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A CASE-STUDY VISION

Design of a full mesh network for non-interconnected zones (NIZ)

Diseño de una red full mesh para zonas no interconectadas (ZNI)

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RESUMEN

En Colombia, a pesar de los avances tecnológicos y sociales, aún existen ZNI a la red eléctrica nacional; a esto se adiciona que, en el tercer trimestre del año 2018, la penetración del internet en el país fue de apenas del 62%. Además, institucionalmente se encuentra que la Unidad de Planeación Minero Energética –UPME- y el Instituto de Planificación y Promoción de Soluciones Energéticas para las ZNI –IPSE- ambas entidades adscritas al Ministerio de Minas y Energía, debieron reorientar sus funciones con el objeto de identificar, promover, fomentar, desarrollar e implementar soluciones energéticas efectivas. Lo anterior motivó la presente investigación -cuyos resultados se describen en este artículo- con el objetivo fundamental de mitigar dos falencias: interconexión eléctrica y conexión a internet en veredas y cabeceras municipales de ZNI ubicadas en el departamento de Caquetá. En consecuencia, se diseña y simula una red *full mesh* conectada a internet en uno de sus puntos, junto con un sistema fotovoltaico para abastecer estos nodos de energía eléctrica. Los resultados de la medición de los parámetros sobre los nodos permiten seleccionar adecuadamente radio enlaces de alto throughput, proporcionando acceso a internet para propósitos de capacitación, educación y apertura de comercio, en ZNI rurales.

ABSTRACT:

In Colombia, in spite of technological and social advances, NIZ still exists in the national power grid; in adition that, in the third quarter of 2018, Internet penetration in the country was only 62%. In addition, it is institutionally found that the Mining and Energy Planning Unit -UPME- (by its acronym in Spanish) and the Institute of Planning and Promotion of Energy Solutions for the NIZ -IPSE- (by its acronym in Spanish) both entities attached to the Ministry of Mines and Energy, had to redirect their functions in order to identify, promote, foster, develop and implement effective energy solutions. The above motivated the present investigation -whose results are described in this paper - with the fundamental objective of mitigating two shortcomings: electrical interconnection and internet connection in villages and municipalities of NIZ located in Caquetá department. Consequently, *a full mesh network* connected to Internet is designed and simulated at one of its points, together with a photovoltaic system to supply these electrical energy nodes. The measurement results of the parameters on the nodes allow the proper selection of high throughput radio links, providing Internet access for training purposes, education and trade opening, in rural NIZ.

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1. Introduction

Colombia's current connectivity and digitalization vice-minister indicated in March 2019 that about 20 million Colombians did not have Internet access, which made it very difficult for them to carry out their productive processes effectively and efficiently, especially in rural areas [1]. In addition, a large part of rural population of peripheral departments is located in NIZ, according to UPME and IPSE, [2] as shown in Figure 1.

Figure 1. Map of not interconnected zones to the power grid.
Source: Institute of Planning and Promotion of Energy Solutions for the NIZ –IPSE.

Therefore, generating an interconnected network with multiple redundancies of data and energy, would ensure stable and sustainable solutions in the NIZ because it can provide relevant services to communities: education, direct trade, health, government, among others [3]. For this reason, updated simulations and calculations have made possible the networks interconnection as well as sustainable socioeconomic benefits with public-private investment.

In terms of the foregoing, it is said that the national government has developed WiFi-public zones as an action from MinTic [4], which have allowed populations to have access to Internet, with the difference that these networks are located in municipal capitals and main parks. However, there have also been restrictions on browsing times and there is no self-sustaining development plan involving citizens.
Consequently, this document evidences the results of the project that seek to overcome these negative aspects by making networks more powerful and extending them a little further into rural areas using *full mesh networks*, thus offering more opportunities to vulnerable populations that have difficulty accessing the communication network [5].

