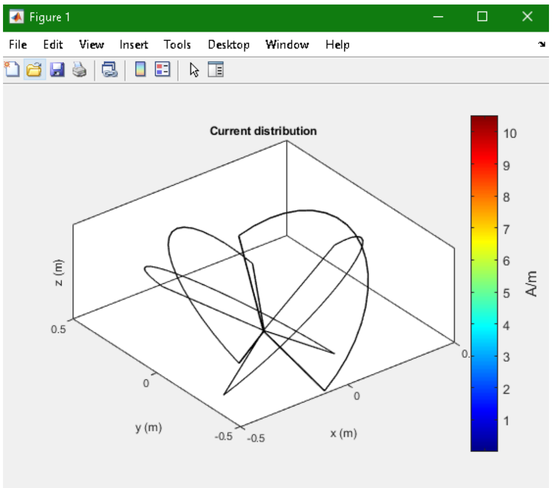

Figure 6. *Optimized antenna current distribution*

To obtain the required power supply data, the software calculates the antenna support at a specific frequency in A/m (Ampere per meter). In this way, the voltage required to feed the antenna is obtained.

According to the applicative, “the feed current when multiplied by the antenna impedance gives the voltage across the antenna” [13]. It then gives the result of the current density in the antenna feed and the other value is the length of the feed (Figure 7).

```
>> cur = feedCurrent (cloverleaf_antennaDesigner, 2.4e9)

cur =

   0.0044 + 0.0028i
```

Figure 7. *Optimized antenna power supply*

Taking into account the above values, they will be multiplied to find the value of the current. This is determined by following the code below, the final value is the result in Ampere (A), this value in milliampere is 5.2 mA (Figure 8).

```
>> mag = abs(cur);

>> mag = abs(cur)

mag =

    0.0052
```

Figure 8. *Optimized antenna magnitude.*

To calculate the supply voltage, the software requires the impedance to be multiplied with the value of the current supply. To calculate the impedance, the antenna and frequency are required.

```
>> Z=impedance(cloverleaf_antennaDesigner,2.4e9);
```

The study proceeded to multiply the impedance with the current supply. In this case, the supply voltage is 1 volt (V) (Figure 9).

```
>> feedV=abs(Z*cur)

feedV =

     1
```

Figure 9. *Optimized antenna supply voltage.*

To detail the directivity value of the Azimuth field at a specific point, the study proceeded to use the following code, where the antenna, the frequency and the range from 0° to the longest-range value, which is 240°, are established. The value is negative, since it is located on the negative X axis (Figure 10).

```
>> Directivity = pattern(cloverleaf_antennaDesigner,2.4e9,0,240)

Directivity =

  -15.2149
```

Figure 10. *Directivity value at a given point.*

To detail the value of the axial ratio of the antenna at a given point, the study proceeded to use the following code, where the antenna, frequency and direction in the environment are specified, which is a value of Azimuth and Elevation. This shows that the antenna accepts circular polarization values at that point, since the axial relationship is only supported in circularly polarized antennas (Figure 11).

```
>> ar = axialRatio(cloverleaf_antennaDesigner,2.4e9,20,30)

ar =

    6.5397
```

Figure 11. *Axial ratio of the optimized antenna.*

To visualize the graph of the antenna axial ratio value in a given frequency range, the following code was used, where the antenna, frequency range and the above-mentioned point are linked (Figure 12).

```
>> axialRatio(cloverleaf_antennaDesigner,freq,20,30);
```

