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Remote Monitoring System for Telecommunications Networks and Energy Management: Case Study in Base Stations of the Río Santiago – Amazonas

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***Abstract*– This paper presents an integrated remote monitoring system for telecommunication networks and energy management in rural areas, developed for the connectivity project in Rio Santiago, Condorcanqui, Amazonas. It uses open source platforms such as Prometheus, InfluxDB and Grafana to monitor critical parameters in real time. A key challenge was to integrate non-SNMP compliant equipment, such as solar energy controllers, which was achieved through custom exporters and alternative protocols. The system offers unified monitoring, scalability, proactive alerts and advanced analytics, contributing to project sustainability and reliability in a challenging Amazonian environment.**

Keywords: Rural, monitoring, Grafana, Prometheus, InfluxDB.

I. Introduction

Since 2019, the Rural Telecommunications Research Group (GTR) of the Pontifical Catholic University of Peru undertook an ambitious project to bring connectivity to one of the most remote and challenging areas of the country: the Santiago River basin in Condorcanqui, Amazonas. This project, titled "Implementation of a Connectivity Solution for the Santiago River Basin" [1], aimed to deploy a telecommunications network covering six localities: Puerto Galilea, Yutupis, Guayabal, Belén, Pagkintsa, and Nieva, all powered by photovoltaic systems. The implementation of this connectivity network represented a significant milestone for the communities in the region, providing them with internet access services and telemedicine services [2]. To ensure its operation, it is necessary to have a comprehensive system that allows managing and monitoring both the telecommunications equipment and the energy systems in a complex environment such as the Peruvian Amazon.

The implementation of this network is of the multi-brand type, using brands such as Mikrotik and Cambium Networks, which are compatible with the SNMP protocol, used for the management and monitoring of network parameters [3] [4]. However, the energy systems installed in the base stations, specifically the VNL brand solar controllers (Micropower), are not compatible with this protocol and require an expensive proprietary system for their implementation. Based on the information provided, the following objective was established: to develop a comprehensive monitoring system that allows real-time supervision and efficient control of the project's telecommunications and energy network. To achieve this, an SNMP-based monitoring solution was implemented to integrate the operational parameters of the telecommunications equipment, an architecture was designed to ensure efficient and secure data collection, and a data acquisition mechanism was implemented to capture data from the solar controllers, to finally integrate them with the general monitoring system.

To ensure the efficient operation and management of the network, an Open Source platform was chosen to meet the requirements and consider the restrictions of the equipment in terms of supported communication protocols. Consequently, a comprehensive remote monitoring system was implemented based on an architecture composed of Prometheus, InfluxDB and Grafana, which offer greater flexibility, local and cloud scalability, without limitations in the amount of equipment, in addition to a customization of being able to integrate data obtained from the solar controllers. This system was installed on a local server within the Project's telecommunications network, which allowed for effective supervision adapted to the specific needs of the infrastructure, thus ensuring complete and customized monitoring.

II. Methodology

The techniques and methods used to design and implement the prototype of the monitoring system typically involve a structured approach consisting of several key phases:

a) Evaluation of the current network design of the Río Santiago connectivity project in Condorcanqui, Amazonas: Topology, number of devices, brand, model, metric extraction protocols, and other aspects to consider for the development of the monitoring platform.
b) Technological assessment of the platform deployment: The equipment on which the solution will be deployed must be evaluated, including the memory consumption during monitoring, as well as the device's connection to the network and power supply.
c) Functional and non-functional requirements: Based on the previous evaluations, the specific capabilities and functions the system must perform are described. This considers the stages of a monitoring operation, as shown in Fig. 1.

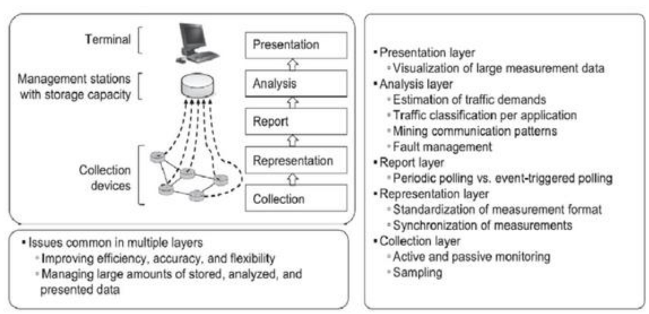


Fig. 1 Sub-classifications of monitoring operations. Reproduced from [5]

d) Selection of platforms and development of the solution architecture: Considering the use of the Open-Source platforms Prometheus, Grafana, and InfluxDB.
e) Integration and laboratory testing: Interconnected telecommunications equipment were used to simulate the network, and the monitoring platform was tested on this setup.
f) Implementation and field evaluation: Conduct tests in real-world environments to ensure the system's proper performance. Additionally, adapt the platform to the specific needs of the network.