The paper is structured as follows: initially methodology is established illustrating the Telecommunications and Alternative Energies multidisciplinarity; then materials and processes of Power grid and Data networks are shown; next implemented alternative is described integrally; then tests of power, time of use, and connectivity are shown; simulated results are followed and exhibited; and finally social and technical conclusions are established.

2. Methodology

Poverty - defined as a condition characterized by lack of resources, means or opportunities to satisfy minimum human needs, both material and cultural - in an area of Colombia such as Caquetá has maintained rates higher than the national historical rate (27.8%) by an average of 13.5 percentage points, and is the ninth poorest department in the country [6].

In addition, it has been found that populations of this department have four fundamental problems that prevent them from interconnecting to the power grids and Internet networks:

Zones away from Internet trunks and the consequent lack of provider coverage.
Lack of electricity with the consequent high costs. (inside the NIZ of the country)
Lack of population economic resources.
Unawareness of information and telecommunication technologies uses.

As a result from the observations made, it is required to develop research and implementation of technological solutions using transversally two study areas that are Telecommunications and Alternative Energies.
Consequently, the proposed study allows to evaluate the interconnection of photovoltaic systems through full mesh networks (wireless) in 4 non-interconnected zones (NIZ) in Caquetá department. Figure 2.

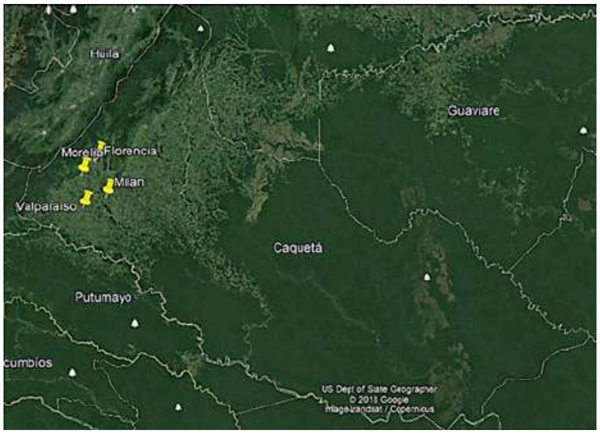

Figure 2. Caquetá department map showing four points where nodes are located.
Source: Institute of Planning and Promotion of Energy Solutions for the NIZ -IPSE - ligocalc web.

Initially, Caquetá NIZ geography is studied and characterized, and four NIZs are selected for network design. Subsequently, the necessary parameters for Full Mesh Network of selected NIZs are established. Then the photovoltaic system necessary to support the network infrastructure is analyzed. And finally the design of Full Mesh Network with its respective photovoltaic system is made, [7].

Based on the fact that NIZ are usually areas of difficult access and far from the main cities, and the project does not contemplate personnel dedicated to support -for reduction of costs-, it is decided to create a system of multiple redundancies as much as the electrical feeding and the Internet connection. This allows to have tolerance to failures in long time periods without presenting service unavailability [8]. Table 1 shows power grid materials.

Node	Quantity	Item	Brand	Reference
1	2	Photovoltaic panel	Jeico	320W
	2	Batteries	*Nenotix*	75 Ah
	1	Load controller	MPPT	MPPT
	1	MC4	N/A	MC4X-A2
	1	MC4	N/A	MC4x-B2
2	2	Photovoltaic panel	Jeico	320W
	2	Batteries	*Nenotix*	60 Ah
	1	Load controller	MPPT	MPPT
	1	MC4	N/A	MC4X-A2
	1	MC4	N/A	MC4x-B2
3	2	Photovoltaic panel	Jeico	320W
	2	Batteries	*Nenotix*	60 Ah
	1	Load controller	MPPT	MPPT
	1	MC4	N/A	MC4X-A2
	1	MC4	N/A	MC4x-B2
4	2	Photovoltaic panel	Jeico	320W
	2	Batteries	*Nenotix*	75 Ah
	1	Load controller	MPPT	MPPT
	1	MC4	N/A	MC4X-A2
	1	MC4	N/A	MC4x-B2

Table 1. Photovoltaic node materials. Source: own.

