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Design of the MESH Network for the Rural Educational Institution of Mambita, located in the Municipality of Ubalá - Cundinamarca Colombia

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Abstract

This article presents the design of a MESH network and the creation of wireless antennas to provide Internet access and other services to the community of the Institución Educativa Rural Departamental Mambita located in the village/caserío of Mambita in the municipality of Ubalá in the department of Cundinamarca. The development was carried out within the framework of a project developed by students and professors of the Universidad Libre in Colombia. As a result, a MESH network consisting of four nodes was designed and simulated and four antennas were created for communications between the branches that make up the educational institution.

Keywords: MESH network, connectivity, topology, communication standards, antennas, protocols.

INTRODUCTION

The pandemic situation caused by covid-19 meant that most schools in Colombia were forced to develop their academic activities remotely, using the technologies at their disposal, having the Internet as the main means of communication, in certain cases, the use of calls through mobile networks or conventional telephony (Rojas-Díaz, 2022) when there was no Internet at the students' or teachers' homes. In other cases, all three forms of communication were used at the same time.

The aforementioned situation, evidenced the lack of communication technology in many schools or public educational institutions in the country, especially in rural areas of difficult access (Valencia Certuche & Bautista Gamba, 2021), as is the case of the Institución Educativa Rural Departamental Mambita located in the village of Mambita, which is part of the municipality of Ubalá in the department of Cundinamarca. This school has 292 students, 16 teachers and 5 people with administrative functions. During the pandemic in 2021, their activities were completely suspended, being forced to develop the activities remotely, but due to the lack of sufficient technology for their students who live in and around the village of Mambita, all the thematic contents of the courses delayed. Teachers and family members used strategies so that the students could have access to the different study materials for each course and subject.

For all of the above, together, teachers and students of the Universidad Libre in Colombia created a project to conduct a study that would allow this educational community to have the first designs and alternatives for a network of low resources where their students and teachers can enjoy the internet and other services it offers. Due to the high costs of communication equipment to bring internet to a whole community, the project was oriented in a first stage, in a good design of a meshed network (MESH) and the creation of communication antennas, so the following question arose: How the design of a MESH network for the Regional Educational Institution of Mambita, will solve the problems of access to education that currently have the educational population of this population?

The formal characteristic of the project demanded the use of the conventional methodology for the study and development of works pertinent to the area of soft technology, as is the case of the design and construction of teleinformatic solutions, for which, the set of activities presented in this article is established as a modular reference of action.

THE MODEL

The elaboration of the network design is based on the documents and research previously carried out, where the type of topology, equipment to be used and coverage provided by the solution are evidenced. The information gathering was carried out by doing a face-to-face reconnaissance of the area where the project would be carried out (see figure 1). Subsequently, each village where the network would be implemented was visited. During each visit, the team took photos where the antennas would possibly be installed in a future implementation (see Figures 2 and 3).

Fig 1. Overview Mambita Apple Maps

In the first instance, wireless connections were proposed between the main headquarters of the Municipal Educational Institution of Mambita located in the municipality's main town (Figure 3-c) and some schools located in neighboring villages such as San Roque (Figure 3-b), Boca de Monte (Figure 2) and Mambita 2 (Figure 3-a).

Fig 2. Boca de Monte Branch

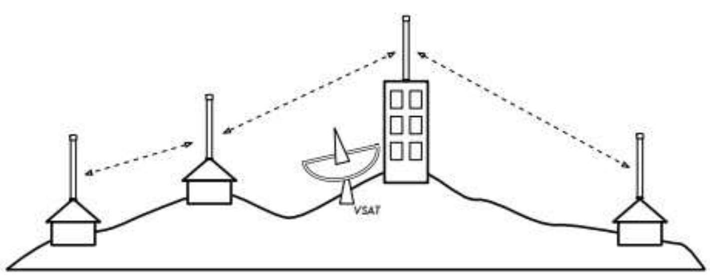
a) b) c)

Fig 3. Mambita 2, San Roque and Main Mambita Branches

For this purpose, it was of vital importance to know how the equipment would be organized, so that it could reach the wireless clients, whether it had to reach an office in a building or extend for many miles.

In the case of the MESH network design at Mambita, the multipoint-to-multipoint network design (see Figure 4), which is also known as an ad-hoc or mesh network (MESH), was used. In a multipoint-to-multipoint network, there is no central authority. Each node in the network carries the traffic of as many others as necessary, and all nodes communicate directly with each other (Pietrosemoli, 2006).

