Automated Drive-Test System for Mobile Communication Networks

Heber Miguel dos Santos
Instituto Federal do Paraná - IFPR
Foz do Iguaçu, Brasil
heber.eng.eletronica@gmail.com

Matheus Riquelme Gonsalves
Instituto Federal do Paraná - IFPR
Foz do Iguaçu, Brasil
matheusriquelmegonsalves@hotmail.com

Israel Furtado Santos Souza
Instituto Federal do Paraná - IFPR
Foz do Iguaçu, Brasil
israel.furtado@outlook.com.br

***Abstract*— The technological advancement referred to as Industry 4.0 is directly linked to the evolution of telecommunications. A prominent example of this relationship is the emergence of fifth-generation mobile communication standards, commonly known as 5G, which have enabled the industrial application of disruptive technologies such as artificial intelligence, augmented reality, big data, IoT, among others, in an increasingly scalable manner. In light of this scenario, it is of utmost importance that solutions for analyzing and monitoring the performance of mobile networks become more accessible, not relying solely on high-cost equipment, proprietary software, or applications limited to networks compatible with smartphones. In this context, the main objective of this work was to develop an automated drive-test system for mobile communication networks, capable of generating georeferenced heat maps that represent the received signal strength through the RSRP (Reference Signal Received Power) parameter in performance tests conducted in a specific operational area of a mobile network. It is important to highlight that the validation of the current system functionalities was conducted on a private 5G network, thanks to the infrastructure provided by Itaipu Parquetec, which generously authorized the validation tests within its coverage area. However, the system was designed to be adaptable to other types of mobile network technologies, depending only on the possibility of integration between the developed system and the devices connected to the network to be analyzed. The system architecture was defined to encompass the following layers: data acquisition, where a 5G development kit and a georeferencing module were used integrated with a computational data acquisition interface; data layer, consisting of a non-relational database; application layer, composed of a server implemented with FastAPI, React, Node.js, Bootstrap, and Leaflet; and finally, a presentation layer that should be displayed in a web browser. After comparative analysis between the tests conducted, an approximate reduction of 89% in test execution time was observed when using the developed automated drive-test system compared to the manual method, highlighting the significant potential of this tool.**

***Keywords*—5G; Mobile networks; Internet of Things (IoT); Drive-test; Heatmap.**

I. INTRODUCTION

Mobile communications play a fundamental role in technological advancement and socio-economic development worldwide. From the emergence of the first mobile devices to the advanced smartphones and tablets of today, these technologies have revolutionized not only how we communicate but also how we work, learn, entertain ourselves, and interact with the world around us. In an increasingly connected world, mobile communication networks represent the backbone of the global digital infrastructure. They enable instant communication and access to information anywhere and anytime, boosting productivity, innovation, and collaboration across a wide range of sectors, including industry, healthcare, education, commerce, transportation, and entertainment.

For instance, the potential of 5G technology currently plays a crucial role in the three main technological pillars that support the Fourth Industrial Revolution: physical, digital, and biotechnologies [1]. The use cases enabled by innovation in fifth-generation mobile network architecture, characterized by advanced mobile broadband, ultra-low latency, and extremely high reliability, as well as the exponential increase in the capacity for simultaneously connected devices, can drive the development of technological solutions based on artificial intelligence, the Internet of Things (IoT), big data, cloud computing, advanced robotics, and other enabling technologies of Industry 4.0.

Moreover, mobile communications have a significant impact on economic development, especially in regions where fixed communication infrastructure is limited. They offer opportunities for digital inclusion, providing access to financial services, remote employment opportunities, and educational resources, even in remote and underserved areas. Ericsson, in collaboration with Juniper Research, released a study on the growth of mobile financial services. According to the report, a 40% adoption rate of new users and an 80% increase in transaction value is expected over the next five years [2]. This is just one example of how the evolution of wireless communication can contribute to global development.