Table 2, meanwhile, shows materials required for the Full Mesh data network implementation taking into account: capacity and power consumption of the devices depending on zone topography and climatic considerations:

Node	Quantity	Item	Brand	Reference	Consumption (W) max.	Máx consumption per Node
1	1	Router	Mikrotik	RB3011 UiAS-RM	10	292
	1	Switch	*Nenotix*	WS-12-250-DC	250	
	4	Radio link	Ligo Wave	RapidFire 5N Pro	8	
	4	Antenna	ALGcom	32 dBi	0	
	5	Network wire	UTP	Cat 6	0	
2	1	Switch	*Nenotix*	WS-12-250-DC	250	282
	4	Radio link	Ligo Wave	RapidFire 5N Pro	8	
	4	Antenna	ALGcom	32 dBi	0	
	4	Network wire	UTP	Cat 6	0	
3	1	Switch	*Nenotix*	WS-12-250-DC	250	282
	4	Radio link	Ligo Wave	RapidFire 5N Pro	8	
	4	Antenna	ALGcom	32 dBi	0	
	4	Network wire	UTP	Cat 6	0	
4	1	Router	Mikrotik	RB3011	10	292
	1	Switch	*Nenotix*	WS-12-250-DC	250	
	4	Radio link	Ligo Wave	RapidFire 5N Pro	8	
	4	Antenna	ALGcom	32 dBi	0	
	5	Network wire	UTP	Cat 6	0	

Table 2. Network materials list for project implementation with power consumption according to datasheets. Source: own.

3. Implementation alternative

Being able to offer a stable internet solution is indispensable for communities to appropriate the proposed alternative. That is why the *full mesh network* is selected, a network topology that offers greatest redundancy. Figure 3 shows connectivity with a double ISP in two different system points to guarantee that, if there is a problem in one of them, the other channel can support it. One of the characteristics that make the full mesh network a more reliable type of redundancy, is connection all to all that even if the communication fails at more than one point the data find a way to reach the desired node.

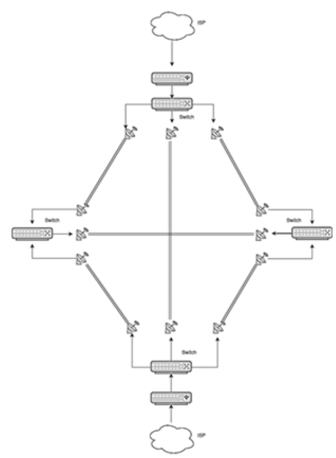

Figure 3. Topological diagram of the data solution. Source: own.

The Spanning *Tree Protocol* [3]*(SPT)* will be used to generate redundancies without presenting loops that could cause the service to fall *or broadcast storms* [4] that slow it down; to use the two channels a static route system is used with priorities that will work in *failover.* [5]

3 Is a network protocol that builds a loop-free logical topology for Ethernet networks. The basic function of STP is to prevent bridge loops and the broadcast radiation that results from them.
4 It is a form of data transmission where an emitting node sends information to a multitude of receiving nodes simultaneously, without the need to reproduce the same transmission node by node.
5 It is a back-up operating mode in which the system component are assumed by components of the secondary system when the main component is not available.

3.1. Data network design

Figures 5-10 show the link study according to geography and altimetry obtained from Google Earth using the *LigoWave*[6] simulator, that allows to validate distances, sight lines and estimated signal according to selected equipment [9], with implementation of towers 40 meters high.

Taking into account geographical location, high distances between villages and mountainous areas, high throughput radio links with connected antenna [10] were chosen; for redundancy system in layer 2 switches were selected that allow direct DC connection, as are the *nenotix*[7] that have as a special feature to work a wide range of DC inputs (9-250VDC) allowing direct connection to the battery and, finally, an equipment with load balancer possibilities and firewall functions, that works layers 1 to 7 of the OSI model, for its capacity of adaptability and support the mikrotik brand was selected, [12].

