ENGINEERING METHOD AND ANALYSIS OF REQUIREMENTS CED TI2.

Development:

1. Engineering method.

Problematic context.

A company providing Internet connectivity services in rural areas has faced significant challenges in one of the locations it serves. In recent times, numerous complaints have arisen due to frequent network outages in that particular area. This situation has had a negative impact on users and has affected their ability to conduct online activities smoothly.

The problem is intensified by the fact that the company has only one network antenna to provide a signal to the entire locality. The lack of additional infrastructure limits the company's ability to provide reliable and stable service in this particular area.

As a result, local residents and businesses are adversely affected, experiencing frequent interruptions in their internet connection, affecting their productivity, communication and access to online services.

Expansion of the network infrastructure: A network expansion mechanism must be established to provide greater coverage in the affected locality, so as to reduce the areas with deficient or non-existent signals.

Improved network stability: The solution must guarantee a more stable and reliable Internet connection, minimizing network downtime and ensuring optimal performance at all times.

Resource optimization: It is essential to make efficient use of available resources, taking into account the limitations of the rural location and the associated costs. The solution must seek a balance between service quality and profitability.

Maintenance and monitoring: A network maintenance and monitoring system must be implemented to quickly identify and resolve any incident or failure in the Internet connection.

Customer service: The solution should consider customer satisfaction as a key factor. It is expected to establish effective communication with users, provide timely and efficient technical support, and adequately handle complaints and queries related to the Internet service.

Solution development.

Step 1. Identification of the Problem.
Problem:

Identification of needs and symptoms.

Needs:

- **Extended coverage:** The company needs to use some method to improve network coverage in the affected locality and reduce areas with poor or no signal.
- **Network stability:** A solution is required that guarantees a more stable and reliable Internet connection, minimizing network downtime and ensuring optimal performance at all times.
- **Resource optimization:** It is necessary to make efficient use of available resources, taking into account the limitations of the rural location and the associated costs, to find a balance between service quality and profitability.
- **Maintenance and monitoring:** A network maintenance and monitoring system must be implemented to quickly identify and resolve any incident or failure in the Internet connection.
- **Customer service:** Customer satisfaction is a key need. Effective communication with users, timely and efficient technical support, and proper handling of complaints and queries related to the Internet service are required.

Symptoms:

- **Frequent network outages:** Users experience frequent interruptions in their Internet connection, affecting their productivity, communication and access to online services.

- **Deficient or non-existent signal:** There are areas in the affected locality where the internet signal is weak or non-existent, limiting users' ability to use online services seamlessly.

- **Negative impact on users and local businesses:** Internet connection interruptions have a negative impact on users' productivity and communication and affect the ability of local businesses to carry out their online activities. In addition, many business networks complain about the efficiency of the network.

- **Lack of additional infrastructure:** The company only has one network antenna to provide signal to the entire locality, which limits its capacity to offer reliable and stable service in the affected area.

- **Complaints and inquiries from users:** The company has received numerous complaints and inquiries from users due to connection problems and lack of stability in internet service in the affected locality.

Definition of the problem.

The objective problem is the lack of coverage and stability of the Internet connection service in a specific rural location. This is due to the limited network infrastructure, with only one antenna available, which is insufficient to provide a reliable and stable signal to all users in the area. As a result, there are frequent network outages, poor or non-existent signal areas, negatively impacting productivity, communication and access to online services for local users and businesses. In addition, user complaints and inquiries show dissatisfaction with the current service.

Step 2. Information Collection.

Power Line Communication (PLC): A technology that allows data transmission over the existing electrical network. Instead of using dedicated data cables, the PLC uses the electrical wiring already installed to transmit communication signals. PLC can be used in both domestic environments and industrial applications. In the domestic environment, it is mainly used to transmit data over the electrical network for the interconnection of devices in the home, such as computers, smart TVs, security systems, etc. This avoids the need to install additional network cables and allow for more convenient connectivity.

