Estimation of Distances to Integrate the National Fiber Optic Backbone Network into the Peruvian Army

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Abstract*– Currently, data transport networks represent a crucial strategic infrastructure for interconnection between countries as well as between the population and governments. For instance, in Australia, the National Broadband Network (NBN) has improved access to digital services in remote communities through the combined use of technologies such as fiber optics, satellite, and wireless networks. In the case of Peru, the National Fiber Optic Backbone Network (RDNFO) was designed to reduce the digital divide and ensure access to the internet and communication services in rural and vulnerable areas through modern telecommunications infrastructure. However, the connectivity of the Peruvian Army to this network is limited, as it currently depends partially on the private telecommunications operator NEXTNET, which incurs high implementation and maintenance costs. To address this issue, this paper presents a tool to estimate the necessary distances between the units and dependencies of the Peruvian Army and the access and distribution nodes of the RDNFO, with the goal of optimizing the design and deployment of the fiber optic network. The developed tool utilizes Google Apps Script, a JavaScript-based scripting environment that enables task automation and efficient handling of geospatial data through integration with services such as Google Maps API. The tool estimated the distances between the Backbone Network nodes and the units of the Peruvian Army (III-DE) with an average error of 12.41%. This resulted in an additional 23.446 kilometers, generating an extra cost of USD 18,756.80. Despite the increase, the tool ensures greater accuracy and reliability, minimizing risks during the fiber optic deployment process.

Keywords*– Distance Estimation, Connectivity, National Fiber Optic Backbone Network, Peruvian Army, App Script.

I. Introduction

In the last 30 years, the number of internet users has reached approximately 5 billion, which has fostered digital innovation that influences socioeconomic development. However, this technology is not being fully utilized. Currently, the goal is to achieve universal and effective connectivity that makes it possible to access a secure, productive, and accessible line for all members of society. It is important to mention that one-third of the global population still lacks internet access, and a large part of those who do have access suffer from poor quality and low-speed service, creating digital divides at a global level. A primary global challenge is for nations to generate public policies that encourage governments and private companies to develop infrastructure and equipment with the aim of providing the population with access to broadband internet and mobile telephony services, as well as optimizing organizational structures and supporting private investment to increase productivity, social welfare, and accelerate the reduction of various social gaps, specifically the digital divide [1]. The digital divide in access to and use of Information and Communication Technologies (ICT) in Peru remains a critical issue that reflects deep inequalities between regions and communities in the interior of the country. Despite efforts to improve access to ICT in rural areas, there are failures in reducing this gap due to the lack of adaptation to local cultural characteristics and needs [2]. The National Fiber Optic Backbone Network (RDNFO) in Peru, as of December 2020, was only utilizing 3.2% of its total installed capacity, generating revenue that covered only 7.7% of its expenses. The RDNFO, which connects the country's departments, is essential for an interconnected public communications system. Government networks remain highly relevant for advancing broadband access in our country, especially in rural areas [3]. According to the 2024 Internet and private data network service contract, which establishes tables of connected units at the national level [4], the Peruvian Army is currently interconnected via fiber optics to 20% of the total units and/or dependencies listed in its Unique List of Units.

In this regard, there is a significant digital connectivity gap, which is why it is necessary to implement interconnection projects for the Army's units and dependencies to increase access to digital services for end users. An important parameter for estimating costs in fiber optic installation projects is the length of the transmission line from an access or distribution node to the final client location. According to the quotation from RyR Concca SAC, the cost for one kilometer of fiber optic installation is 800 dollars.

This paper presents a tool for the automatic estimation of distances for fiber optic installation, developed using Apps Script, a cloud-based solution built on JavaScript that leverages Google Drive technology. This tool allows for the integration and automation of tasks, taking advantage of the intelligent capabilities of the platform. The main objective is to calculate the necessary distances to connect the Peruvian Army to the National Fiber Optic Backbone Network, contributing to cost estimation in fiber optic infrastructure projects. This will help close connectivity gaps, increase communication coverage for Army units, and ensure access to both private computing services and the internet.

This paper is structured into six sections, with the first being the present introduction. Section II briefly describes concepts related to fiber optic installation distance estimation and data transport networks. Section III discusses related works on distance estimation using programming tools. Section IV presents the proposed tool, outlining the four phases of its development. Section V describes the experiments and results from the fiber optic installation distance estimation tool. Finally, Section VI presents the conclusions of this work.

II. Estimation of Distances and Data Transport Network

A. Distance Estimation

Optimal route algorithms are computational methods designed to find the most efficient path between two points within a network, such as roads, transport lines, cables, or data connections. These algorithms are fundamental in applications like Google Maps, GPS navigation systems, telecommunications networks, and logistics management [5].

Distance estimation is carried out based on Dijkstra's algorithm and its enhancement, the A* (A-star) algorithm. The A* algorithm is based on the concept of informed searches to make optimal decisions regarding the paths to follow. It uses heuristic information to determine the best path toward the destination.

The A* algorithm uses an evaluation function, $f(n) = g(n) + h'(n)$, where $h'(n)$ represents the heuristic value of the node to be evaluated from the current node, n, to the destination, and $g(n)$ represents the actual cost of the path taken to reach that node, n, from the starting node. A* maintains two auxiliary data structures, referred to as "open" (implemented as a priority queue sorted by the value of $f(n)$ for each node) and "closed," where the information of visited nodes is stored. In each step of the algorithm, the node that is first in "open" is expanded, and if it is not the goal node, it calculates $f(n)$ for all its child nodes, inserts them into "open," and moves the evaluated node to "closed."

The algorithm is a combination of breadth-first search and depth-first search: while $h'(n)$ tends toward depth-first search, $g(n)$ tends toward breadth-first search. This way, the search path changes whenever there are more promising nodes [6].

Figure 1 illustrates an example of how the A* algorithm works, where the origin node is green, and the destination node is blue. A restricted movement area is set in column 10, and each node has a weight that represents the jump or edge of the movement. In this sense, the heuristic estimating the distances from the origin node to the destination node is based on exploring the neighbors of the origin node, which, through an iterative process, are stored as they transition from "open" to "closed," ultimately establishing a depth and width calculation that determines the optimal route, shown in red, from the origin node to the destination node.