III. DESING AND IMPLEMENTATION PROCESS

To achieve the stated objective, a monitoring solution architecture was designed, integrating multiple technologies to create a robust and scalable system for infrastructure supervision. This solution is specifically tailored for monitoring telecommunications equipment using the SNMP protocol and energy equipment through code-based tools.
To accomplish this, the solution incorporates three key components, as shown in Fig. 2, which interact with each other across six modules, explained below.

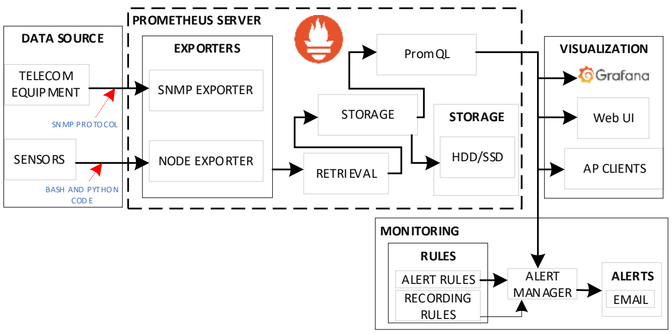


Fig. 2 General architecture of the monitoring solution

- **Data Sources:** These include telecommunications equipment, from which the parameters to be monitored are extracted using the SNMP protocol. Additionally, in the solar controller, an energy management device, tools based on Python and Bash code were used for metric extraction and monitoring.
- **Prometheus Server:** It performs periodic queries to metric interfaces and stores data for analysis. It includes Exporters (SNMP and Node Exporter) for data translation, Retrieval for collection, Storage for storage (HDD/SSD), and PromQL as the query engine. [6] It is the core of our architecture, as it enables the integration between metric exportation from devices and their processing within Prometheus.
- **Processing and Database:** Telegraf connects Prometheus with InfluxDB, processing metrics through the HTTP Listener v2 plugin and the Prometheus Remote Write Parser. [7] This enables efficient data storage in InfluxDB, which, along with Prometheus, serves as one of the system's databases. The decision to use two databases was made to ensure redundancy and data backup.
- **Visualization and Monitoring:** Grafana transforms time-series data (TSDB) into meaningful graphs, connects various sources through plugins, and allows configuring alerts based on predefined thresholds. [8] It integrates data collected by Prometheus and stored, displaying it in customized dashboards for real-time analysis. In this module, Grafana is introduced as a key component for visualizing metrics through panels that form a structured dashboard.

To complement the architecture, a structured data flow has been designed, consisting of four stages. Based on the sub-classifications of monitoring operations presented in [5], I develop a similar structure to integrate SNMP-based metrics into our system. Fig. 3 illustrates how this adaptation was applied in the implementation.

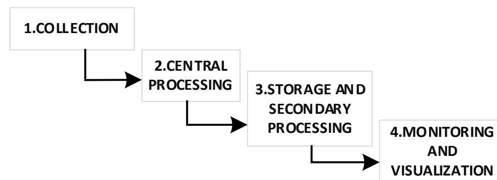


Fig. 3 Data Flow in the monitoring system

1. Collection: The metrics from telecommunications equipment were captured using the SNMP protocol. In the case of the solar controller, metrics were collected through Bash and Python code, as the VNL device has its own commands for metric extraction using these languages.
2. Central Processing: The metrics from telecommunications and energy equipment were captured using the SNMP protocol and Bash/Python scripts, respectively. The VNL solar controller relies on its own commands for metric extraction using these languages. Once the data is collected from both telecommunications and energy devices, Prometheus queries, normalizes, and temporarily stores it, serving as the central processing unit of the system.
3. Storage and Secondary Processing: Telegraf transforms and sends the metrics to InfluxDB for long-term storage.
4. Monitoring and Visualization: Grafana presents the data in interactive dashboards and manages alerts.

To ensure an efficient and structured implementation process, the solution was divided into two key components:

A. *Subsystems of the Río Santiago Connectivity Network:*

- *Telecommunications Subsystem:*

The architecture is based on a Point-to-Point (PTP) and Point-to-Multipoint (PMP) topology based on rio Santiago Project[9]. This hybrid configuration optimizes network distribution according to the specific needs of each locality, considering factors such as distance, the number of institutions to be connected, and the required capacity.