Low Earth Orbit (LEO): These are satellites that are located at a relatively low altitude above the Earth, generally between 160 and 2,000 kilometers. Unlike satellites in higher orbits, LEO satellites are closer to the Earth's surface and complete a lap around the Earth in a relatively short period of time, usually between 90 minutes and 2 hours. LEO satellites are used in a variety of applications, including telecommunications, Earth observation, navigation, and scientific data collection. Some of the best-known LEO satellite-based systems include the Global Positioning System (GPS), which provides navigation and positioning services, and satellite constellations to provide global Internet connectivity.

Attenuation: The most commonly used attenuation formula for estimating the power loss of a signal as it propagates in an environment is known as the Free-Space Path Loss (FSPL) attenuation model formula. This formula is based on the inverse of the square Iey and is applicable under ideal propagation conditions in unobstructed open space. The free-space attenuation model formula is as follows:

FSPL (dB) = 20log10(d) + 20log10(f) + 20log10(4π/c)

Donde:

FSPL: Power loss in dB.
d: Distance between the signal source and the receiver (in
meters) f: Frequency of the signal (in Hertz)
c: Vacuum Iuz velocity (approximately 3 x 10^8 meters/second)

It is important to note that this free space attenuation model formula is a simplification and does not take into account the effects of physical obstacles, reflections, refractions or other environmental conditions that may affect signal propagation in real environments. This formula only provides a basic estimate of power loss and does not take into account all the factors that can influence signal strength in more complex situations. In real environments, it is necessary to use more advanced models and consider other parameters to obtain a more accurate estimate of signal attenuation.

Sources:
https://es.wikipedia.org/wiki/Power_Line_Communications

https://www.internetsociety.org/es/blog/2022/02/que-es-un-sistema-de-satelite-leo-y-como-puede-ayudar-a-que-internet-sea-mas-grande/

https://forum.huawei.com/enterprise/es/que-es-la-atenuaci%C3%B3n-en-una-red-wlan/thread/714541-100239#:~:text=La%20p%C3%A9rdida%2C%20tambi%C3%A9n%20conocida%20como,cable%20o%20en%20el%20aire.

Step 3. Search for Creative Solutions.

These possible solutions were brainstormed among the members of the group, along with research on network and telecommunications infrastructures in the world today.

- **Deployment of long-range wireless technology:** Instead of relying solely on a network antenna, the option of using long-range wireless technologies, such as mesh networks or point-to-point links, could be explored. These solutions would allow more robust and stable connections to be established in distant areas, extending coverage efficiently without the need to install multiple antennas.

- **Use of broadband satellites:** Consideration could be given to contracting internet services through broadband satellites. These satellites provide global coverage and could be used to provide connectivity to remote rural areas. Although it may require a significant initial investment, this solution would overcome geographical limitations and provide a more stable and reliable service to users.

- **Collaboration with local and community providers:** The Internet service company could enter into partnerships with local service providers or with the community itself. This could involve installing antennas on existing buildings or infrastructure, such as schools, churches or community centers, to extend coverage in a decentralized manner. In addition, collaboration with the community can help identify creative solutions tailored to the specific needs of the locality, leveraging local resources and expertise.

- **Use of mesh network technology:** Implement a mesh network consisting of multiple transmitting and receiving nodes strategically distributed in the locality. These nodes will communicate with each other and share the load of the internet connection, allowing a wider and more stable coverage. This solution would also provide redundancy in case of failure of a specific node.

- **Use of power line technology for data transmission:** Take advantage of the existing electrical infrastructure in the locality to establish a data transmission network through power lines. This technology, known as Power Line Communication (PLC), would allow internet connection through power lines, avoiding the need for new antennas or additional infrastructure.

- **Use of Low Earth Orbit (LEO) satellite communication technology:** Explore the possibility of using Low Earth Orbit (LEO) satellite constellations to provide connectivity to the locality. These satellites offer lower latency and higher bandwidth

capacity compared to traditional satellites, which would result in a faster and more reliable connection for rural users

Step 4. Transition from Ideas to Preliminary Designs.
After a deliberate dialogue among the team members and analysis of the special needs of the problem, the following preliminary designs were discarded:

Alternative 2: Use of broadband satellites

- In terms of connection quality, this system is considered one of the most advanced solutions available today. However, it is important to note that it is also the most expensive alternative. The expenses associated with the acquisition and maintenance of this satellite could result in financial losses for the company.