7	6	5	6	7	8	9	10	11		19	20	21	22
6	5	4	5	6	7	8	9	10		18	19	20	21
5	4	3	4	5	6	7	8	9		17	18	19	20
4	3	2	3	4	5	6	7	8		16	17	18	19
3	2	1	2	3	4	5	6	7		15	16	17	18
2	1	0	1	2	3	4	5	6		14	15	16	17
3	2	1	2	3	4	5	6	7		13	14	15	16
4	3	2	3	4	5	6	7	8		12	13	14	15
5	4	3	4	5	6	7	8	9	10	11	12	13	14
6	5	4	5	6	7	8	9	10	11	12	13	14	15

Fig. 1 Operation of the A* Algorithm

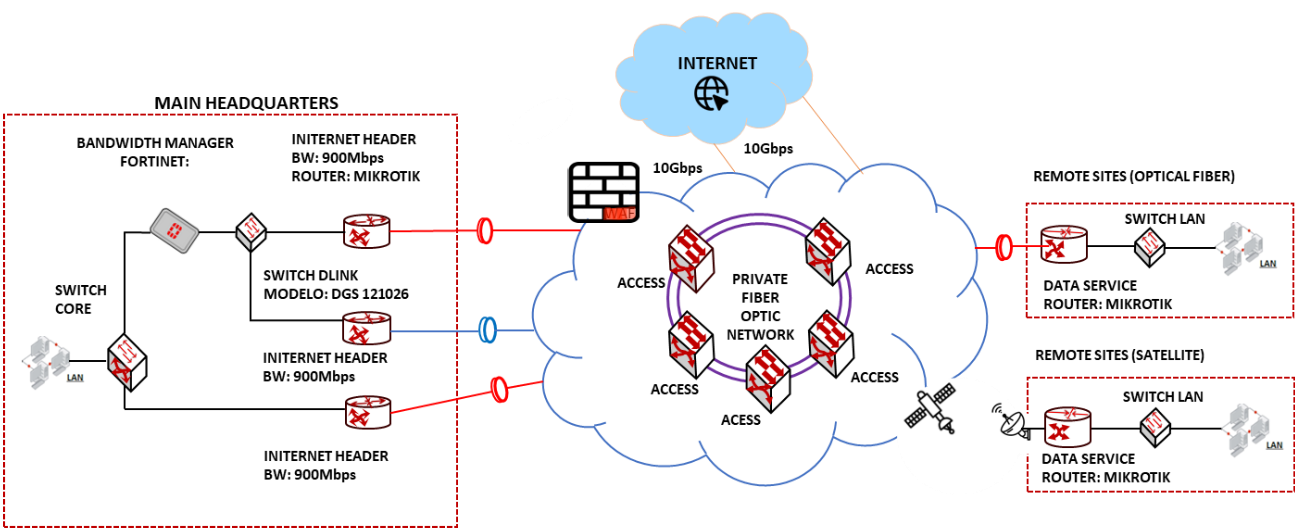

Fig. 2 Data Transport Network Topology of Nextnet and the Peruvian Army

B. Data Transport Network

A transport network transfers user information from one location to another in either a unidirectional or bidirectional manner. A transport network can also transfer various types of network control information, such as signaling and operations and maintenance data for the control of the functional group. Since the transport network is an extensive and complex system with various components, it is essential to design and manage it by developing an appropriate network model with well-defined functional entities [7]. Fiber optic data transport networks are infrastructures that enable the transmission of large volumes of data through fiber optic cables, using light signals to communicate information between different locations. These networks are the backbone of modern telecommunications, connecting data centers, internet operators, cloud services, mobile networks, and more [8]. Figure 2 presents the data transport network topology implemented by the telecommunications company Nextnet - Fiberlux and the Peruvian Army, where a ring design is used for transport, integrating various nodes of the Army Units.

Fiber Optic Data Transport Networks are infrastructures that enable the transmission of large volumes of data through fiber optic cables, using light signals to communicate information between different locations. These networks are the foundation of modern telecommunications, connecting data centers, internet providers, cloud services, mobile networks, and more [9]. Among their main features are: (a) Extremely High Transmission Capacity: They support data speeds in terabits per second (Tbps), making them ideal for the growing demands of the internet and digital services; (b) Low Latency: The use of light transmission in fiber optics significantly reduces delays; (c) Long Distance Without Significant Loss: Data can travel hundreds of kilometers before requiring repeaters or amplifiers, (d) Resistance to Interference: Fiber optic cables are not affected by electromagnetic interference, ensuring a clear and reliable signal; (e) Security: It is difficult to intercept data traveling through fiber optics without causing detectable disruptions.

C. National Fiber Optic Backbone Network

Through Law No. 29904, "Law for the Promotion of Broadband and Construction of the National Fiber Optic Backbone Network" (AF-2012), the government aims to promote the development, use, and widespread adoption of broadband across the country, both in urban and rural areas, encouraging the deployment of infrastructure, services, content, applications, and digital skills to support social and economic inclusion in rural regions [10].

The Technical Secretariat of the Telecommunications Investment Fund (FITEL) of the Ministry of Transport and Communications, in accordance with the powers granted in Article 7.4 of Law No. 29904, has developed twenty-one (21) Regional Projects for the installation of broadband for connectivity and social development. Thirteen (13) of these projects have signed contracts and are in the investment phase, two (02) projects have been awarded and are awaiting contract signature, and six (06) projects are in the promotion phase [11].

The scope of these projects will connect 1,530 district capitals (82% of the country's districts) through a high-speed, high-capacity, and reliable telecommunications network. This means that more than 6,620 locations will have access to high-speed internet, benefiting around 4 million Peruvians, 7,348 educational institutions, 3,735 healthcare establishments, and 566 police stations. Additionally, private entities and other public institutions within the project areas will also have access to these services.

Figure 3 shows the deployment of the fiber optic transport network corresponding to the National Fiber Optic Backbone Network (RDNFO) for the year 2019, provided by the regulatory policy and competition management of the Telecommunications Supervisory Agency (OSIPTEL) [12]. The blue lines correspond to the installation of the National Fiber Optic Backbone Network throughout the Peruvian territory, while the red points indicate access and/or distribution nodes, which are located in all departmental capitals except Iquitos and Tumbes.