This subsystem is composed of the backhaul network, access network, and LAN network. The following devices will be monitored, as detailed in TABLE I:

TABLE I
Equipment and Metrics to Monitor in the Telecommunications Subsystem

Network Type	Device	Metrics
Backhaul network	Cambium PTP670	Transmission and reception power, eIRP, link loss, vector error, link distance, reception and transmission rate, etc.
	Mikrotik RB4011iGS	Input and output traffic, bytes transmitted and received, interface status, multicast and broadcast packets, code errors, and general device characteristics.
Access Network	DynaDish 5	RxRate and TxRate, TxCCQ, signal-to-noise ratio (SNR), transmission and reception power, characteristics of connected neighbors, and overall system status.
	Mikrotik DISC Lite 5	
	Mikrotik mANTBox 19s	
LAN network	Mikrotik BaseBox 2	Input and output traffic, bytes transmitted and received, interface status, TxCCQ, noise level, and overall system status.
	Mikrotik RB2011iL	Input and output traffic, bytes transmitted and received, interface status, multicast and broadcast packets, code errors, and general device characteristics.

- *Energy Management Subsystem:*

For the energy management subsystem, a specially designed approach was considered, as it involves the VNL Micro Power System solar controller, which does not support the SNMP protocol for metric export. Therefore, the system's native commands, explained in the following table, will be used.

TABLE II
Parameters of the VNL Controller

Device Commands	Description
microstatus	Retrieves the overall system status.
mpptstatus	Retrieves information from the Maximum Power Point Tracking (MPPT) controller.
snetconfig	Retrieves network configuration
usmstatinfo	System status information
usmthreshold	Configured threshold values
mppthwinfo	MPPT hardware information
mpptstatdata	MPPT statistical data.
mpptsolthr	Umbrales solares
micromppthr	Umbrales del micro MPPT

B. Stages of the Monitoring System Construction Process:

- *Data Collection Stage: Integration of SNMP Protocol and Prometheus*

For network device metrics extraction, the SNMP Exporter from Prometheus was implemented, translating information from MIBs (Management Information Base) into a format that Prometheus can process. Fig. 4 illustrates the workflow of this process.

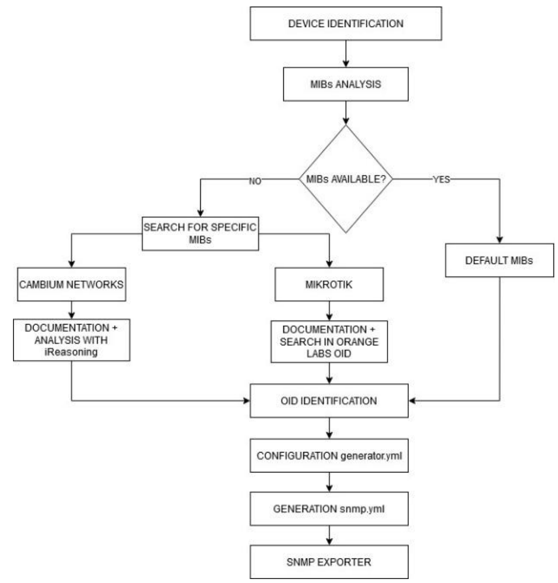


Fig. 4 Data Collection flow with MIBs

The implementation involved a detailed analysis of MIBs for each device. For devices with standard MIBs, the exporter's default configurations were used. However, for specific devices, such as Cambium Networks radios, the iReasoning MIB Browser [10] was used to perform SNMP walks, validate OIDs, and understand their hierarchical structure.

For Mikrotik devices, additional metrics not included in the default configuration were identified. These metrics were retrieved from the Orange Labs OID repository from the ITU OID Project [11].

The SNMP Exporter configuration was carried out using the generator and the snmp.yml file from Prometheus [12], which define authentication, analyzed objects, and parameters for SNMP queries. This process enabled an efficient integration between network devices and Prometheus, ensuring the systematic collection of critical operational metrics.

- *Database Design*

The metrics collection and storage architecture integrate three key components: InfluxDB and Prometheus as time series database engines, and Telegraf as the metrics collection agent, providing a robust solution for real-time monitoring.
InfluxDB handles large volumes of time-series data through an optimized model of measurements, tags, and fields, managed via buckets with write tokens for security. The interaction with Telegraf uses the InfluxDB Line Protocol [13][7].