  In addition, it is important to highlight that this type of systems are subject to possible failures due to signal obstruction in areas with rainy weather or strong winds. These weather conditions may affect the quality of the connection, which would generate interruptions in the service.

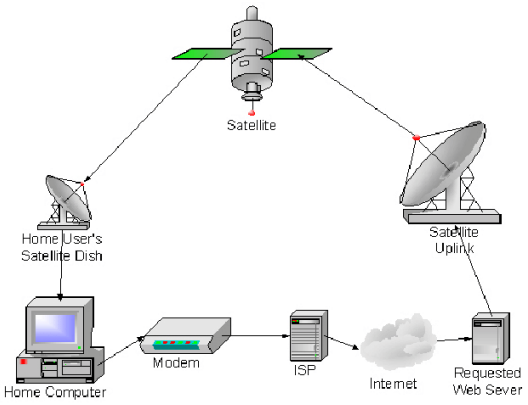

Imagen 1: Example of satellite broadband connection
https://www.researchgate.net/figure/Satellite-Broadband-Network-Architecture_fig1_228556895

Alternative 5: Use of technology of power lines for data transmission

- Although PLC offers advantages in terms of ease of installation and range of coverage, it also has some limitations. For example, data transmission speed may be slower compared to other communication technologies, such as Wi-Fi or Ethernet cable. Signal quality can be affected by the presence of electrical noise and the distance between connected devices. In addition, it is difficult for this technology to measure up for an infrastructure of this size.

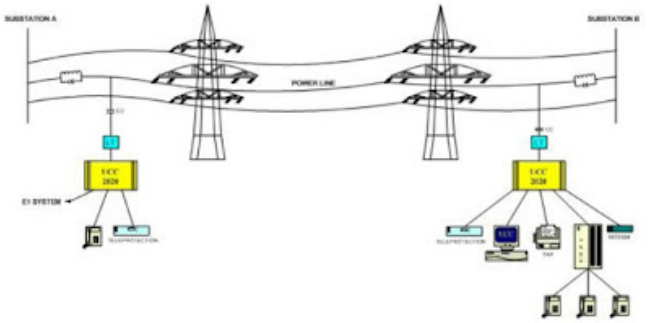

Imagen 2: Example of PLC connection
https://electricalbaba.com/power-line-carrier-communication-plcc/

Alternative 6: Use of low-orbit satellite communication technology

- While it is a cheaper alternative to a broadband satellite. Due to their low orbit, LEO satellites experience increased atmospheric drag, which exerts a force on them and causes them to gradually lose altitude and eventually re enter the Earth's atmosphere. This implies the need to perform maintenance maneuvers and replace satellites periodically to keep the constellation operational. Costs that the company would have to assume periodically.

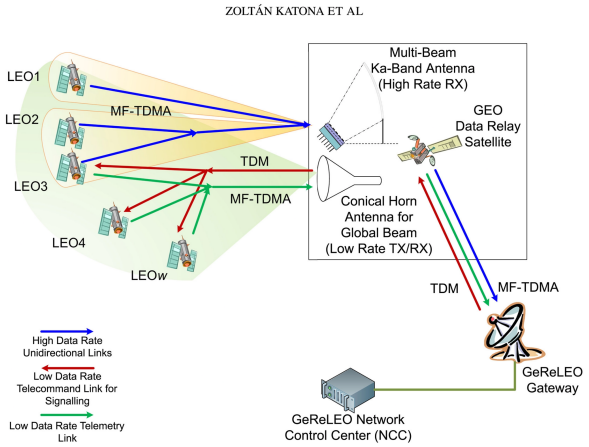

Imagen 3: Example of LEO connection
https://onlinelibrary.wiley.com/doi/full/10.1002/sat.1333

Step 5. Evaluation and Selection of the best solution.
Criteria

A basis of criteria has been defined to evaluate which of the proposals coincides with the best solution. In this case, three different criteria have been established to determine the best solution.