The great benefit of this type of network design is that no matter that none of the nodes is reachable from the access control point, they can communicate with each other, in addition to this, a good implementation of MESH networks will allow the nodes to be self-healing because routing problems are automatically detected and corrected (Aparecida Cabral & Robson Mateus, 2010). Extending a MESH network is as simple as adding more nodes. If one of the nodes in the "cloud" has access to the Internet, all clients (other nodes) can share that connection (Simanca H, Blanco Garrido, & Triana Moyano, 2018).



Source: Wireless Networks in Developing Countries (Pietrosemoli, 2006).

Fig. 4. Multipoint-to-multipoint mesh network

Once the desired network topology was proposed, the next step was network planning to verify through simulation whether the radio links are physically feasible and if not, through coverage studies and inspection of the orography, to determine where possible repeater nodes can be installed (Hu, Jijun , & Yan , 2006). The process of determining whether the link is feasible is called power budget calculation. Whether or not signals can be sent between radios will depend on the quality of the equipment being used and the signal impairment due to distance, called path loss (Alim Al Islam, 2015).

The equipment characteristics to consider when calculating the link budget are:

Transmit Power: Expressed in millwatts or dBm (decibel-milliwatt), it often depends on the transmission rate.

Antenna Gain: Antennas are passive elements and create the amplification effect due to their physical shape. Gain is expressed in dBi.

Receiver Sensitivity: Minimum Received Signal Level is expressed in negative dBm and is the lowest level of signal that the radio can distinguish.

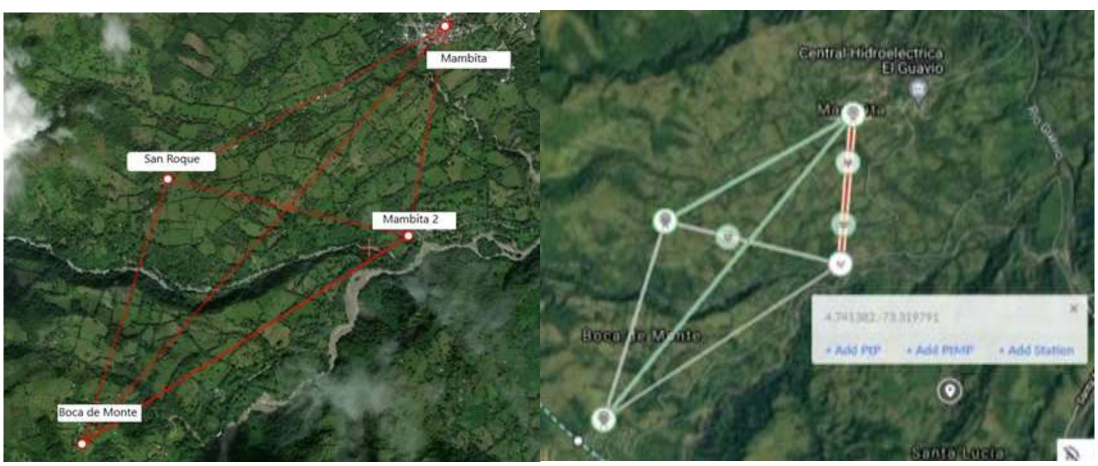
Cable Losses: Some power is lost in the cables and connectors that go from the radios to the antennas. It is usually in the 2-3 dB range.

When calculating the path loss it is very important to consider the free space loss. Using decibels to express the loss and using a generic frequency f1, the equation for the free space loss is:

$$L = 32.4 + 20 * \log_{10}(D) + 20 * \log_{10}(f) \quad (1)$$

Where L is expressed in dB, D in Km and f in MHz. Placing all these parameters together leads to the calculation of the link budget. If different radios are being used at the two ends of the link, the path loss must be calculated twice, once for each direction (using the appropriate TX power, RX power, antenna TX gain, and antenna RX gain for each calculation).

The AirLink tool has been used for link planning, to calculate free space loss and other relevant factors (such as tree absorption, terrain effects, weather, and even estimation of path losses in urban areas).



a) b)

Fig 5. AirLink Simulation.

The study yielded the following results when establishing links between the following sites (nodes):

The first link will be between Mambita and the village of Mambita 2, the tool does not indicate that this link is obstructed, so two repeaters should be installed, one at coordinates 4.759632,-73.327955 at a minimum height of 5m and another at coordinates 4.754671,-73.328341 at a minimum height of 2m as shown in Figure 5-b. The other links are formed by Mambita and Boca de Monte, Mambita and San Roque, San Roque and Vereda Mambita 2, this last link between San Roque and Vereda Mambita 2 is obstructed (as denoted in Figure 5-b so a repeater must be installed at coordinates 4.753829, -73.338046 at a minimum height of 13m). The last link is San Roque - Boca de Monte, Boca de Monte - Mambita 2.