Prometheus, dedicated to SNMP metrics, was configured as a systemd service with a data retention policy of 30 days and a 30GB storage limit, optimizing resources while maintaining a meaningful historical record. Its TSDB is stored in /var/lib/prometheus.

As shown Fig 5, the metrics collected by the SNMP Exporter are processed and stored in both Prometheus and InfluxDB (via Telegraf), ensuring redundancy and efficient data storage.

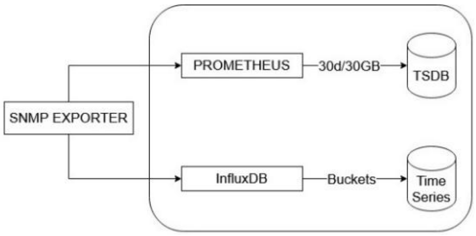
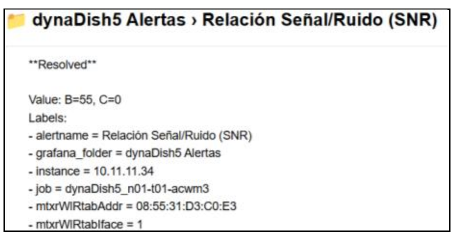


Fig.5 Storage Flow

- *Reporting Stage: Alert Configuration*

In the alert configuration stage, an integrated monitoring system was implemented using Grafana's native capabilities. Alert rules were defined based on time series to monitor critical network parameters, ensuring real-time detection of anomalies. A secure notification channel was established via SMTP, using Gmail as the email service. Additionally, custom notification templates were created to include detailed information, such as metric values, tags, device and location identification, and recommendations for issue resolution. Alerts are generated and reported within 15-30 seconds, ensuring rapid responses to potential issues. Fig. 6 and Fig. 7 illustrate the structure of the notification templates, highlighting the specific values, labels, and recommendations provided.

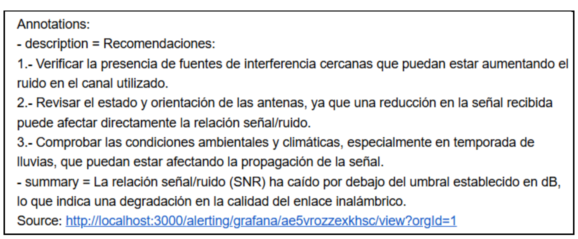


dynaDish5 Alertas › Relación Señal/Ruido (SNR)

Resolved

Value: B=55, C=0
Labels:
- alertname = Relación Señal/Ruido (SNR)
- grafana_folder = dynaDish5 Alertas
- instance = 10.11.11.34
- job = dynaDish5_n01-t01-acwm3
- mtxrWlRtabAddr = 08:55:31:D3:C0:E3
- mtxrWlRtabIface = 1

Fig. 6 Example of an alert notification (a)



Annotations:
- description = Recomendaciones:
1.- Verificar la presencia de fuentes de interferencia cercanas que puedan estar aumentando el ruido en el canal utilizado.
2.- Revisar el estado y orientación de las antenas, ya que una reducción en la señal recibida puede afectar directamente la relación señal/ruido.
3.- Comprobar las condiciones ambientales y climáticas, especialmente en temporada de lluvias, que puedan estar afectando la propagación de la señal.
- summary = La relación señal/ruido (SNR) ha caído por debajo del umbral establecido en dB, lo que indica una degradación en la calidad del enlace inalámbrico.
Source: http://localhost:3000/alerting/grafana/ae5vrozzexkhsc/view?orgId=1

Fig. 7 Example of an alert notification (b)

The configured alerts enable proactive system monitoring by sending detailed email notifications when monitored parameters, such as the signal-to-noise ratio (SNR), exceed predefined thresholds. These alerts not only provide technical recommendations for resolving issues but also include direct links to Grafana dashboards for further analysis. This setup enhances operational efficiency and ensures timely interventions to maintain system stability.

- *Representation Stage: Visualization of Metrics in Grafana*

In the representation stage, a layered user interface was developed to facilitate efficient network navigation and monitoring. As shown in Fig.8, the navigation flow between dashboards is illustrated.