- Criterion **A: Stability.** The stability of each option in terms of internet connection should be considered, this implies evaluating the ability to maintain an uninterrupted connection, minimizing signal loss and downtime. Option stability is measured in three categories:
    - Stable: A reliable solution, which solves one of the main problems the company is currently facing: frequent network downtime.

    - Moderately Stable: An affordable solution, which meets the company's main problem, but has a constraint(s) to consider that would, in the long term, cause the problem to persist.
    - Unstable: A solution that fails to meet the needs or that presents different limitations that can bring major problems to the company.

- Criterion **B: Cost.** The current situation of the company must be considered, due to the need to adapt the solution to the current resources of a single network antenna, and the solution must be economically feasible:
    - Economic: The proposed solution helps to keep costs low for the company and is sustainable in the long term.
    - Adjusted: The proposed solution has low costs and is viable, however, it can be presented that the resources for this solution to remain sustainable in the long term have highly variable costs.
    - Costly: The proposed solution exceeds the costs that the company has in mind, although it solves the problem, it generates inconveniences for the company due to its maintenance.

- Criterion **C: Practicality.** The solution considers the need to be applicable in the specific rural environment. This implies considering factors such as resource availability, existing system infrastructure and geographic limitations, thus three categories are defined for this criterion:
    - Effective: The proposed solution is practical, since it uses available resources efficiently and takes advantage of the existing infrastructure in the rural environment, which makes it viable and beneficial for both the company and the community.
    - Useful: The proposed solution is moderately practical, as it is feasible in the rural environment. However, there are some variations in the resources required to keep it sustainable in the long term, which could create some additional challenges for the company in terms of planning.
    - Impractical: The proposed solution is not practical, as it exceeds the resources established by the company. Although it solves the connectivity problem in the rural environment, it generates significant inconveniences for the company, which makes it not advisable in this specific context.

- Criterion **D: Coverage.** The solution considers the capacity to provide broad and effective coverage in the rural area, considering the extension, scope and overcoming geographical obstacles. This criterion can be divided into three categories:
    - All Risks. The solution offers wide and effective coverage in rural areas. The signal has a considerable range, reaching remote areas without problems and overcoming significant geographical obstacles.
    - Limited: The solution provides acceptable coverage in the rural area. The signal has a moderate range, although there may be some remote or hindered areas where the connection is less stable.

- Insufficient: The solution has very poor coverage in rural areas. The signal has a reduced range, making it difficult to reach remote areas and overcome geographical obstacles. This can result in poor, intermittent or even absent connectivity in some areas of the rural locality, which severely limits internet access for users.

Assessment

Evaluating the above criteria in the previously proposed alternatives, we obtain the following table:

Alternative	Criterion A	Criterion B	Criterion C	Criterion D	Total
Long-range wireless technology implementation (A)	2	1	3	3	9
Collaboration with local and community suppliers (B)	2	3	2	3	10
Use of network technology mesh (C)	3	2	3	3	11

Selection

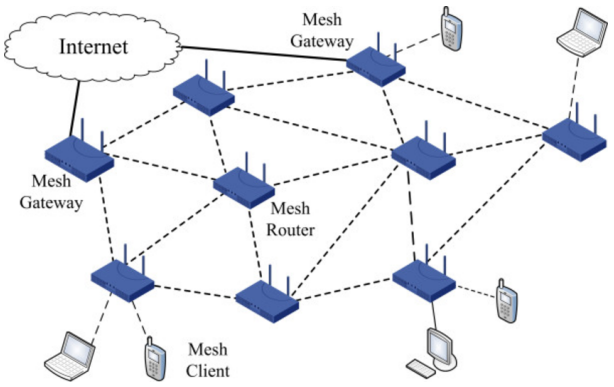

Imagen 4: Ejemplo de Red Mesh

https://www.researchgate.net/figure/Wireless-mesh-network-architecture-with-mesh-gateway-mesh-routers-and-mesh-clients_fig2_257877841

Based on the previous evaluation, the alternative of using mesh network technology is the best option for this problem situation, standing out especially in its Stability, Practicality and Cost. Although the other options could be considered as they stand out in other aspects, they lack the capabilities that solution C possesses.