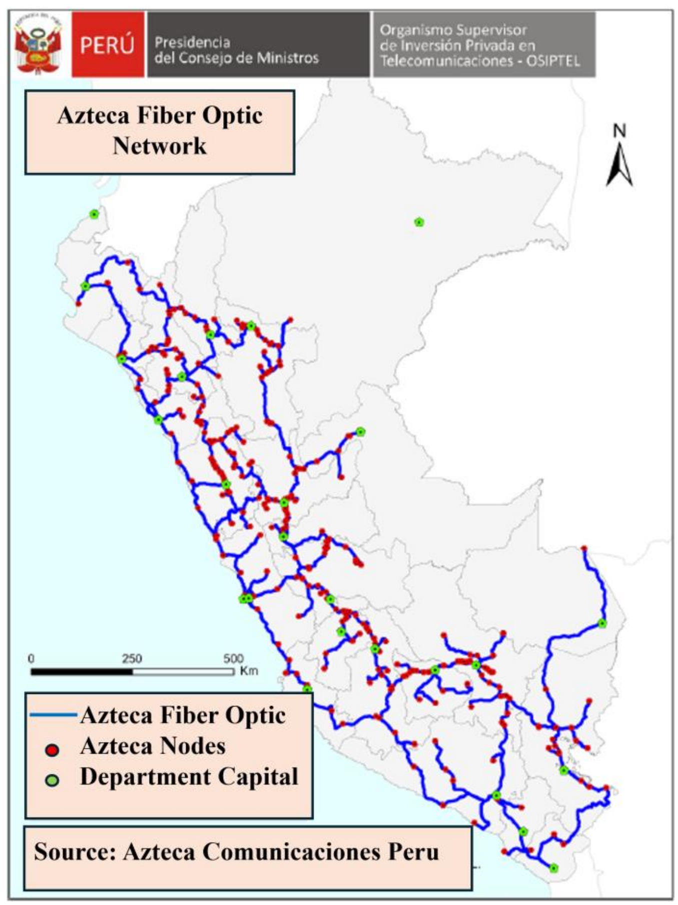

Fig. 3 Deployment of the Fiber Optic Transport Network (RDNFO)

D. Fiber Optic Cable Installation

For fiber optic cable installation, environmental, technical, and safety requirements must be followed. This is considering that the laying of the fiber optic conductor can be done on energized power lines and, in other cases, on fiberglass structures, ensuring efficiency and minimizing associated risks. According to [13], the conductors must comply with the 230E1 standard, which specifies the vertical distance between cables and equipment at floor level, in crossings of roads, streets, paths, rivers, etc., which increases the length of the fiber optic cable used. For fiber optic installation, it is essential to first understand the characteristics of the section to be implemented. Therefore, the following steps should be followed:

1. Perform a section verification on maps, locating nearby areas and access routes.
2. Take a route tour for site reconnaissance, verifying the feasibility of construction, identifying the characteristics of the section, and locating critical points.
3. Verify the feasibility of laying the cable along the route according to the design and identify the locations of the coils to be installed according to span.
4. Replan the route if necessary.

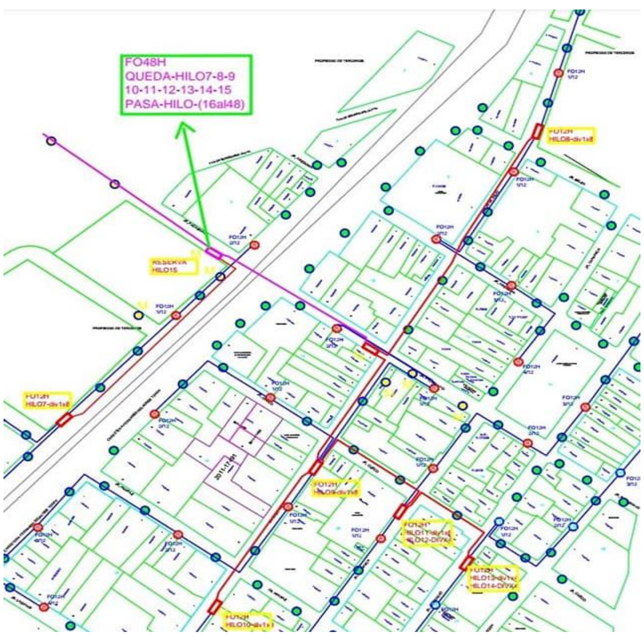

Fig. 4 Design of Optical Fiber Section on Map

For From what was mentioned earlier, it is established that the first important step is to verify the optical fiber plan on maps, as shown in Figure 3. In this sense, the design and formulation of these plans are essential, as they establish the routes, as well as the required length for the optical fiber deployment. All of this culminates in the establishment of the budget and execution timelines, as well as the selection of materials for the network project implementation, such as OLT, EDFA, FUSION MACHINES, NAP boxes, ONU equipment, complete fusion kits, among others, as well as their preventive and corrective maintenance.

D. Connectivity in Units of the Peruvian Army

The Peruvian Army, according to its organization, is made up of Divisions, Brigades, Battalions, and Companies, as well as its command organs in the Army General Command, and its transversal organs related to education and training, logistics, and health, which makes it a complex organization. In [14], the corresponding number of units and dependencies of the Army is established according to Figure 4.