Each node will be located in the highest parts of the areas chosen for the design of the Mesh network, with the clear objective of not having signal interference problems due to obstacles, since it is a mountainous area, also will be located in such a way that each node can provide coverage to an area of 4 km radius.

These data are of great importance since the distance will be fundamental at the time of the construction of the antennas for the implementation of the project in the future.

Once the link budget has been made, the minimum requirements necessary for a future implementation of the MESH network in the rural educational institution of Mambita are established, which are the devices for it to operate and provide internet service in this educational institution in a future implementation (See Illustration). The correct connection, management and administration of all these equipment and devices are the success of the operation of a MESH network, so it is of great importance to analyze the environment, looking at which is the best solution option in each space chosen for the design and future implementation of MESH networks (Valencia Certuche & Bautista Gamba, 2021).

RESULTS AND DISCUSSION

After analyzing the area where the network will be implemented, the logical design and physical design of the network was carried out using the Packet Tracer tool.

Taking into account that the communication between each site will be done by radio frequency in a MESH network, due to the hostile terrain and the low cost of its implementation versus other types of solutions, it must also be considered that in each site there must be an internal network that allows connecting the end users' different equipment, which in this case will be the teachers, students and administrative staff.

Therefore, each site becomes a network node, as shown in Figure 6 and Figure 5 a), in each node there is a level 3 switch (or commonly called layer 3 for its routing capacity) that is responsible for maintaining communication between the node and the other sites (see Figure 6). In order for the layer 3 switch to maintain communication with other sites it must use a routing protocol (Nurlan, 2021), in this case the OSPF (Open Shortest Path First) protocol was used and an OSPF area was created in each of the swicthes of each site or node.

On the other hand, we applied the Spanning Tree Protocol (STP) in the node's internal network. This protocol operates at layer 2 of the OSI model and its main objective is to control the redundant links, ensuring optimum network performance. This protocol is extremely important in this type of topology since there is a connection between all the nodes, which would generate a problem in the network if this protocol is not used.

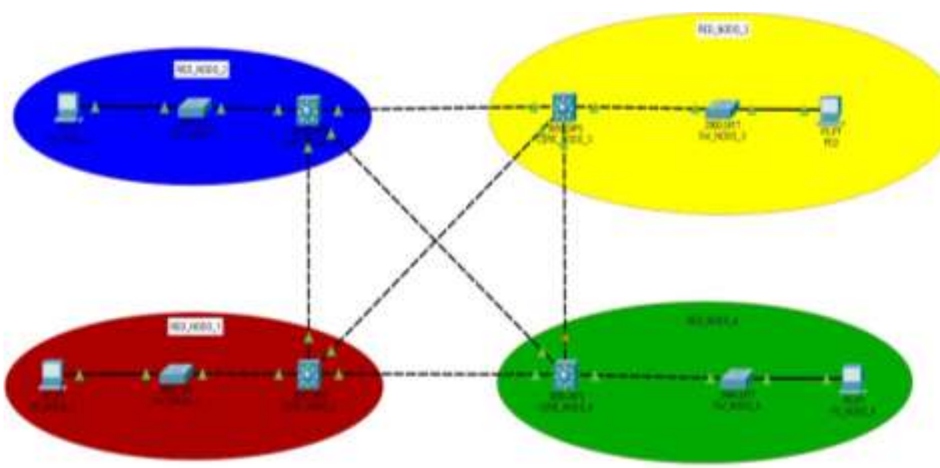


Fig 6 Cisco´s MESH Simulation.

Once the network is set up and distributed as shown in Figure 6, the IP addresses are configured for each computer. Once the IP addresses have been setup, the layer 3 switch is configured, assigning IP addresses to each interface as shown in Figure 7.

Fig. 7 IP Assignment to Interfaces.

After this, we created the different VLAN (Virtual LAN) interfaces where VLAN 100 will be the management VLAN, so that all the level 3 switches can see each other and finally the wateway is configured and an OSPF router is created to add all the networks so that the other areas can see these networks (See Figure 8).