- Option A stands out more than others in the criteria of Practicality and Coverage, by handling wireless connections, it would be possible to solve the problem in a satisfactory and simple way, however, in addition to the geographical conditions, it would be necessary to consider the weather conditions, which drastically influence the stability of the solution, not to mention that it is the most expensive solution to implement and maintain in the long term.

- Option B stands out more than others in the Cost and Coverage criteria, by allowing the community of the area to help defray the costs, it could be possible to collaborate to provide a better service, and with the help of these same people, a better understanding of the area and how to organize a sustainable system could be achieved, however, the practicality and stability of this joint system may decline over time since which requires capital and constant collaboration to operate uninterruptedly.

2. Specification of requirements.

Requirements Analysis Table.

Client	Communications Company
User	Network Manager
Functional requirements	**1 - Add node:** The program must allow the registration of a Mesh network node. **2 - Modify node:** The program must allow the modification of a Mesh network node from a provided IP address. **3 - Delete node:** The program must allow the removal of a node from the Mesh network. **4 - Create link:** The program must allow communication links to be established between Mesh network nodes. **5 - Modify link:** The program must allow the network manager to modify the properties of an existing link in the Mesh network. **6 - Delete link:** The program must remove a link between nodes in the Mesh network.

	7 - Shortest path between two nodes: The system allows to find the shortest path between two nodes to establish a data traffic subnetwork through Dijkstra's algorithm. **8 - Show the most efficient connection:** The system allows to find the most optimal general network connection as the main connection between the nodes through the Prim algorithm. **9 - Show reachable nodes:** The system allows to visualize a list of reachable nodes from a source node, in order to visualize missing nodes in the network and implement strategies, for that purpose BSF is used.
Context of the problem	In a specific rural location, an Internet connectivity service provider faces significant challenges due to the lack of coverage and stability in its network. With only a single network antenna available, residents and local businesses experience frequent connection drops, affecting their productivity, communication and access to online services. In order to improve the quality of service, it has been decided to implement a Mesh network using networks as the technological basis. This will allow the establishment of a decentralized network infrastructure and optimize communication between nodes to provide a more reliable and stable connection to the rural community.
Non-functional requirements	**1 -** The program must handle the exceptions that may be generated when searching for a node or link, when the signal stretch doesn't satisfy the rules to distribute traffic appropriately. **2 -** Generate alerts or notifications in the event of connection failures or degradations.
Product requirements	**1 -** Must have at least 10 commits within 1 hour of each other. **2 -** The design of data structures should be designed using the ADT.

Functional Requirements Analysis Tables.

Name or identifier	**1 - Add node**
Summary	Add a node to the mesh network

Inputs	Input name	Datatype	Selection or repetition condition
	ipAddress	String	Can't be empty
	bandwidth	double	Can't be null, or below zero
	name	String	Can't be empty
General activities necessary to obtain the results	**The system will validate the information and create the new node.**		
Result or post-condition	Returns a successful message.		
Outputs	**Output name**	**Datatype**	**Selection or repetition condition**
	msg	String	

Name or identifier	**2 - Modify node**		
Summary	Checks that the node exists and allows modification of the node.		
Inputs	**Input name**	**Datatype**	**Selection or repetition condition**

	ipAddress	String	Must be different of null
	newBandWith	double	Can’t be below zero
General activities necessary to obtain the results	It will search in the system data the node info that has an equal IP address based on the provided IP address.		
Result or post-condition	The modify node with the new information		
Outputs	**Output name**	**Datatype**	**Selection or repetition condition**
	Node	node	Must be the only one with the same IP address
	msg	String	Change according to the status

Name or identifier	**3 - Delete node**		
Summary	Checks that the node exists and allows delete of the node.		
Inputs	**Input name**	**Datatype**	**Selection or repetition condition**
	ipAddress	String	Must be different of null
General activities necessary to obtain the results	It will search in the system data the node info that has an equal IP address based on the provided IP address. Eliminate the node and the connections between the other nodes		