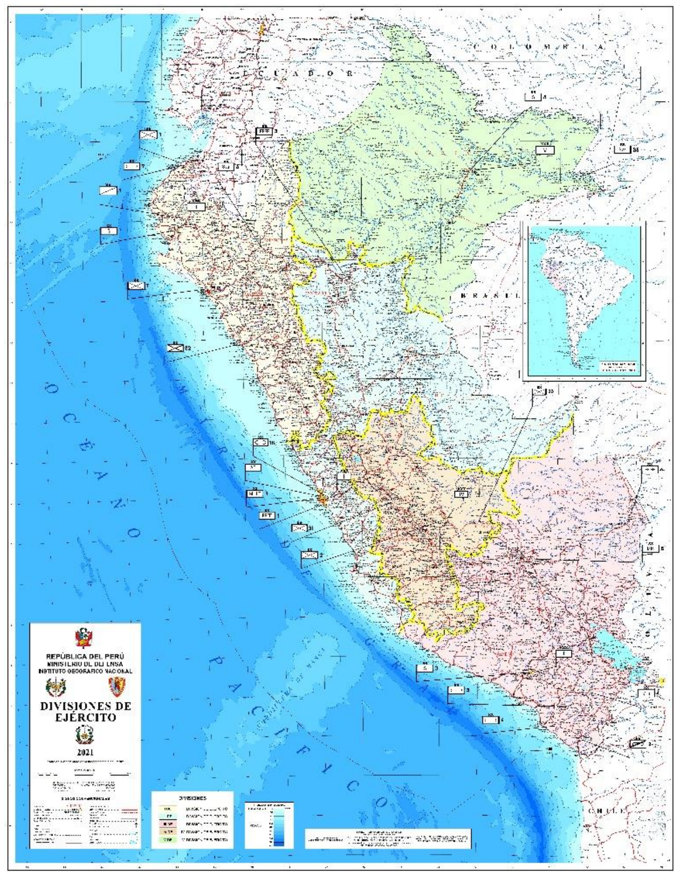

Fig. 5 Units of the Peruvian Army

As of today, at the Division and Brigade level, or units of the same magnitude, they are 100% interconnected with the data center through an Internet Service Provider. At the battalion level, only 2% of interconnection is achieved, creating an infrastructure gap in terms of coverage to connect the units and/or dependencies of the Army to provide them with access to voice, data, and internet transmission services.

E. Google Applications

Apps Script is a low-code platform that streamlines and facilitates the creation of business solutions that integrate, automate, and extend Google Workspace. Its main advantages include providing powerful data tools for creating custom applications and automations, fostering effective collaborative innovation, and optimizing business work by offering tools that integrate with Google Workspace. Some of the actions that can be performed are: (a) Add custom menus, dialogs, and sidebars to Google Docs, Sheets, and Forms, (b) Write custom functions and macros for Google Sheets, (c) Publish web apps, either standalone or embedded in Google Sites, (d) Interact with other Google services such as AdSense, Analytics, Calendar, Drive, Gmail, and Maps, (e) Build add-ons and publish them in the Google Workspace Marketplace. One of its main features is the development of applications without coding, thanks to Google's artificial intelligence, which allows automation of processes easily and from anywhere, saving time and talent. It also connects with the power of IoT devices to access data such as GPS, images, drawings, barcodes, QR codes, and character recognition [15].

On the other hand, Google Sheets is an online spreadsheet tool developed by Google, which is part of its productivity suite in Google Workspace. In addition to its cloud access, real-time collaboration, compatibility, and connectivity features, it has advanced functions that allow for mathematical, statistical, and logical formulas and functions, pivot tables, and charts for data analysis, database connections, and custom scripts through Google Apps Script. These scripts can be linked with dynamic data, such as integrations with Application Programming Interfaces (APIs) [16].

III. State of the Art

The algorithms of evolutionary computation allow solving optimization problems through iterations and defined stages. One of the most commonly used techniques for such problems is differential evolution, which contains properties of small-world complex networks, and its study is important due to the results it generates for optimization problems [17].

In [18], it is concluded that one of the advantages of the A* Search algorithm is that after performing an initial search, the found route can be optimized; this can be done using the extra information stored by the algorithm about what the agent has encountered during the journey. Since the algorithm has the ability to store the traveled route and the neighboring nodes, future work suggests including an option to optimize the route within the A* Search algorithm.

In [19], an algorithm is described for creating a set of candidate solutions for the route planning problem. This works by collecting information from a small number of calls to an appropriate cloud-based mapping API. All remaining calculations are carried out on the client side, where the vertices of each polygon act as reference points in a route. Most APIs provide methods to quickly identify GPS coordinates near existing streets.

In [20], a new perspective is offered in the field of data processing, representing a notable advancement in solving complex problems with practical applications in various areas of engineering.

In [21], using a qualitative and descriptive methodology, algorithms are applied for locating heritage sites. With the concept of augmented reality, this provides information to the user. The orientation of the device and the distances between different points in a geographic coordinate system are established. It is designed for use on mobile devices, and test functionality includes some historical places in the database, along with aspects related to cultural heritage. The system incorporates an innovative user experience using sensors, allowing access to content in a simple and attractive manner. This new technology, which combines virtual content in a real scenario, is available for smartphone or tablet users running the Android operating system.

On the other hand, [22] proposes using an incremental K-means-based algorithm to group the available routes. Subsequently, if a new route is entered into the system, it decides whether it should be assigned to an already created cluster due to its similarity with the existing routes, or if a new cluster should be created. The aim is to study the best way to represent route variables, considering feature engineering and dimensionality reduction techniques to facilitate and improve the clustering algorithm's results.

IV. Proposed Tool

This work proposes a tool to estimate the fiber optic laying distances between the nodes of the RDNFO and the units of the Peruvian Army, utilizing Apps Script as an automation tool and Google Sheets as the database and results visualization platform. The methodology and procedures followed to estimate the distances between the RDNFO and the Peruvian Army units are detailed in Figure 5, which outlines four phases.

The first phase involved the creation of a database containing relevant information regarding the coordinates of RDNFO nodes and the locations of the Peruvian Army units. In the second phase, the distance estimation tool was developed. During the third phase, Google Sheets was used to generate a link to Google Maps, enabling visualization of the proposed fiber optic laying route. Finally, in the fourth phase, the average error percentage of the present work was calculated.