In the context of mobile networks, service quality plays a crucial role in the user experience and the effectiveness of the applications and services offered. Therefore, continuous evaluation and optimization of performance are essential to ensure consistent delivery of high-quality services and meet the ever-increasing expectations of users. In this scenario, the automated drive-test system becomes fundamentally important. By enabling the systematic collection of performance data in real-world operational environments, this system provides valuable information on signal coverage quality, network capacity, service integrity, and other essential aspects of mobile network performance. This information is crucial for telecommunications operators, service providers, and equipment manufacturers in identifying issues, making informed decisions, and continuously improving the quality of service offered to users.

One way to conduct RF (radiofrequency) performance tests is through the use of spectrum analyzers, which can provide a wide range of technical information about the analyzed signal, such as signal strength, noise, frequency, peaks, among others. However, these devices also have a wide price range depending on the functionalities and the frequency range reached by the model, varying from approximately R$ 200,00 to over R$ 100,000.00. This makes them less versatile and accessible for testing in different types of networks.

There are also some smartphone applications available for conducting drive-tests. However, they are limited to use in cellular networks, which drastically reduces the application range of these solutions as they do not allow for use cases in networks utilized by specific communication devices, especially in IoT applications, such as LoRa, ZigBee, Z-Wave, among others.

Another way to implement performance testing is the fully manual method, which involves transporting a router connected to the network between different pre-defined and georeferenced points within the coverage area to be analyzed, accessing the equipment's configuration interface at each point of interest, collecting the desired signal indicator, and finally recording all this information in a system that can generate a heatmap of the test. This process, in addition to requiring a considerable amount of execution time, is highly susceptible to inaccuracies due to human error, making it slow and unreliable.

Given the afore mentioned points, this work proposes the development of an automated drive-test system as an alternative methodology for performance analysis of different types of wireless networks, capable of generating georeferenced heatmap reports in various application scenarios.

The following sections of this paper are organized as follows: Section II details the methodology employed, outlining the system architecture and its four main layers—data acquisition, data storage, application, and presentation. The role of each layer and its corresponding hardware and software components are explored to illustrate how they contribute to performance test automation. In Section III, the results are presented, including a validation environment and comparative analysis between the automated system and traditional manual methods. Section IV concludes by discussing the main results observed, such as the efficiency of the developed system in reducing data collection time and minimizing human errors, along with potential areas for future work. Finally, acknowledgments and appendices are provided to provide additional context and resources that support the development of this study.

II. RELATED WORKS

The field of mobile network analysis and monitoring has evolved significantly, particularly with the complexity brought by 5G and Industry 4.0. Numerous studies have proposed approaches to optimize mobile networks, focusing on methodologies, automation tools, and performance analysis techniques that closely relate to the objectives of this work. This chapter reviews relevant studies, emphasizing contributions in areas such as automated configuration, network optimization, real-time data analysis, and visualization methods.

Mané (2018) explores a comprehensive framework for automating mobile network configuration, focusing on the integration of economic and environmental factors in network planning processes. This methodology complements the objectives of this study by aiming to reduce human intervention through optimized network configuration processes across complex environments [3]. Similarly, Franco (2014) centers on Self-Organizing Networks (SON) methodologies in LTE networks, proposing algorithms to detect sector misalignments and optimize coverage. Using drive-test data, this work highlights how automation enhances network reliability, underscoring SON’s role in streamlining network operations and minimizing manual oversight. Such strategies resonate with the goals of this study, which also seeks to leverage automation for improved network diagnostics [4].

Furthering the focus on automated network performance, Martins (2024) explores statistical methods for fault detection in mobile networks, offering a data-driven framework to identify operational issues and optimize performance. The emphasis on statistical modeling aligns with this study’s approach of using georeferenced heatmaps for real-time performance visualization, where data analysis plays a crucial role in identifying network anomalies [5]. Lopes Neto (2024) also contributes to automation efforts in network performance, examining the use of multi-criteria decision-making and machine learning for cell classification in mobile networks. The automation methods explored in Lopes Neto’s study are directly relevant to this work’s objectives of enhancing diagnostics efficiency and reducing network maintenance costs [6].