3.2. Power grid design

Based on the objectives of covering NIZ - as well as on the current impulse of Clean Energies - a photovoltaic system was designed based on maximum equipment consumption selected for the data network. Considering that solar radiation varies depending on the area to be treated, the average minimum values of the Caquetá villages and nearby towns [13] to be covered were taken. Based on NASA's pages for solar radiation [14], Figure 4 is obtained.

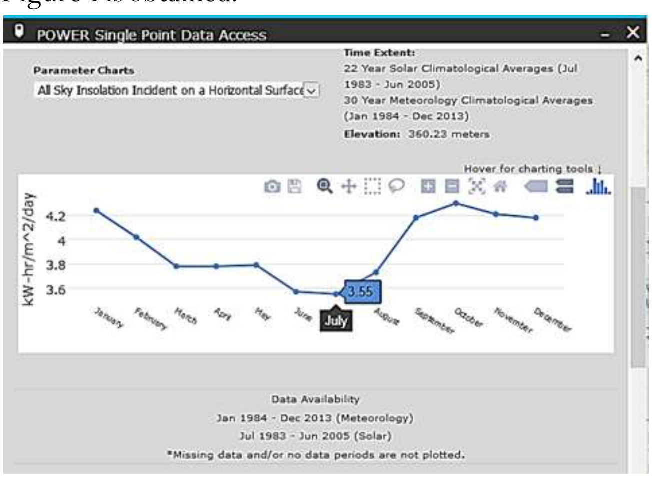

Figure 4. Horizontal average radiation NASA data [10].

July being the month with lowest average, was taken as a reference point for the design in order to prevent system failures during that month due to lack of power, and, additionally, the design proposes 2 days battery autonomy system, allowing giving system sustainability even on days of greater cloud cover and rain or photovoltaic panel failures.

3. Test and results

- **Nodes 1 and 4**

The sum of powers multiplied by the time of use -which is 24 hours a day- is carried out. Taking into account that maximum consumption of the 250*W* switch is taken from the datasheet used as PoE in all its ports, for this case 4 ports are used as PoE plus the same switch consumption, given in (1).

$$\{(WSwitch\ Solo) + (WRouter) + (WRadios)\} \quad (1)$$
$$\{(8W) + (10W) + (8W * 4)\} * 24 = 1200W$$

Based on minimum radiation -obtained from NASA- and the base formula for panel number calculation it is obtained that, (2):

E = *Daily power consumption*
1,3 = *Safety factor*
HSP = *Daily effective radiation time*
Wp = *Panel power to be used*

$$\frac{E*1{,}3}{HSP*Wp} = \frac{1200\ W*1{,}3}{3{,}55*320W} = 1.37324 \quad (2)$$

Bearing in mind that the panel number should always be rounded to the nearest whole number, it is concluded that two 320W panels are required to supply this system. Thus obtaining a residual protection by which the inverter efficiency is neglected, about 98%.

Because Caquetá is near Equator Line, it is possible to infer that the light and dark hours are equal, i.e. 12 hours of light and 12 hours of darkness; Additionally, taking into account that it is desired to work a 24V system due to panel characteristics and efficiency in front of a 12V system where the current will be double -by Ohm's law-, and before the advantage that it presents for the switch nenotix management -which works in a range from 9 to 250 VDC with a disconnection alert at 11 V- it is obtained a 24 V system with a greater range of work in

6 Develops high-performance wireless products with an emphasis on innovation, versatility and ease
7 The Netonix® WISP Switch™ product line was designed specifically for the WISP industry with a rugged chassis and extended operating temperature range

case the batteries fail: it is concluded that it is necessary to work at 24 V, (3-4).

E = Daily power consumption
Vt = System Voltage
Id = Daily current

$$\frac{E}{Vt} = Id \qquad \frac{1200\,W}{24\,V} = 50\,A \tag{3}$$

Battery Bank
Nb = Number of batteries
Da = Autonomy days
Id = Daily current
0,7 = Battery discharge depth

$$Nb = \frac{Da * Id}{0{,}7}$$
$$Nb = \frac{2*50A}{0{,}7} = 142.85\,A \tag{4}$$

Taking into account that the system voltage is 24V and most common and commercial batteries are 12V, current is divided into 2, (5):

$$\frac{142.85\,A}{2} = 71.425\,A \tag{5}$$

The commercial batteries closest to the obtained value are 75 Ah, which will be selected for implementation.