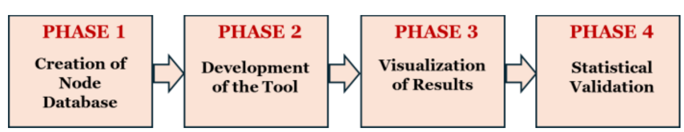

Fig. 6 Phases of the proposal

A. Creation of the node database

A.1. Database of the RDNFO

For the creation of the node database for the RDNFO, Annex B – List of ducts and chambers nationwide – from the document titled "Basic offer of access for the provision of complementary facilities to the carrier service provided through the National Backbone Fiber Optic Network in compliance with the Resolution of the Board of Directors N° 073-2016-CD/OSIPTEL" was used. This information was transferred to Google Sheets, where the database was established. As shown in Figure 7, it mainly contains the populated center where the connection node is located and the geographic coordinates in sexagesimal format with decimal values, consisting of its latitude and longitude. A total of 322 nodes distributed across the Peruvian territory are included, which will be used for the initial calculation to select the node that will connect to the required Peruvian Army Unit in order to perform the optical fiber laying distance estimation calculation.

ID	REGION	PROVINCE	DISTRICT	POPULATION CENTER/LOCALITY	LATITUDE-LONGITUDE
1	AMAZONAS	BAGUA	BAGUA	BAGUA	-5.64416666666667,-78.5266666666667
2	AMAZONAS	BONGARA	JUMBILLA	JUMBILLA	-5.90416111111111,-77.7997305555556
3	AMAZONAS	CHACHAPOYAS	CHACHAPOYAS	CHACHAPOYAS	-6.22111111111111,-77.8788888888889
4	AMAZONAS	LUYA	LAMUD	LAMUD	-6.14931111111111,-77.9492666666667
5	AMAZONAS	LUYA	LUYA	LUYA	-6.16634166666667,-77.9467666666667
6	AMAZONAS	LUYA	SAN JERONIMO	PACLAS	-6.06034166666667,-77.9751305555556
7	AMAZONAS	RODRIGUEZ DE MENDOZA	SAN NICOLAS	MENDOZA	-6.39692777777778,-77.4760694444445
8	AMAZONAS	UTCUBAMBA	BAGUA GRANDE	BAGUA GRANDE	-5.76444444444444,-78.4311111111111
9	AMAZONAS	UTCUBAMBA	JAMALCA	LA CALDERA	-5.85766388888889,-78.2283777777778
10	ANCASH	AIJA	AIJA	AIJA	-9.78055555555556,-77.6116111111111
11	ANCASH	NTONIO RAYMOND	LLAMELLIN	LLAMELLIN	-9.10278611111111,-77.0156583333333
12	ANCASH	ASUNCION	CHACAS	CHACAS	-9.16453888888889,-77.3648861111111
13	ANCASH	BOLOGNESI	CHIQUIAN	CHIQUIAN	-10.1540277777778,-77.1554722222222
14	ANCASH	CARHUAZ	ANTA	ANTA (ANCASH)	-9.35833333333333,-77.5975
15	ANCASH	CARHUAZ	CARHUAZ	CARHUAZ	-9.28358333333333,-77.6428888888889
16	ANCASH	CARHUAZ	TINCO	PAMPAC	-9.2631,-77.6723055555556
17	ANCASH	OS FERMIN FITZCAI	SAN LUIS	SAN LUIS	-9.09355555555556,-77.3298888888889
18	ANCASH	CASMA	CASMA	CASMA	-9.46880833333333,-78.2918722222222
19	ANCASH	CORONGO	CORONGO	CORONGO	-8.56951944444444,-77.9006305555556
20	ANCASH	CORONGO	CUSCA	URCON	-8.57444444444444,-77.7877777777778

Fig. 7. Database of RDNFO coordinates

A.2. Database of the Peruvian Army Units

For the creation of the database of the Army Units, the Military Geoviewer platform [23] was used to gain access to information corresponding to the III-DE, which was then utilized to build arrival nodes for the optical fiber laying estimation. Considering that the information is classified, Figure 8 shows a view of the portal where the coordinates are displayed, as well as the type of Peruvian Army unit, including armored units, artillery, communications, among others.

Fig. 8. Military Geoviewer.

B. Development of the tool for estimating distances

For the development of the tool, the Google Sheets extension is enabled to access Apps Script, linked to the database created in Phase 1.

In Figure 9, a block diagram describing the development of the proposal is shown. The process begins with the entry of coordinates corresponding to a unit of the Peruvian Army, which then operates with the database of nodes from the National Optical Fiber Backbone Network. From this, the variable containing the node is extracted, which will be used to estimate the fiber optic laying distance. Subsequently, the route and distance calculation are performed using the library provided by Apps Script called Class DirectionFinder, where instructions are set for routes between locations. It allows working with mandatory passing reference points, the establishment of an origin and destination point in latitude and longitude coordinates, as well as the mode of transport.

Furthermore, Algorithm 1 describes the route calculation and map visualization. The algorithm calculates routes between addresses and displays interactive maps. It takes a list of addresses and first checks that there are at least two. Then, it establishes the first address as the origin and the last one as the destination, adding intermediate addresses as waypoints. It uses a map API to calculate the route between the origin and the destination and stores the data for each segment, including the starting address, ending address, and distance, in a spreadsheet. Additionally, it generates an interactive map depending on the user's selection, showing either a single address or the entire route, and displays it in a sidebar. This allows for both the calculation of routes and the graphical visualization of them.