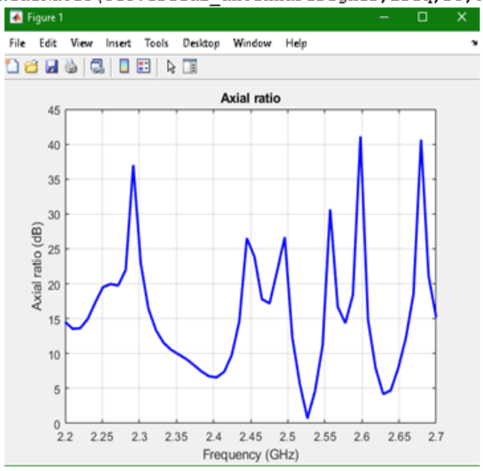

Figure 12. *Axial ratio plot of the optimized antenna.*

To plot an antenna beamwidth and evaluation angles, the study proceeded to use the following code, where the antenna, frequency and direction in the environment are specified, this is a value of Azimuth and Elevation in a given range, which is azimuth 0 and elevation 1, in the plane from 0° to 360°. This allows detailing the main range peak by linking elevation and Azimuth (Figure 13).

```
>> [bw, angles] = beamwidth(cloverleaf_antennaDesigner,2.4e9,0,1:1:360)

bw =

   14.0000

angles =

   135   149
```

Figure 13. *Beamwidth at certain angles of the optimized antenna.*

To plot the standing wave voltage ratio voltage of the antenna, the study proceeded to use the following code, where the antenna, frequency range and impedance are specified. This chart shows that the wave emitted by the antenna has very little interference with waves of the same nature at the required frequency (Figure 14).

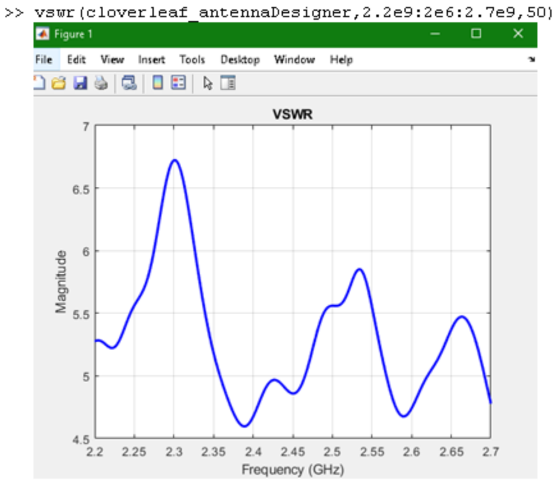

Figure 14. *VSWR of the optimized antenna.*

3.3 Antenna Construction

In order to build the antennas, it was necessary to take into account the materials, suppliers and data analyzed throughout the research process.

With respect to the type of material and components required for the construction of the antenna used in the software, the study proceeded to look for companies capable of supplying the materials. It was taken into account that the establishments were located in the city of Bogota and that they could provide optimal materials at an economical price.

The antenna's design starts with the development of its petals. Based on the dimensions of the software that gives the length of each petal and the length of the straight parts, the study proceeded to elaborate the plan with the X, Y and Z axes, in cardboard straw. Below is the location and length of the flat parts of each petal and their respective length, including the box where the coaxial cable and the copper wire are located (Figure 15).

Figure 15. Final Antenna Design.

4. Discussion

The antenna operates efficiently, depending on physical variables, in this case the MATLAB software facilitated the design of the antenna and showed that, under different types of elements used and the architecture of the antenna, it will operate in different ways. It should be noted that the software uses exact parameters in the antenna architecture and lacks external variables that affect the antenna performance, such as the type of obstacles in the path and exact location where the antenna is located.

In the construction process, taking into account the exact values provided by the software, favored and streamlined the construction process. This also made it possible to dimension the step-by-step elaboration and its functionality.

Although the antenna was built under very rough metrics compared to the measurements provided by the software, the physical functionality range does not approach the total range provided by the software. The diameter of the antenna emission would reach 1/3 of the total projected by the software. Although it should be noted that this process is performed by the antenna individually. The location is also highlighted, since the antenna tested in an area with obstacles in the way, affects its functionality compared to the one tested in an open field.

5. Conclusions

There are several types of antennas with different functionalities. It is important to identify the right antenna for the network or the appropriate performance. In the project, an antenna with omnidirectional signal transmission capability and capable of being used in MESH networks in rural environments was preferred.

MESH networks are ideal for areas where group and contingency network transmission is required. This allows network supply and coverage in different areas of the territory without the inconvenience of losing network transmission when an access point falls in the territory.