In the project it is not considered an inverter because the *nenotix* is powered directly from the batteries and has PoE ports that powers the *Mikrotik* and radios, it is only estimated the use of a charge controller to avoid battery damage.

- **Nodes 2 and 4**

The sum of powers is made multiplied by the time of use which is 24 hours daily. Bearing in mind that maximum consumption of the 250W switch is taken from the datasheet used as PoE in all its ports, but for this case 4 ports are used as PoE plus the same switch consumption.

$$\{(WSwitch\ Solo) + (WRadios)\}$$
$$\{(8W) + (8W * 4)\} * 24 = 960W \tag{6}$$

Based on minimum radiation obtained from NASA and the base formula for panel number, it is obtained that, (7):

E = Daily power consumption
1,3 = Safety factor
HSP = Daily effective radiation time
Wp = Panel Power to be used

$$\frac{E*1{,}3}{HSP*Wp} = \frac{960\,W*1{,}3}{3{,}55*320W} = 1.0986 \tag{7}$$

E = Daily power consumption
Vt = System Voltage
Id = Daily current

$$\frac{E}{Vt} = Id$$
$$\frac{960\,W}{24\,V} = 40\,A \tag{8}$$

Battery Bank
Nb = Number of batteries
Da = Autonomy days
Id = Daily current
0,7 = Battery discharge depth

$$Nb = \frac{Da * Id}{0{,}7}$$
$$Nb = \frac{2*40A}{0{,}7} = 114.285\,A \tag{9}$$

Considering that the system voltage is 24V and most common and commercial batteries are 12V, current is divided into 2, (10).

$$\frac{114.285\,A}{2} = 57.1428\,A \tag{10}$$

The commercial batteries closest to the value obtained are 60 Ah, which will be selected for the project implementation.

In the project no inverter is proposed because the nenotix is powered directly from the batteries and has PoE ports that power the radios, only the use of a charge controller is estimated, to avoid battery damage.

4. Simulation

In order to anticipate the connection possibility, a simulation is carried out with the equipment to be used, by means of its online tool that allows an estimation of link quality to be visualized.

4.2.1. Valparaíso – Morelia

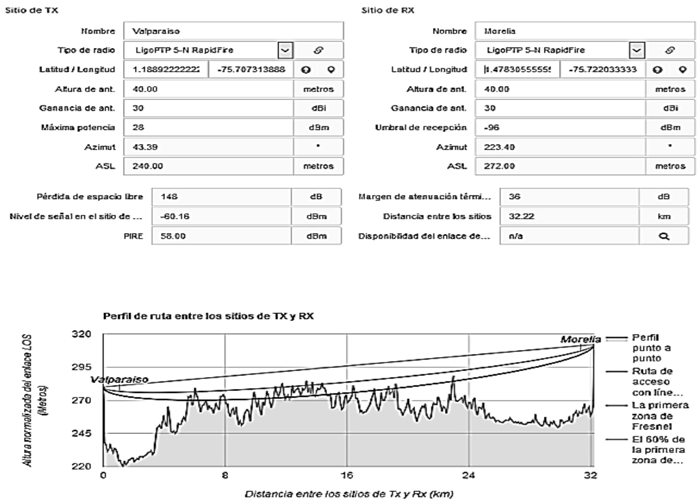

Figure 5. Radio link simulation between Valparaíso and Morelia villages. Source: Ligocalc web.