Result or post-condition	A message that notify the successful delete operation		
Outputs	**Output name**	**Datatype**	**Selection or repetition condition**
	msg	String	Change according to the status

Name or identifier	**4 - Create link**		
Summary	The program must allow communication links to be established between Mesh network nodes, allowing to define the quality of each link (e.g., signal strength or bandwidth) to optimize network performance.		
Inputs	**Input name**	**Datatype**	**Selection or repetition condition**
	initialNodeIP	String	Node IP must be different than null
	finalNodeIP	String	Node IP must be different than null
	signalStrength	Double	Quality must be not negative
General activities necessary to obtain the results	The link must have a valid Start Node and End Node, and specify the desired link quality.		
Result or post-condition	A new link between Initial and Final Node has been created		
Outputs	**Output name**	**Datatype**	**Selection or repetition condition**
	msg	String	- Link has been created - Link already exists
	LinkId	String	- LinkId must be unique

Name or identifier	**5 - Modify link**		
Summary	The program must allow the network manager to modify the properties of an existing link in the Mesh network.		
Inputs	**Input name**	**Datatype**	**Selection or repetition condition**
	option	Integer	Option must be one of the modifiable variables (quality)
	linkID	String	It must be different than null
General activities necessary to obtain the results	The existence of the connection is checked and its information is changed.		
Result or post-condition	The modification of the link has been successfully performed.		
Outputs	**Output name**	**Datatype**	**Selection or repetition condition**
	msg	String	- Link has been modified - Link doesn't exist

Name or identifier	**6 - Delete link**		
Summary	The program must remove a link between nodes in the Mesh network		
Inputs	**Input name**	**Datatype**	**Selection or repetition condition**
	option	Integer	Option must be one of the modifiable variables (quality)
	linkID	String	Link id must exist
General activities necessary to obtain the results	The existence of the connection is checked, the node and his links are deleted.		

Result or post-condition	The Link has been successfully removed.		
Outputs	**Output name**	**Datatype**	**Selection or repetition condition**
	msg	String	- Link has been delete - Link doesn't exist

Name or identifier	**7 - Shortest path between two nodes**		
Summary	Finds the most efficient connection between two nodes.		
Inputs	**Input name**	**Datatype**	**Selection or repetition condition**
	initialNodeIP	String	Must be different of null
	destinationNodeIP	String	Must be different of null
General activities necessary to obtain the results	Find the adjacent nodes and update accumulated distances. A priority queue is used to efficiently select the next node to scan, prioritizing the one with the lowest accumulated distance.		
Result or post-condition	Array containing the cumulative distances from the initial node to all other nodes in the network		
Outputs	**Output name**	**Datatype**	**Selection or repetition condition**

	dijkstra	String[]	Changes according to the cycles

Name or identifier	**8 - Show the most efficient connection**		
Summary	Shows the links selected for efficient connection of all nodes from an initial node.		
Inputs	**Input name**	**Datatype**	**Selection or repetition condition**
	intialNodeKey	String	Must be different from null.
General activities necessary to obtain the results	Obtain the key of the initialNode. After that, it verifies the existence of the initial node, then it initializes a priority queue, then, in a loop, it extracts the lowest weighted edge from the queue and checks if the target node has already been visited. If it has not been visited, it is added to the list of visited nodes and the link is registered. The edges of the target node are then added to the queue, as long as the target nodes have not been visited. The process continues until the queue is empty. At the end, it is checked if all nodes have been visited to determine if the network is connected.		
Result or post-condition	The result is returned as a string showing the selected links.		
Outputs	**result**	**String**	**-**

Name or identifier	**09 - Show reachable nodes**		
Summary	Allows to see all reachable from a source node for an overview and to facilitate decision making.		
Inputs	**Input name**	**Datatype**	**Selection or repetition condition**
	ipAddress	String	Must be different of null
General activities necessary to obtain the results	The node is checked for existence, distances to reachable nodes in the network are displayed.		
Result or post-condition	A list of the node's bandwidth with all the reachable nodes		
Outputs	**Output name**	**Datatype**	**Selection or repetition condition**
	list	String	Change according to the status