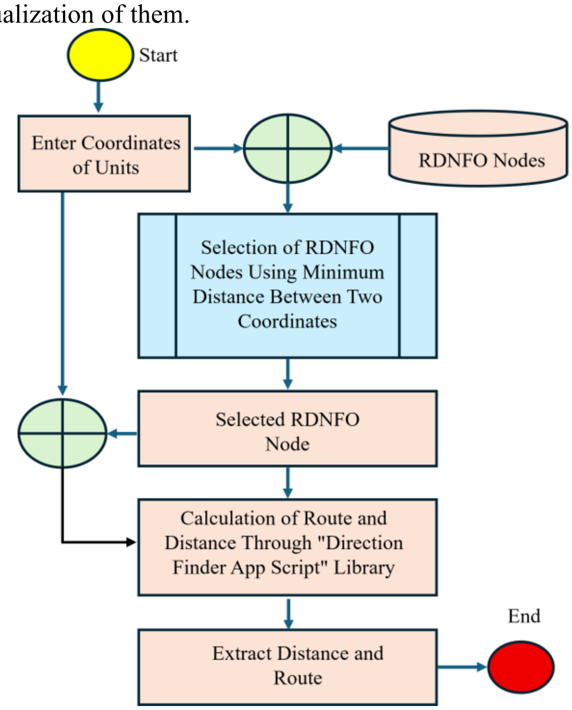

Fig. 9. Block diagram for the development of the proposal

Algorithm 1: Route Calculation and Map Display

Input: L: List of addresses from the "addresses" sheet

Result: Route data written to "routes" sheet, Interactive map displayed

1. **Procedure RouteCalculationAndMapDisplay (L)**
2. **Create menu with options:**
   - Calculate distances between addresses
   - Show map of selected address or route
3. **Function CalculateDistances()**
   - If length of L < 2:
     - Display 'Error: Need at least two addresses'
     - Return
   - Set origin to L[0]
   - Set destination to L[last]
   - For each intermediate address in L[1, last-1]:
     - Add as waypoint
   - Use Maps API to calculate route from origin to destination
   - For each leg in the route:
     - Write leg's start address, end address, and distance to the "routes" sheet
     - Return success message with route data
4. **Function ShowMap()**
   - If a single address is selected:
     - Generate map for selected address
   - If a route is selected:
     - Generate map for the entire route
   - Display map in the sidebar
5. **End procedure**

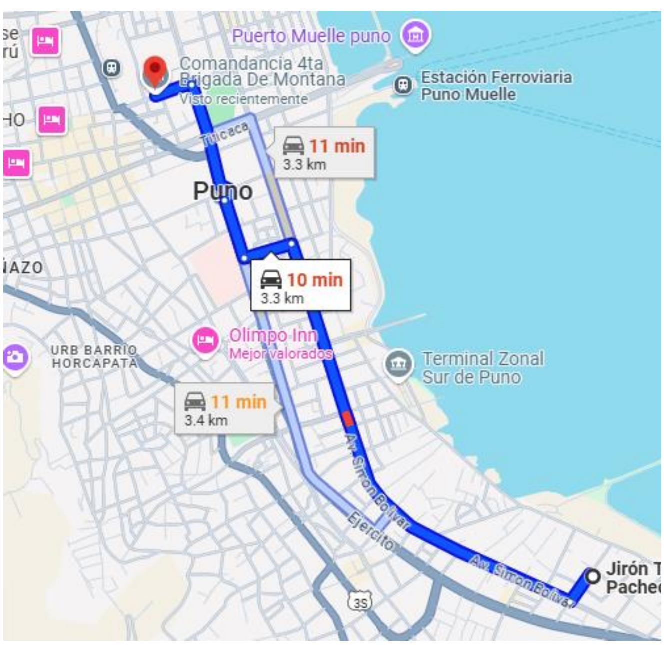

Fig. 10. Visualization of the Fiber Optic Laying Route

C. Visualization of the fiber optic laying trajectory results

Once the route and distance have been established in the previous phase, the results are visualized through the hyperlink function, which directs to the Google Maps website, concatenating the locations determined in the second phase. In Figure 10, the route and fiber optic laying distance between the "Puno" node and the Command of the Fourth Mountain Brigade are shown. The route crosses Simón Bolívar Avenue, Ejército Street, and intersects Titicaca Street. The approximate distance is 3.3 kilometers from the starting point to the final destination.

D. Statistical Validation of the Tool

In this phase, the objective is to determine the average percentage error of the fiber optic laying distance estimation tool. This is done through Equation 1, where the theoretical measurements (those calculated manually) and the measurements obtained through the estimation tool (developed for the project) are taken as variables. The average percentage error helps assess how accurate the estimation tool is in comparison with the manual calculations. Equation 1 calculates the average percentage error between the theoretical distance (x_v) and the estimated distance (x_i) for each of the considered segments. This calculation is important for understanding the reliability and potential overestimations or underestimations that the tool might have.

$$\bar{\varepsilon_r}\% = \left(\frac{1}{n}\sum_{i=1}^{n}\left|\frac{(x_i - x_v)}{x_v}\right|\right) \times 100\% \qquad (1)$$

Where:

n = Number of estimated distances.

x_i = Value of the measurement determined by the developed estimation tool.

x_v = Theoretical value determined by the manual tracing of the proposed fiber optic laying.

For the establishment of the theoretical measure, references [24] and [25] were used to perform the fiber optic laying route on public roads. In Figure 11, the manual fiber optic laying trace in black can be seen, which interconnects the "284 Puno" node with the headquarters of the Fourth Mountain Brigade and its corresponding distance. The previously obtained value corresponds to the variable x_v, which was compared with the fiber optic laying distance estimation of the proposed tool observed in Figure 10, corresponding to the variable x_i . Iteratively, the process was repeated for the other units of the III Army Division to establish the average percentage error of the fiber optic distance estimation tool.

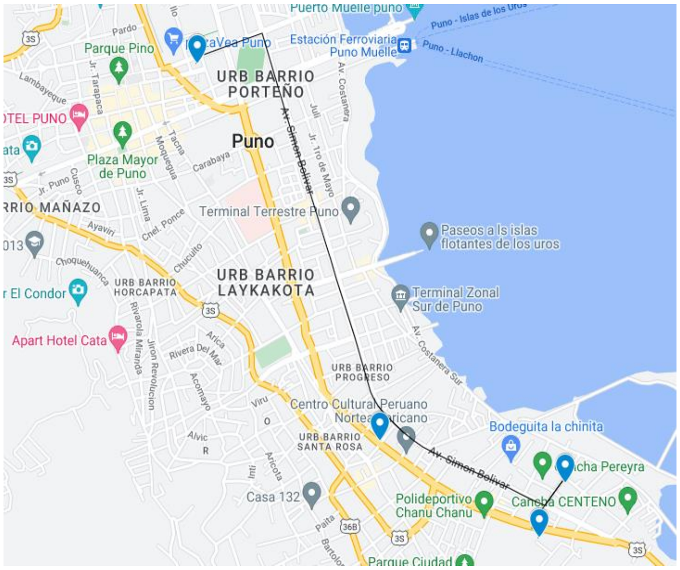

Fig. 11. Manual Fiber Optic Laying Distance Estimation

V. Results and Discussion

A. Results

For the development and validation of the fiber optic laying estimation tool, four key phases were established. As part of these phases, an experiment was conducted applying the tool to the III Division of the Peruvian Army. The objective was to evaluate the tool's capability to estimate the distances between the nodes of the National Fiber Optic Backbone Network (RDNFO) and the Army's facilities.