4.2.2. Valparaíso – Florencia

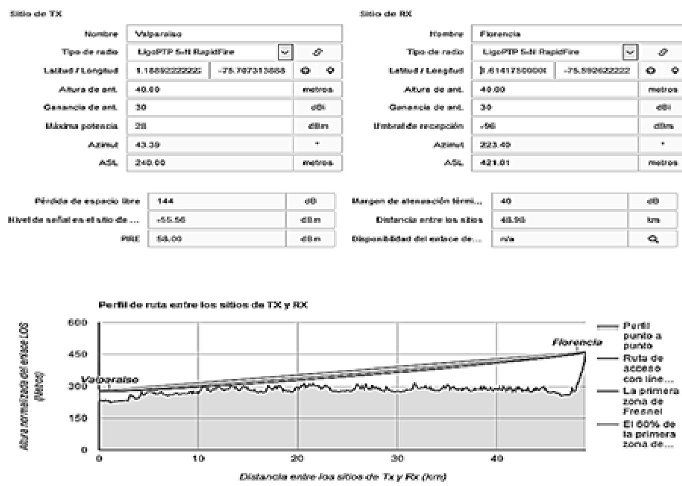

Figure 6. Radio link simulation between Valparaíso and Florencia villages. Source: Ligocalc web.

3.2.3. Valparaíso – Milán

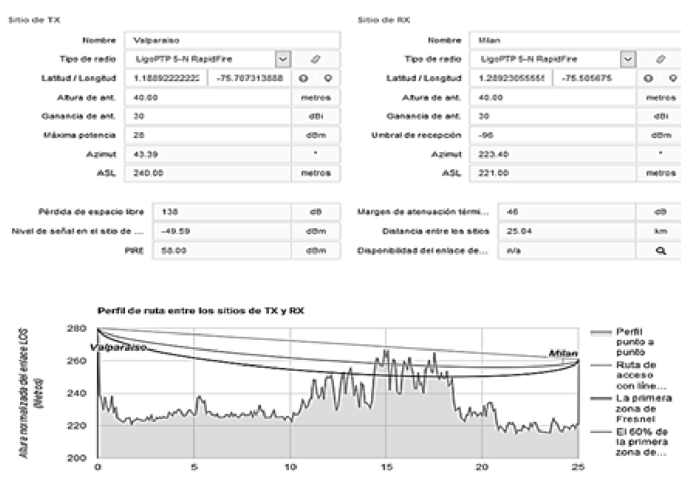

Figure 7. Radio link simulation between Valparaíso and Milán villages. Source: Ligocalc web.

4.2.4. Morelia – Milán

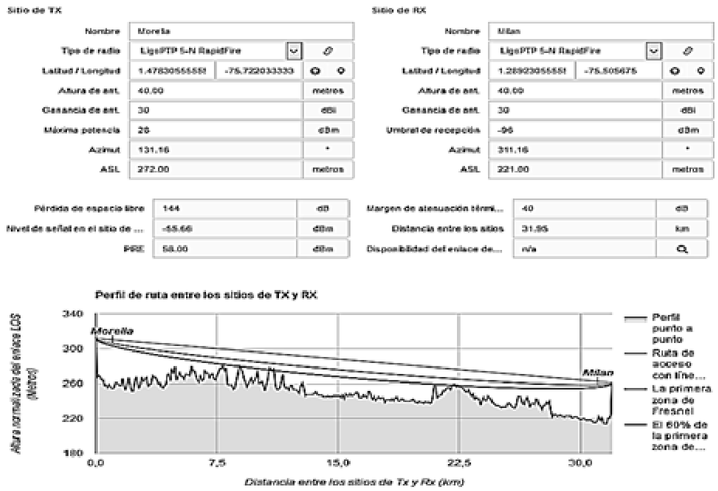

Figure 8. Radio link simulation between Morelia y Milán villages. Source: Ligocalc web.