Wortmann and Flüchter (2015) investigate the role of 5G in Industry 4.0 applications, particularly its potential for IoT and real-time industrial processes. With low latency and high device connectivity, 5G facilitates the development of smart factories, transforming network-dependent environments. This work aligns with the vision presented in these studies, as it focuses on an adaptable and cost-effective testing system that serves Industry 4.0 environments. The scalable and flexible nature of 5G testing tools illustrates their broad application potential in enhancing connectivity and automation across sectors [7].

An efficient approach to drive-test automation is presented by Sun et al. (2022), who develop a deep generative model called GenDT that enhances the efficiency of mobile network drive testing. This study focuses on synthesizing high-fidelity time series data for key performance indicators (KPIs) from a relatively small amount of real-world measurement data, significantly reducing the need for extensive field measurements. By learning the relationship between contextual factors and radio network KPIs, GenDT allows for the generation of synthetic data for new drive test trajectories, thereby minimizing measurement efforts while maintaining accuracy. This automation strategy is particularly relevant as it aligns with the objectives of this work to improve network performance evaluation through innovative modeling techniques.. Complementary insights from Rappaport et al. (2013) underscore the importance of precise testing methodologies, especially in urban environments where 5G's millimeter-wave technology demands high accuracy to ensure performance [8, 9].

Applications of big data in network monitoring also inform the present study's methodology. Yin and Kaynak (2015) discuss challenges associated with big data visualization and real-time processing, underscoring the need for robust tools to manage large data volumes efficiently. [10].

Finally, heatmap-based visualization in network analysis is further explored by Allion Labs (2020), who emphasize the critical role of heatmaps in representing wireless signal strength and density. Allion Labs discusses how heatmap analysis provides a clear graphical representation of wireless performance, using color coding to indicate signal strength, red for strong signals, yellow for medium, and green/blue for weak signals. This method allows for the identification of weak coverage zones, which is crucial for ensuring reliable connectivity in IoT environments. The analysis incorporates key performance indicators such as latency, throughput, and packet loss, which help assess connection quality and identify stability issues that may arise in various settings. [11].

In summary, the review of these works emphasizes the need for adaptable and automated solutions in mobile network analysis. While previous studies often depend on high-cost proprietary tools, this study introduces an open-source alternative focused on accessibility and adaptability. This system retains the precision and scalability necessary to meet the demands of modern network environments, supporting advancements in telecommunications and IoT for Industry 4.0 applications.

III. METHODOLOGY

To achieve the main objective of this work, which consists of developing and providing an open-source methodology for conducting performance tests in mobile networks as a viable alternative to both the traditional manual data collection method and the use of proprietary solutions and high-cost equipment, the system architecture was designed to encompass four main layers: data acquisition, data storage, application, and presentation. Thus, the system covers everything from integration with hardware for recording the signal strength values collected during the tests to the generation of heat maps for report analysis. The described structure can be visualized in Figure 1:

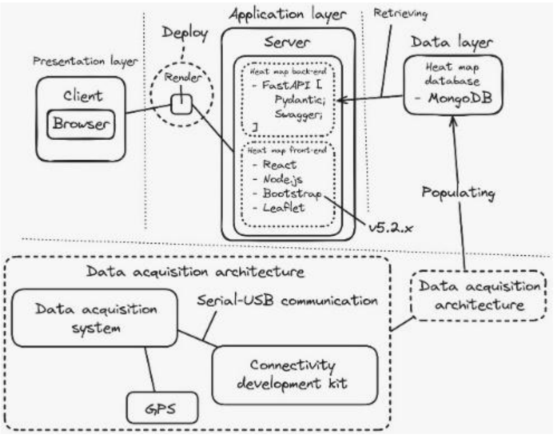


Fig. 1. Architecture of the automated drive-test system. Source: The authors. Date of preparation: 10/02/2024.