The obtained results included the selection of RDNFO nodes based on the geographic coordinates of the selected Army facilities. Subsequently, the distances estimated by the tool were compared to the manually calculated distances for each network segment.

The results of this experiment and the calculation of the tool's average percentage error are presented in **Table 1**, which compares the estimated distances to the manually measured ones. This data allows the evaluation of the tool's precision and reliability for fiber optic laying tasks.

TABLE I
Manual and Tool-Estimated Distances

No	III-DE (Origin))	RDNFO Node (Destination)	Manual Distance (Km)	Tool Distance (Km)	$\bar{\varepsilon}$, %
1	3ra Brig Com	Arequipa	8.865	8.925	0.007
2	Brig Serv	Arequipa	4.801	6.13	0.277
3	CG III-DE	Arequipa	6.321	7.068	0.118
4	5ta Brig Mtñ	Cusco	6.063	6.502	0.072
5	C. Pachacutec	Quillabamba	2.29	2.188	0.045
6	BC 613	Pto. Maldonado	2.31	2.382	0.031
7	GCAA 4	Ilo	5.604	5.549	0.010
8	C.los Angeles	Moquegua	6.899	11.858	0.719
9	GAC 3	Moquegua	6.806	7.692	0.130
10	3ra Brig Blind	Moquegua	2.719	3.556	0.308
11	BIM 33	Mazocruz	17.993	18.701	0.039
12	GAC 11	Mazocruz	64.156	77.493	0.208
13	4ta Brig Mtñ	Puno	3.313	3.442	0.039
14	C. Manco Capac	Puno	0.345	0.383	0.110
15	RCB 9	Puno	0.546	0.539	0.013
16	C. Bolognesi	Juliaca	2.493	2.694	0.081
17	6ta Brig Blind	Locumba	16.908	16.823	0.005
18	3ra Brig Cab	Tacna	2.074	2.027	0.023

Table 2 presents the overall results of the analysis of estimated distances for fiber optic deployment in the Peruvian Army's 3rd Division. This analysis compares manual calculations with those obtained through the proposed developed tool. The total theoretical manual distance for fiber optic deployment is 160.506 km, while the distance estimated by the tool is 183.952 km. The average percentage error between the two calculations is 12.41%, indicating that the tool overestimates the distance compared to the manual calculation. Since the cost of fiber optic deployment is 800 USD per kilometer, this increase in distance directly impacts deployment costs. The manually estimated cost of fiber optic deployment is 128,404.80 USD, whereas the cost estimated by the tool rises to 147,161.60 USD. This represents an increase of 18,756.80 USD due to the additional 23.446 km estimated by the tool. Although this additional cost may appear to be a drawback, it is important to emphasize that the tool provides greater accuracy and reliability in distance estimation. This ensures that there is no shortage of fiber during installation. The improved precision helps avoid interruptions during the deployment process and reduces the risk of incurring additional costs that could arise from unforeseen needs for more fiber.

TABLE II
Global Results of the Distance Analysis

Attribute	Value
Theoretical total manual distance for the III-D	160.506 km of optical fiber
Total distance estimated by the tool for the III-DE	183.952 km of optical fiber
Average percentage error of the tool	12.41%
Estimated fiber optic laying cost for the III-DE (Manual)	128,404.80 USD
Estimated fiber optic laying cost for the III-DE (With the proposed tool)	147,161.60 USD

B. *Discussion*

The results obtained during the validation of the fiber optic laying estimation tool for the III-DE of the Peruvian Army showed an average error of 12.41%, as presented in Table 2. This error reflects an overestimation of the distance when comparing the distances estimated by the tool with the manual measurements. This finding is significant because, although the error is notable, the tool provides a more reliable estimation in terms of avoiding fiber shortages during installation, which could generate even higher additional costs if unforeseen issues arise during the project execution.

In terms of costs, the difference of 23.446 km additional estimated by the tool implies an increase of 18,756.80 USD compared to the manual calculation. Although this overcost may be seen as an inconvenience, in practice, the tool helps prevent potential interruptions, which could result in higher costs if additional fiber purchases are required. Thus, the overestimation is not only a technical issue but also a strategy to ensure the continuity and reliability of the network laying.

The results obtained are consistent with existing literature regarding the accuracy of automated estimation tools, which, in many cases, tend to overestimate distances to ensure a safety margin. This additional margin could be particularly valuable in critical infrastructure projects, such as fiber optic laying in the military field, where reliability is a priority and any deficiency could have significant operational repercussions.

On the other hand, one of the main strengths of the tool is its ability to extrapolate distance estimates across the entire III-DE quickly and efficiently, which is highly useful in a context like that of the Peruvian Army. However, restricted access to sensitive geographic information, such as the exact locations of Army facilities, limits the possibility of extending the tool's coverage to other units or regions extensively.

Regarding comparisons with previous studies, no similar applications were found that use automated tools, such as apps script or similar software, to estimate distances in the context of fiber optic laying in the military domain. This highlights the novelty and innovative potential of this work, which contributes to the field of military telecommunications and could lay the groundwork for future research in this area.

A potential improvement for future research would be the integration of new variables that could increase the accuracy of the estimates, such as the location of intermediate posts or the exploration of other geospatial modeling technologies. Additionally, it is suggested to explore the possibility of automating not only the distance estimation but also the final design of the fiber optic network, which could further optimize operational processes and reduce additional costs.

VI. Conclusions

Automated applications for distance estimation in critical infrastructure projects, such as fiber optic laying, represent a significant advancement in terms of efficiency and reliability. In the context of the Peruvian Army, the use of tools like the one presented in this study provides an innovative approach to communication network planning, facilitating the management of complex projects that require precision and speed. The validated tool has proven effective for estimating distances in fiber optic laying, with an average error of 12.41%. Although this error results in an overestimation compared to the manual calculation, it should not be interpreted as a flaw. On the contrary, it functions as an intentional safety margin designed to prevent fiber shortages during installation, which could generate delays, technical failures, and greater corrective costs.