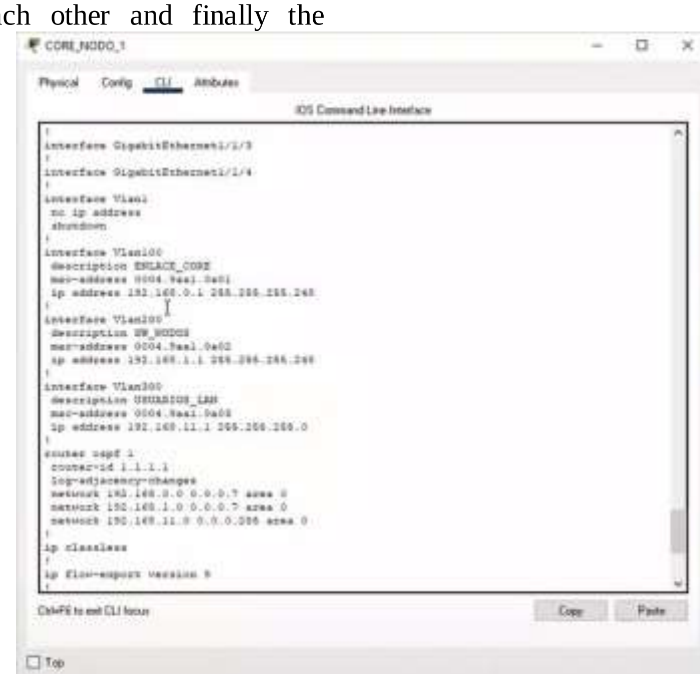


Fig 8. IP Assignment to VLANs

Finally, a ping is performed between a user in area 1 and a user in area 2 (see Figure 9) to verify that the simulation configuration is correct and that there is a successful connection between all the nodes in the network, as shown in Figure 10.

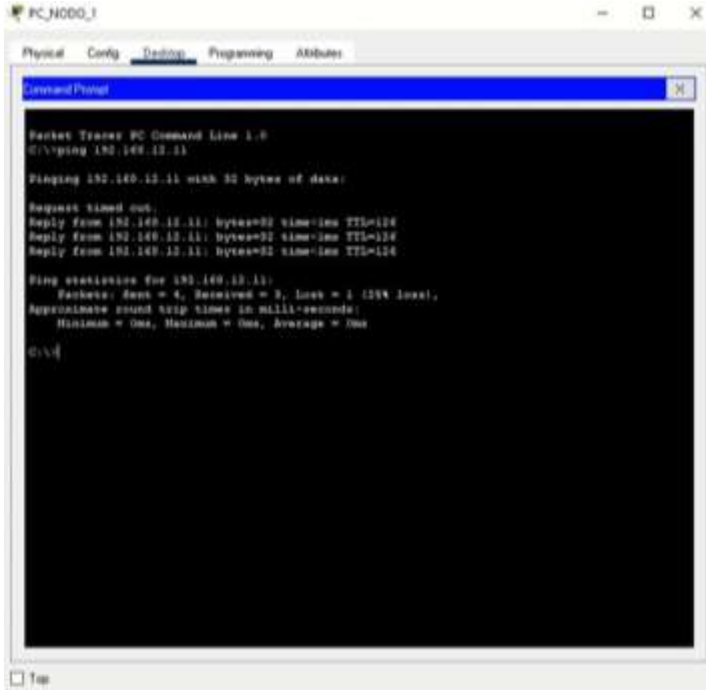


Fig 9. Verification of users on the Network

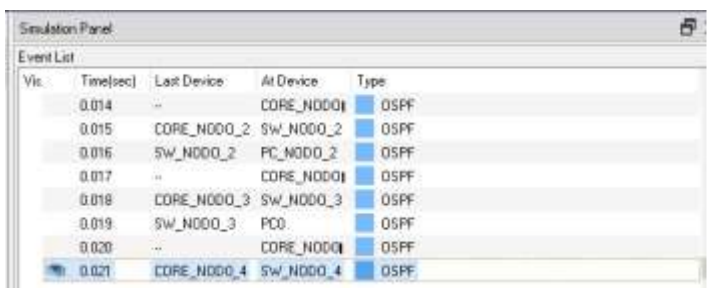


Fig 10. Interface panel

Finally, we proceed to include the routing tables with their respective information where we can observe the subnets that were created as shown in Table 1.

Table 1: Network Segmentation.

Nodo	*Vlan*	*Nombre / IP*
Redes	VLAN 100	ENLACE_CORE
	VLAN 300	USUARIOS_LAN
	VLAN 200	SW_NODOS
Nodo 1	VLAN 100	192.168.0.0/29
	VLAN 300	192.168.2.0/29

	VLAN 200	192.168.12.0/24
Nodo 2	VLAN 100	192.168.0.0/29
	VLAN 300	192.168.3.0/29
	VLAN 200	192.168.13.0/24
Nodo 3	VLAN 100	192.168.0.0/29
	VLAN 300	192.168.3.0/29
	VLAN 200	192.168.13.0/24
Nodo 4	VLAN 100	192.168.0.0/29
	VLAN 300	192.168.4.0/29
	VLAN 200	192.168.14.0/24

The physical model takes into account each of the coverage distances that each access point can cover. It is proposed to use 4 nodes in a meshed configuration in order to provide redundancy to the communication system for the design of the MESH network. Figure 5-a shows the arrangement of the nodes to be used for the MESH network in the Mambita Educational Institution; these nodes will have redundancy among themselves to guarantee the connection and communication at all times even if there is a loss of the link in any of the nodes.