In the following subsections, the details of the software and hardware elements used in the development of each layer of the system will be presented.

A. Data Acquisition Layer

It is responsible for collecting signal indicators from the mobile network using a Python interface script that communicates with different types of hardware compatible with 5G, 4G, LoRa, Zigbee networks, etc. It is at this stage that real-time performance metrics of the network are obtained during the drive test. These modules are connected to a portable computer and, through serial communication present in most of them, information regarding signal quality is requested, which can include data such as RSSI (Received Signal Strength Indication), RSRP, RSRQ (Reference Signal Received Quality), SNR (Signal to Noise), among others. This data is processed and prepared to be sent to the database.

In parallel to the integration with the hardware elements, the Python interface script simultaneously communicates with a GNSS (Global Navigation Satellite System) module, thereby receiving the georeferenced location of the data acquisition point for network performance. This combination allows for the automated collection of a very important factor: signal quality in a specific location. This information is formatted into a file that will be ready to be sent to the database. The formatting structure is based on JSON (JavaScript Object Notation) notation, which essentially consists of a format that enables the exchange of structured data between different systems, platforms, or interfaces. In Figure 2, it is possible to understand an example of this notation.

```
{
    "timestamp":"datetime.now()",
    "latitude":"interpolated_latitude",
    "longitude":"interpolated_longitude",
    "received_signal_strength_indication":"received_signal_strength_indication",
    "record":"record_name"
}
```

Fig. 2. Structured formatting of data in JSON format. Source: The authors. Date of preparation: 02/08/2024.

To validate the proposal regarding the hardware for acquiring signal quality data, a 5G development kit from

Quectel, the 5G-M2 EVB Kit, provided by Itaipu Parquetec, was used. This equipment is utilized for development and basic testing with Quectel modules from the RM500Q, RM502Q, and RM505Q-AE series, featuring various communication interfaces. The significant advantage of this hardware is that the communication module is capable of connecting to private standalone 5G networks. Thus, it is possible to establish communication between the Python script and the 5G module through a serial AT command interface, enabling the reception of RSRP data, which represents the power of the received reference signal. The kit and the mentioned 5G module can be seen in Figure 3.

Fig. 3. Quectel 5G development kit and module. Source: Quectel [12]. Date accessed: 03/09/2024.

For the georeferencing of the acquisition points, the GNSS module used during the validation tests was the STOTON GN-701, shown in Figure 4, which features a 7th generation embedded chip from Ublox. Through serial communication with the component, the Python script is able to identify the location where the performance data was collected. After the data collection is performed by the Python script, the data formatted in JSON notation is sent to the database.

Fig. 4. STOTON GN-701 module. Source: The authors. Date of preparation: 23/08/2024.

B. Data storage layer

The data storage layer is primarily composed of a database that is updated with each test cycle, ensuring data persistence for subsequent analysis. To create a secure and scalable database, MongoDB Atlas was selected for data management. The decision to use a non-relational database is driven by the need to handle real-time data collection efficiently. Given the dynamic nature of the data generated during drive tests, where signal quality and geolocation metrics are continuously transmitted, a non-relational approach allows for greater flexibility and faster processing of data.

Each value collected during the drive test is stored in a structured document format, which includes a unique document identifier, a timestamp, latitude and longitude values, the received RSRP data, and a reference to the test from which the data originates. This structure not only facilitates rapid data ingestion but also allows for efficient retrieval and analysis of information in real-time. Consequently, the data acquisition layer feeds this database with the collected values in the specified format, while the application layer retrieves these data points for further processing.

C. Application layer

It is composed of all the processes and components that are part of the system server, where the processing of the data stored in the previous layer takes place. This data is treated and analyzed to generate relevant information about network performance.