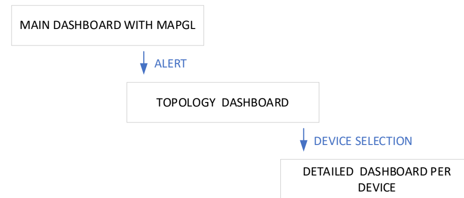


Fig. 8 Navigation Flow Between Dashboards

The main interface utilizes Grafana's MapGL plugin to provide a geographic visualization of the project's base stations (BTS), as shown in Fig. 9. Each point on the interactive map represents a BTS, enabling intuitive monitoring and navigation.

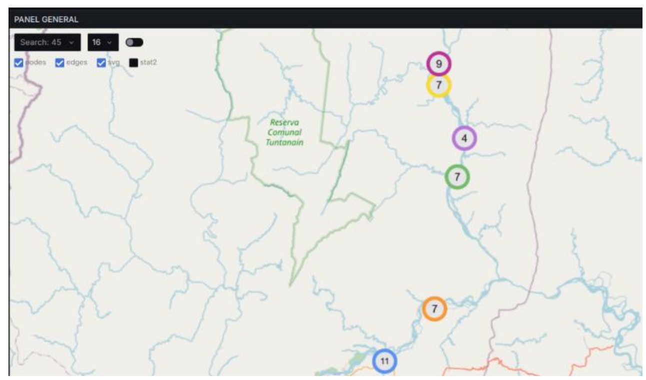


Fig. 9 General Map with all BTS

By accessing each of the BTS shown in Fig. 9, a detailed dashboard for each component is displayed, as illustrated in Fig. 10. This dashboard organizes metrics into panels designed to facilitate their interpretation and visualization. Additionally, comments were incorporated to help users easily identify the presented metrics. Visual alert thresholds were also added to highlight critical parameter measurements, enhancing data monitoring and understanding.

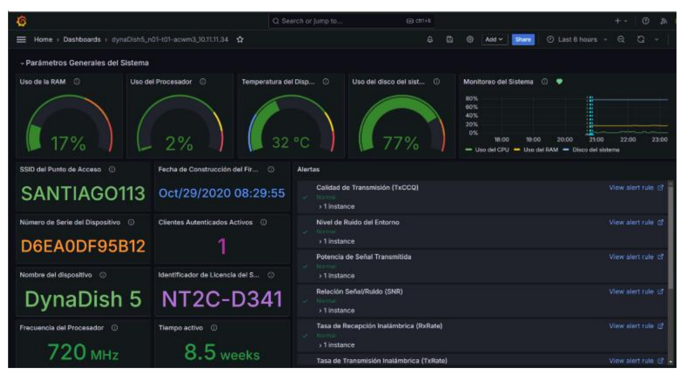


Fig. 10 Example of Dashboard

IV. Test and Results

Implementation tests for the devices in the monitoring system were conducted. Initially, local tests were performed using devices available at the laboratory. Subsequently, a

Coofun mini server was deployed to establish the actual connection between the monitoring system and the project's equipment.

i. Prometheus Configuration:

The initial step involves establishing a connection between all devices in the energy and telecommunications subsystems and the Prometheus targets.

As shown in Fig. 11, the devices are in an UP state (indicated by green dots), confirming their readiness for integration with Grafana and InfluxDB. The Figure displays the various endpoints configured in Prometheus, each corresponding to a network device, validating the successful integration and the system's capability to collect metrics from all monitored devices.

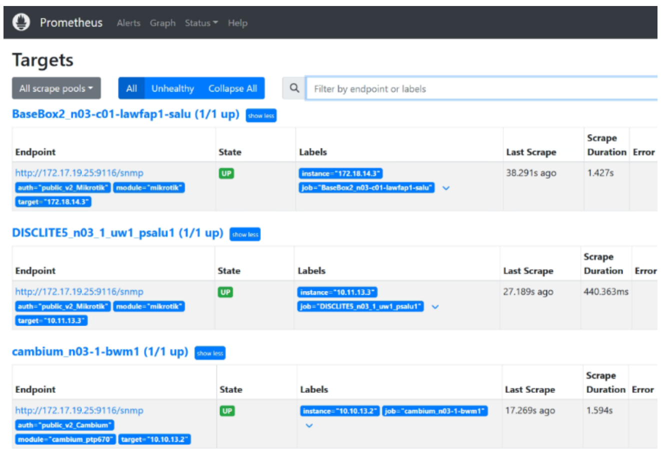


Fig.11 Wireless link capacity measurement results

ii. Implementation of InfluxDB:

The data is stored in InfluxDB using buckets designed to contain the metrics of each device, managed through Telegraf. These buckets are organized by device type, facilitating segregation and efficient management of metrics.