These nodes will be located as follows: the administration area will be located at the main branch of the Institución Educativa Rural Departamental Mambita. The other nodes will be located in the villages of San Roque, Mambita 2 and Boca de Monte.

A wireless node is made up of different components that must be connected to each other with the appropriate wiring (Asfirane, 2019) (Rojas-Díaz, 2022). This requires at least one computer connected to an Ethernet network, a wireless router, or a bridge on the same network. Radio components must be connected to antennas, but along the way may require an amplifier, a lightning protector (this is a three-terminal device, one connected to the antenna, the other to the radio, and the third to ground), or other device. Many of these require power, either through another AC cable, or using a DC transformer (see Figure 11). All of these components use various kinds of connectors, not to mention a wide variety of cable types of different gauges (Zhang, 2018).

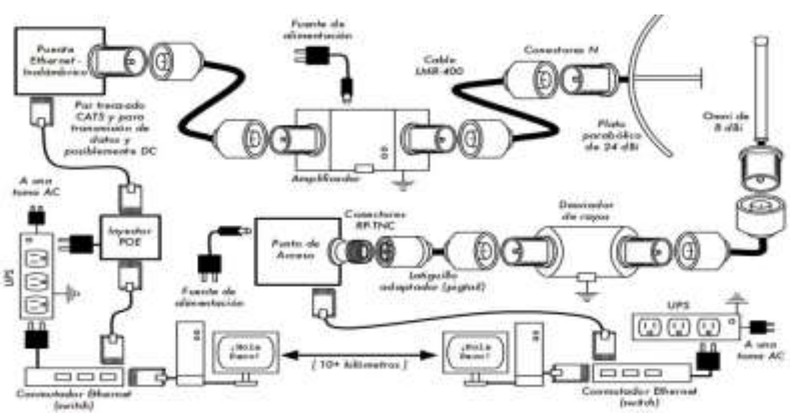


Fig 11. Components Interconnection.

To make the project economically viable, students from the Universidad Libre designed and built 5 low-cost antennas (see Figure 12), which will be established as nodes that will be connected to the same network as shown in Figure 6, where each end is a node and the network is distributed by each of these nodes.

As explained in (Simanca, 2022) the antennas were built under the characteristics of table 2, starting from the idea that the antenna should have a range of more than 3 kilometers (Simanca H, Blanco Garrido, & Triana Moyano, 2018), it is estimated that the antenna to be built will have a gain greater than 15 dBi, which is equivalent to the range greater than 3540 meters or what is equivalent to 3.54 kilometers, perfect for the rural area of the municipality. The 50 ohm is intended to be used to transport voltage and energy. The 100 Watts is the value needed to use energy in the antenna. The antenna was chosen to handle the range of 2.4 GHZ, taking into account that what is sought is to reach and connect to any device without excluding any other device; however, it is estimated slowness in the connection.

Table 2: Antenna Parameters

Parámetro	*Valor*
Ganancia	15 dBi
Impedancia	50 Ω
Potencia Máxima	100 W
Conector	SMA Macho
GHZ	2.4 - 2.5

For the monitoring, construction, materials and other elements for the elaboration of the antenna, we analyzed, verified and validated different tutorials and research on antenna design and construction (WNI, 2021). Taking into account the antenna dimensions, the antenna was designed using the Antenna Toolbox software (Simanca, 2022).

Fig. 12 Built Antennas

CONCLUSIONS

Once the design and simulation of the MESH network was completed, the following conclusions can be drawn: The use of MESH type network topologies ensures uninterrupted communication of all network members, even if any of the nodes fail or are disconnected, the network will be able to remain converged, although with considerable information processing.

According to the identified problems and the proposed objectives, the initial requirements of the

MESH network were defined for its future implementation in the Mambita Departmental Rural Educational Institution.

The equipment and locations to be considered for a future implementation of the network in this institution were presented.

MESH networks are very useful for implementation in rural areas, since the cost of implementation is low and also offers a very important community service for areas where there is currently no internet coverage due to difficult access, as is the case in the municipality of Mambita. Finally, the MESH network design was validated through Cisco simulation.

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