This layer features an API (Application Programming Interface) built using the FastAPI web framework, aimed at providing efficient development of access points, which are queried by the front-end to retrieve structured data. The API offers the necessary endpoints and possesses the robustness required to ensure data integrity and scalability. The data undergoes a validation step performed by the Pydantic library, in which it must adhere to the format specified by the developer. The endpoints have been documented with the support of the Swagger tool.

The retrieved data is provided to the presentation layer, ensuring that it is properly prepared to be consumed by the plotting library, following the expected state of the data.

D. Presentation layer

In general terms, this layer is responsible for displaying the results generated by the application layer in a clear and intuitive manner for the end user, which may include the display of graphical interfaces, dashboards, and customized reports.

The front-end of the application runs in a Node.js execution environment and has its components based on React. For plotting the values on a map, the open-source library Leaflet was used, which features a detailed and up-to-date map, as well as allowing the use of plugins for various plotting variants. One of these is a heat map with intensity points, which was utilized in the prototype.

E. Comparative study

In order to evaluate the effectiveness and efficiency of the developed system within the operational context of field tests, a comparative analysis was conducted between the implemented automated methodology and the standard method of collecting signal indicators and plotting heat maps in a completely manual manner.

The comparative method involves analyzing the points of convergence and divergence between data groups to gain a better understanding of the results obtained. From this observation, it was possible to more accurately assess the benefits generated by the automated process and identify areas for improvement that can be implemented in future work.

The decision to conduct a comparative analysis between the performance test of the 5G network executed manually and through the automated system is based on the similarity between the two methodologies in terms of cost and versatility.

Both approaches are characterized by their lack of need for sophisticated equipment and their applicability across different types of mobile networks, making them relevant for performance evaluation in various contexts. However, the automated system presents significant advantages over the manual method, including reduced data collection time, minimized human errors, and the ability to generate results more efficiently and accurately. These results will be further elaborated in the next section of this article.

IV. RESULTS

A. Validation Environment

After completing all the development stages as well as the integration of each system layer, the project proceeded to the validation phase in a controlled environment with the goal of generating results for the comparative study. These tests were conducted within the coverage area of the 5G laboratory network at Itaipu Parquetec. The institution hosts the 5G Lab, a pioneering laboratory in Brazil that features a standalone private 5G network dedicated to research, development, and open innovation in 5G technologies.

The laboratory infrastructure enabled testing using both the Quectel 5G module integrated into the automated system and manual data collection of RSRP from a connected 5G router. Since the tests were conducted within the same coverage area, it allowed for comparison of results under similar operational conditions.

B. Test Using the Manual Method

The manual method for testing the performance of mobile networks consists of several steps: 1. Define the test route and specific data logging points (Figure 5);2. Manually verify and record the coordinates of the points; 3. Carry out the route with a router connected to the mobile network; 4. Access the router's configuration interface during the route and manually log the signal quality data at each pre-defined point; 5. Organize a table correlating each logged data point with its respective coordinates; 6. Input all the information into a Geographic Heatmap application; 7. Generate the heatmap (Figure 6).

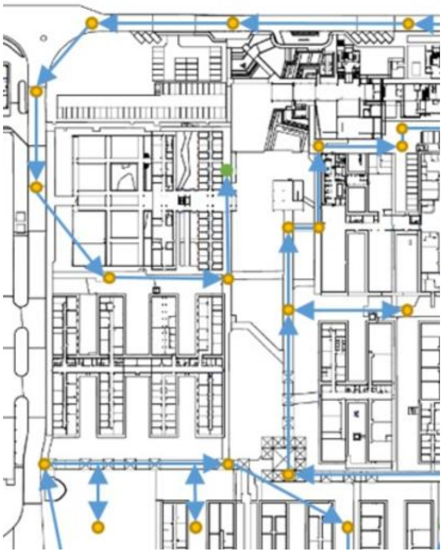


Fig. 5. Definition of data logging points for the test using the manual method. Source: The authors. Date of preparation: 05/09/2024.