The antenna was built taking into account the software design, but it is not exactly the same as the one projected in the software. The architecture values are very approximate, but not exact. Although the software projected a signal emission amplitude value of the antenna designed for this project, the diameter of the constructed one did not cover the entire projection. The constructed achieved amplitude covered 1/3 of the stipulated value.

The antenna is sufficiently rigid to withstand climatic disturbances and the presence of animals in the installation area. Rain, blizzard or tremors, all of them moderate, were taken into account. The presence of small animals such as birds was also taken into account. The antenna operates efficiently, fulfilling its function of transmitting and receiving Wi-Fi, taking into account that it was designed for 2.4GHz frequencies. On the one hand, it represents slow signal performance, but on the other hand there are more devices that can be linked to the network.

The functionality tests performed were successful, taking into account the operability compliance. Each one took into account different approaches to the operation of the antenna architecture, ranging from the correct union of the parts, the reception and emission of the signal and also the amplitude of emission. The place of implementation of the antennas should be between five and ten meters, it should also be clear or with minimal obstacles in the signal propagation medium. This in order to use the maximum potential of the antenna.

Reference

[1] V. J. Cruz Rozo and J. Collazos Collazos, “Infrastructure model for mesh networks,” Bogotá, 2016.

[2] D. M. Acuña Martinez and R. J. Roncallo Kelsey, “Redes inalámbricas enmalladas metropolitanas,” Cartagena de Indias, 2007.

[3] C. R. Rivera Montalvo and Y. A. Gomez Bejarano, “Design, simulation and construction of an antenna for signal propagation at a frequency of 2.4 ghz,” Bogotá, 2009.

[4] M. C. Cepeda Martinez, “Design and implementation of a mesh network as an alternative solution for community or rural networks,” Bogotá, 2014.

[5] J. G. Estrada Escobar, “Design, evaluation and construction of a digital television antenna for vehicles,” 2013.

[6] D. Aguirre Salcedo, “Design and construction of an antenna model to receive information from polar orbiting meteorological satellites in hrpt format, at 1.7ghz,” 2017.

[7] J. Verdú Tirado, “Design and fabrication of an antenna with polarization diversity for wifi networks at 2.4 ghz,” Barcelona, 2006.

[8] F. A. Simanca Herrera, F. Blanco Garrido and E. Triana Moyano, Las Redes MESH, Bogotá: Universidad Libre, 2018.

[9] F. A. Simanca Herrera, F. Blanco Garrido and E. Triana Moyano, Las redes MESH II, Bogotá: Universidad Libre, 2018.

[10] J. Lozada, “Applied Research: Definition, Intellectual Property and Industry,” CienciAmerica, vol. 3, no. 1, pp. 47-50, 2014.

[11] G. Vega Malagón, J. Ávila Morales, A. J. Vega Malagón, N. Camacho Calderón, A. Becerril Santos, and G. Leo Amador, “PARADIGMS IN RESEARCH. QUANTITATIVE AND QUALITATIVE APPROACH,” European Scientific Journal, vol. 10, no. 15, pp. 523-528, 2014.

[12] The Mathworks. Inc, “Antenna Toolbox: Design, analyze and visualize antenna elements and antenna arrays,” The Mathworks. Inc, [Online]. Available: https://www.mathworks.com/help/antenna/getting-started.html. [Last access: 17 March 2021].
[13] The Mathworks. Inc, “Get started with antenna Toolbox,” n/d.
[14] J. Penalva, “Mesh WiFi networks: what they are, how they work and why they can improve your home WiFi network,” 2018.
[15] D. O. Nacimba Coello and L. D. Roman Solorzano, “Antenas pagoda y trebol,” Quito, 2020.
[16] O. Nave, “Classification of Polarization,” n/d.
[17] A. C. Lozano Garcia, “Propagation systems and antenna design focused on the analysis of telecommunication links,” 2002.
[18] K. I. Cardenas Morocho, “STUDIO DE RADIOFRECUENCIAS PARA EL DISEÑO DE UNA RED MESH EN LA UNIVERSIDAD DE GUAYAQUIL (Universidad de Guayaquil Facultad de Ciencias Matemáticas y Físicas Carrera de Ingeniería en Networking y Telecomunicaciones),” 2016.