The additional 23.446 km estimated by the tool, equivalent to an increase of USD 18,756.80, must therefore be considered as part of a redundancy strategy that strengthens the reliability and continuity of the project. In critical contexts such as military operations, this margin is not only justified but essential, since any miscalculation in the availability of communication resources could have serious operational repercussions. Thus, the apparent overcost represents an investment in security and mission assurance, ensuring that fiber deployment remains uninterrupted even in adverse or unforeseen conditions.

Another relevant contribution of the tool is its scalability: beyond a single calculation, it allows distance estimations to be extrapolated across large areas, such as the entire III-DE, supporting faster and more accurate planning in the military domain. Despite the limitations imposed by restricted access to sensitive geographic information, the innovation of this tool lies in its ability to automate a process that was traditionally manual and time-consuming, thereby making a significant contribution to the modernization of military telecommunications.

Finally, this study not only highlights the novelty of employing automated applications such as Google Apps Script for distance estimation but also opens avenues for further improvement. Future work should integrate additional variables, such as the location of intermediate posts, or adopt advanced geospatial modeling technologies to refine precision. Moreover, extending automation beyond distance estimation to encompass the complete design of fiber optic networks would further increase efficiency and reduce operational costs. In this sense, the presented tool represents not just a methodological contribution but also a replicable model for enhancing resilience, sustainability, and technological independence in the military communication infrastructure of Peru and beyond.

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REFERENCES

[1] Informe sobre la Conectividad Mundial, Unión Internacional de Telecomunicaciones de 2022
[2] J. Marín “Informe sobre la situación de conectividad de Internet y banda ancha en Perú”, Revista, Universidad San Martín de Porres, Perú 2022
[3] H. Conche “La Red Dorsal Nacional de Fibra Óptica y su Influencia en el Servicio de Internet en el Perú”, Tesis, Universidad Nacional Federico Villareal, Lima, 2021
[4] Contrato del Servicio de Internet Para el Ejército Peruano derivado del Concurso Público N°001-2024-EP/UO-2708.
[5] Google Tech Talks (March 23, 2009). Fast Route Plannning [archivo de video]. Youtube. https://www.youtube.com/watch?v=-0ErpE8tQbw
[6] Russell, S. J.; Norving, P. (2004) Inteligencia Artificial. Un enfoque moderno. (Segunda edición, pp. 110-115). Pearson Educación S.A.
[7] UIT-T G.805, march 2000 “Arquitectura funcional genérica de las redes de transporte”
[8] A. Tanenbaum; D Wetherrall (2012) Redes de Computadoras (Quinta Edición) Pearson Educación.
[9] J. Mur (2024) Redes de Fibra óptica. Conceptos fundamentales (Primera Edición) Ediciones ENI.
[10] Ley N°29904 de 2015. Ley de Promoción de la Banda Ancha y Construcción de la Red Dorsal Nacional de Fibra Óptica”
[11] H. Conche “La Red Dorsal Nacional de Fibra Óptica y su Influencia en el Servicio de Intenet en el Perú”, Tesis, Universidad Nacional Federico Villareal, Lima, 2021
[12] Organismo Supervisor de las Telecomunicaciones. (2019) Redes de fibra óptica y microondas en el Perú. https://repositorio.osiptel.gob.pe/bitstream/handle/20.500.12630/389/dt-42-redes-fibra-optica-microondas-peru.pdf
[13] Organismo Supervisor de Telecomunicaciones (2021); Apéndice II: Condiciones Técnicas del informe N°00060-DPRC/2021 (22 de abril de 2021) Procedimientos para la Instalación de Fibra óptica.
[14] Ejército del Perú. Lista de Unidades del Ejército (Reservado).
[15] Google, apps cript. [Online]. Available: https://developers.google.com/apps-script/overview?hl=es-419
[16] Google, apps sheets. [Online]. Available: https://workspace.google.com/intl/es-419/products/sheets/
[17] Llanos-Mosquera, J. M., Muriel-López, G. L., Triana-Madrid, J. V. y Bucheli-Guerrero V.A. (2022). Algoritmos evolutivos guiados por redes complejas libres de escala. Revista Científica, 44(2), 228-241.
[18] Gonzales R.. (2015) Desarrollo de un algoritmo planificador de rutas con capacidad de implementación en diversas aplicaciones de la robótica móvil [tesis bachiller-inédita]. Universidad Tecnológica de Pereira
[19] Rhyd L., Padraig C. (2024). Fast Algorithms for Computing Fixed-Length Round Trips in Real-World Street Networks. SN Computer Science. https://doi.org/10.1007/s42979-024-03223-3
[20] P. Soto, G. Figueroa, N. Zamora, “Una Generalización del Problema de Fermat-Weber con aplicaciones al procesamiento de datos”, *SciELO Preprints,* versión 1, setiembre 2023.
[21] J. Tomaselli, H. Pintos, “Algoritmos para búsqueda y ubicación de Patrimonio cultural con realidad aumentada usando dispositivos móviles”, *La Saeta Universitaria,* Vol. 8, N° 1, 2019.
[22] C. Cuervo, “Algoritmo de aprendizaje incremental para agrupar y clasificar running trails”, tesis, máster universitario de la Universidad Oberta de Catalunya, C.D, España, 2020.
[23] Instituto Geográfico Nacional. Portal Geovisor de la III División de Ejército (acceso reservado) https://www.idemil.gob.pe/geovisor/IIIDE/
[24] Ministerio de Transporte y Comunicaciones del Perú. Norma técnica EM-020 para la Instalación de comunicaciones https://cdn.www.gob.pe/uploads/document/file/2686405/EM.020%20Instalaciones%20de%20Comunicaciones.pdf
[25] Reglamento nacional de Edificaciones. Normal técnica EC.040 Redes e instalaciones de comunicaciones. https://www.construccion.org/normas/rne2012/rne2006.htm?srsltid=AfmBOopmpdoXtk8ZJb96dQW3zaqTbrUR7PSmFs8qlpOyDf3hyDUdwqYT