For graphical data visualization, the Heatmapper application was used, which is an online and free platform that facilitates the creation of different types of heatmaps for various applications and datasets [13].

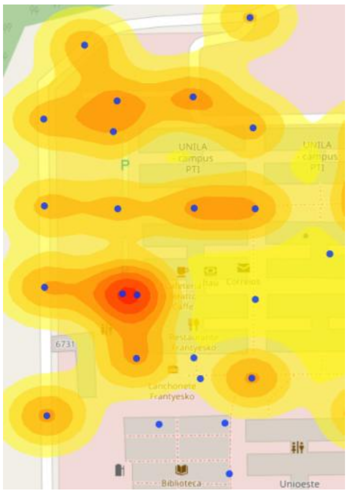


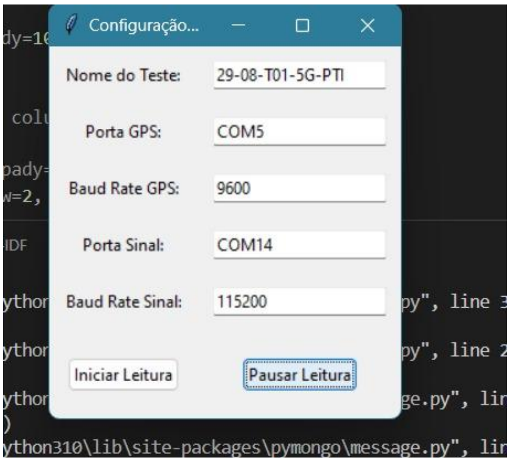
Fig. 6. Heatmap of the test using the manual method generated in Heatmapper. Source: The authors. Date of preparation: 12/09/2024.

In Figure 6, a higher intensity of red color represents better signal quality, while shades closer to yellow indicate the opposite. In other words, the redder the coloration of the region around the recorded point, the closer the RSRP value is to 0 dBm (e.g., -50 dBm), whereas more yellowish regions represent RSRP values further from 0 dBm (e.g., -80 dBm).

C. *Test with Automated Drive-Test System*

The use of the drive-test system developed throughout this work for mobile network performance testing eliminates most of the steps of the manual method described in the previous section. Essentially, the preparation for test implementation consists only of connecting the GNSS module and the communication module to the laptop (Figure 6) running the Python interface script. Once this is done, simply fill in the test configuration fields and start the data collection (Figure 7).

Fig. 7. Equipment and modules used in the test with the automated system. Source: The authors. Date of preparation: 09/09/2024.



Nome do Teste: 29-08-T01-5G-PTI

Porta GPS: COM5

Baud Rate GPS: 9600

Porta Sinal: COM14

Baud Rate Sinal: 115200

Fig. 8. Test configuration interface with the automated system. Source: The authors. Date of preparation: 09/09/2024.

From the start of data collection, the Python interface script automates the entire operational flow of the test. This includes configuring the serial ports; reading, extracting, storing, verifying, and interpolating GPS (Global Positioning System) coordinates; reading the RSRP data; formatting the JSON package and sending it to the database. All these steps are executed without the need for user intervention. In Appendix 1 of the "Appendices" section V, the flowchart of this process is presented in detail.

With the data recorded and structured in the MongoDB Atlas database, the system's front-end can access it via API endpoints, enabling data plotting and heatmap rendering. The figures 8 e 9 illustrate the process.