As shown in Fig. 12, the interface provides advanced filtering and query capabilities, along with aggregation functions such as mean, median, and last, optimizing the analysis of stored data. This structure not only ensures efficient storage but also enhances data retrieval. Additionally, each bucket has specific retention and precision policies, offering detailed control over long-term storage.

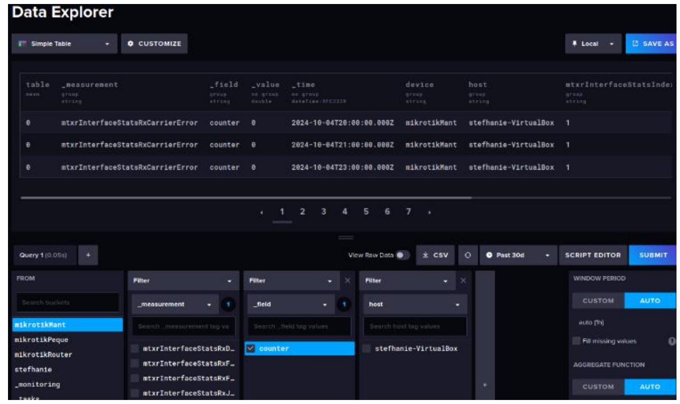


Fig. 12 Integration with InfluxDB

iii. Grafana Configuration:

The visualization of metrics in Grafana was implemented using various types of panels and charts, each specifically selected to optimally represent different types of data. These visualizations were chosen to ensure clear and efficient interpretation of the collected metrics, enabling effective monitoring and data-driven decision-making. The implemented visualizations are detailed below:

- ***Gauge:*** As shown in Fig. 13, this type of chart represents values within a defined range, adopting a design like classic analogy meters. It is particularly useful for displaying metrics where it is important to visualize a single measurement in relation to its minimum and maximum limits.

Fig. 13 Gauge charts

- **Stat:** It is ideal for displaying instantaneous values, such as identifiers, serial numbers, or specific metrics, as shown in Fig. 14.

Fig. 14 Stat charts

- **Time Series:** Displays data over a period by plotting values on the Y-axis against timestamps on the X-axis. It was selected for its ability to effectively visualize trends and patterns over time. Thresholds were added to the measurements to provide a visual alert indicating the metric limits, as shown in the example in Fig.15.

Fig. 15 Time Series charts

- **Tables:** Displays data in a tabular format with rows and columns, allowing for the organized and structured presentation of multiple related fields. This format is particularly useful for presenting details clearly, as shown in the example in Fig.16, where neighbor parameters are visualized.

Identidad del vecino	IP	MAC	Plataforma	Software ID
n1t1-BaR1-nie	10.11.11.33	2C:C8:1B:80:FD:EE	MikroTik	AJKV-1WUQ
n01-LaR1-reds	10.11.11.41	DC:2C:6E:91:C6:7F	MikroTik	CIWW-4UWG
n1c3-AcWS1M3-rds	10.11.11.35	08:55:31:D3:C0:E3	MikroTik	R9SC-Q04N

Fig. 16 Table – tabular format

From a practical and operational perspective, the integrated remote monitoring system developed demonstrates its viability and effectiveness in real-world rural telecommunications environments. This is evidenced by its successful pilot implementation in the locality of Belén, where the system has enabled efficient monitoring of critical telecommunications infrastructure parameters and energy consumption. The proposed architecture, based on Prometheus and complemented by visualization tools like Grafana, lays the groundwork for the potential expansion of the system to other base stations within the Rural Connectivity Project in the Río Santiago region, thereby contributing to the improved management and maintenance of critical infrastructure in remote areas of the Peruvian Amazon.

V. Conclusions and future work

The monitoring system for Rio Santiago exceeds the objectives, integrating SNMP and energy metrics of multi-brand equipment. Highlighting the integration of VNL brand solar controllers, taking advantage of the Telnet connection, developing a non-native SNMP solution to ensure compatibility with Prometheus. This allows a comprehensive monitoring of the telecommunications and energy infrastructure.

The solution optimizes operational efficiency, reducing costs by eliminating expensive proprietary systems. It improves remote management and provides an intuitive interface, allowing local technical staff and operators to maintain effective control over the critical infrastructure of the Rio Santiago project.The solution establishes the basis for future innovations in network management. Its modular nature and ability to integrate various brands and protocols, such as the adaptation of Telnet to Prometheus, ensure its long-term adaptability and effectiveness, empowering local stakeholders in the sustainable management of the project.

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