4.2.5. Florencia – Milán

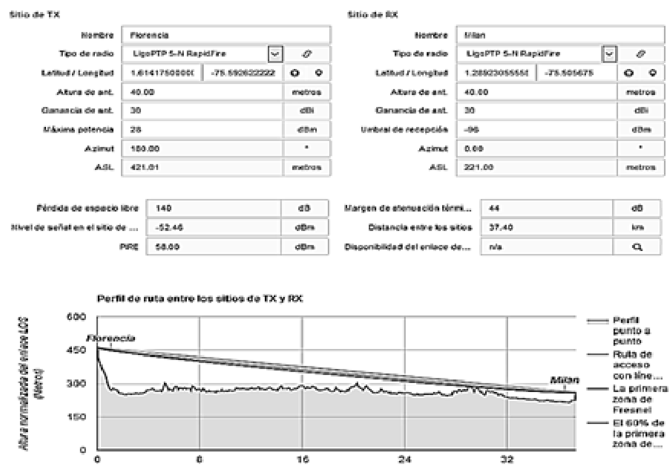

Figure 9. Radio link simulation between Florencia y Milán villages. Source: Ligocalc web

4.2.6. Florencia – Morelia

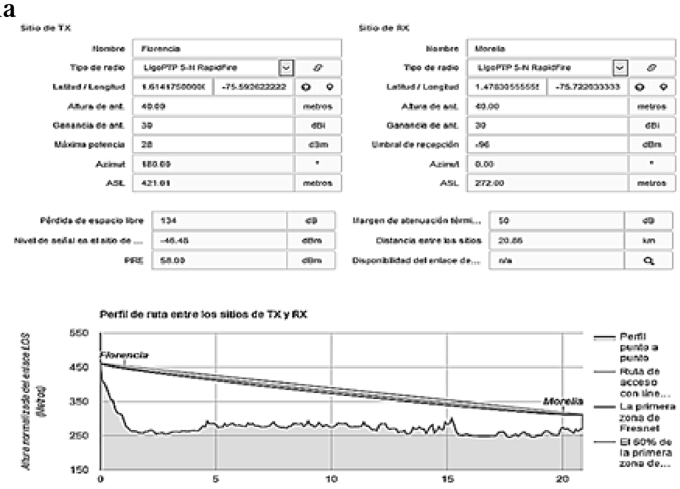

Figure 10. Radio link simulation between Florencia and Morelia villages. Source: Ligocalc web.

5. Conclusions in terms of social development

Proposed alternative is feasible and viable, so it can generate socio-economic development through closing digital breach and digital interconnection of vulnerable populations with by means of deployment of social developments in the following areas:

- **Education:** Internet deployment to remote country zones allows people in these populations to be integrated into virtual education models, and by reducing displacement allows inhabitants to participate in these activities.
- **Commerce:** Caquetá zone is a territory dedicated to cattle raising and agriculture, but because it is an area with hard access, cattle ranchers and peasants have to sell their products cheaper or even lose them, so this project could serve as a direct sales platform, increasing the yields and sales of producers, avoiding third parties and allowing a greater exit from this area of the country. It will also provide community with an example of Alternative Energies implementation since in this area Diesel and coal are widely used as fuels to generate electricity.
- **Government:** Technological advances shown by national government allow the management of various processes by digital means, which translates into economy and a person's time; however, Internet nodes in rural zones would allow this population to access these services allowing them to be in the law and be able to exercise their rights as Colombians.

5.1. Technical conclusions

- The project designed for NIZ is functional for any sector of the planet that has at least one of its points covered by internet connectivity. In this case, four different locations were taken and nodes were calculated on high throughput radio links in such a way that they allow the connection between all the points, guaranteeing to provide service to all surrounding communities.
- These networks can be extended with a star or tree network architecture, generating greater reach at lower cost but sacrificing high availability - this refers to the number of users that can be served in a given period of time-.
- Colombian territory topography makes it difficult to deploy full mesh networks in areas such as Caquetá; however, considering devices of accessible cost and sufficient power it is possible to implement them.
- NIZ have a high cost to national government, and construction of conventional infrastructure such as hydroelectric, thermal generators among others, have a high environmental cost, however; photovoltaic deployment can reach every corner of the country at lower cost and with less environmental impact.

Acknowledgements

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