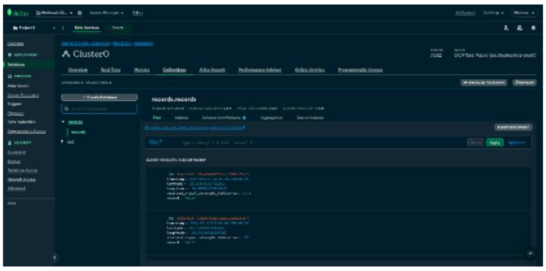
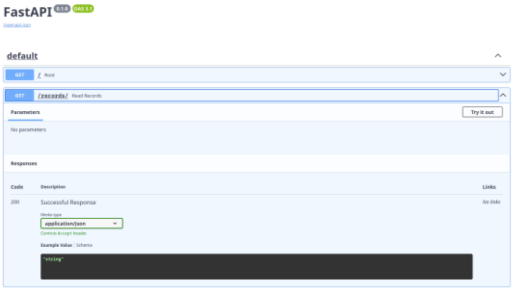


Fig. 9. Structured test data in the MongoDB Atlas database. Source: The authors. Date of preparation: 15/09/2024.



default

GET / Root

GET /records/ Read Records

Parameters

No parameters

Responses

Code	Description	Links
200	Successful Response Media type: application/json Example Value | Schema "string"	No links

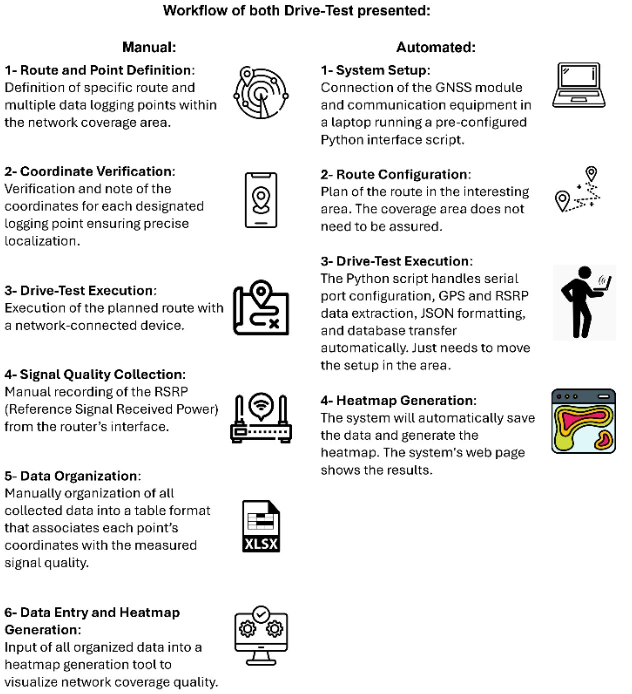
Fig. 10. Communication test with the API in Swagger UI. Source: The authors. Date of preparation: 15/09/2024.

Fig. 11. Heatmap generated in the test with the automated system. Source: The authors. Date of preparation: 15/09/2024.

D. *Comparative Analysis*

After the test results, a comparative analysis was conducted to identify the main similarities and differences between the two methodologies used.

Figure 12 illustrates the step-by-step workflow of each presented method, aiding in understanding their distinctions. It demonstrates that the automated workflow substantially reduces manual labor, minimizes error potential, and expedites the drive-test process by automating data collection, organization, and visualization. In contrast, the manual process is labor-intensive, requiring continuous operator engagement at each stage.



Workflow of both Drive-Test presented:

Manual:

1- Route and Point Definition: Definition of specific route and multiple data logging points within the network coverage area.

2- Coordinate Verification: Verification and note of the coordinates for each designated logging point ensuring precise localization.

3- Drive-Test Execution: Execution of the planned route with a network-connected device.

4- Signal Quality Collection: Manual recording of the RSRP (Reference Signal Received Power) from the router's interface.

5- Data Organization: Manually organization of all collected data into a table format that associates each point's coordinates with the measured signal quality.

6- Data Entry and Heatmap Generation: Input of all organized data into a heatmap generation tool to visualize network coverage quality.

Automated:

1- System Setup: Connection of the GNSS module and communication equipment in a laptop running a pre-configured Python interface script.

2- Route Configuration: Plan of the route in the interesting area. The coverage area does not need to be assured.

3- Drive-Test Execution: The Python script handles serial port configuration, GPS and RSRP data extraction, JSON formatting, and database transfer automatically. Just needs to move the setup in the area.

4- Heatmap Generation: The system will automatically save the data and generate the heatmap. The system's web page shows the results.

Fig. 12. Workflow of drive-test methodologies (manual and automated). Source: The authors. Date of preparation: 28/10/2024.

Table 1 presents the key points of this analysis regarding the execution time of the implemented tests:

TABLE I
EXECUTION TIMES BY STAGE

Test Execution Stages	Average Execution Time (h)		Approximate Percentage Reduction
	Manual Test	Automated Test	
Definition of route and recording points	2	0	100%
Verification and recording of coordinates	2	0	100%
Execution of the drive-test route	0,5	0,5	0%
Recording of RSRP data	0,5	0	100%
Organization and structuring of data	2	0	100%
Insertion/consumption of data	1	0,2	80%
Generation of the heat map	0,2	0,2	0%
Total	**8,2**	**0,9**	**89%**

Observing the numbers presented in the table, it is clear that the use of the drive-test system has a significant impact on execution time parameters when compared to the manual method, achieving an approximate reduction percentage of 89%.

If we compare Figures 6 and 11 presented earlier, which show the heat maps generated during the manual test and the test with the automated system, respectively, we can observe a substantial difference in the density of recorded points. This directly results in greater accuracy of the heat map generated by the automated drive-test system.

V. CONCLUSION

This work presented the development and validation of an automated drive-test system for mobile communication networks, focusing on 5G and related technologies such as LoRa and ZigBee. The implementation of the system, composed of acquisition, storage, application, and presentation layers, allowed for efficient performance testing, significantly reducing data collection time and mitigating the possibility of human errors.

The use of a 5G development kit, which has a lower cost compared to traditional tools, combined with a GNSS module, enabled the creation of georeferenced heat maps with high accuracy in recording the RSRP (Reference Signal Received Power) parameter. The comparison between the traditional manual method and the automated system showed a reduction of up to 89% in total execution time, as well as an improvement in the accuracy of the collected data.

The proposed system stands out not only for its efficiency but also as a low-cost alternative applicable across a wide range of networks, expanding its scope of use. The results obtained validate the potential of the system as a viable and scalable tool for evaluating and optimizing mobile networks, directly contributing to improving the quality of services provided by telecommunications operators, telecommunications system integrators, and the development of innovative solutions within the context of Industry 4.0.

VI. FUTURE WORKS

Future work could focus on several key areas to further enhance the system's capabilities:

- Real-Time Data Analysis and Decision-Making: Incorporating real-time analysis functions could enable the system to identify anomalies and signal fluctuations instantly, allowing operators to make immediate adjustments during testing. This enhancement would be particularly valuable in urban and industrial environments where network performance needs to be dynamically managed.

- Expansion of Supported Technologies: Broadening support to include additional wireless communication protocols like NB-IoT, Sigfox, and Wi-Fi 6 could expand the system's applicability, making it relevant for a wider range of IoT applications and network types.

- Hardware Compatibility and Versatility: Enhancing the system's compatibility with various hardware devices would allow users to select from a broader range of devices based on their specific operational needs. This flexibility could lead to greater adoption in diverse testing environments.

- Machine Learning Integration: Implementing machine learning algorithms to analyze historical and real-time data could enable predictive analytics for network performance. By identifying patterns, the system could assist in predicting potential issues, facilitating proactive network optimization and resource allocation.

- Enhanced Reporting and Data Visualization: Developing customizable reporting features and interactive dashboards could allow users to manage and interpret large datasets more effectively. Advanced visualization tools would improve user accessibility and make the system more adaptable for decision-making in large-scale network management.

- Energy Efficiency Optimization: Exploring ways to make the system energy-efficient for prolonged field operations, especially in remote or off-grid environments, could make it more sustainable and suitable for rural network testing.

These proposed enhancements aim to further solidify the automated drive-test system as a robust, adaptable, and forward-looking tool capable of meeting the evolving needs of mobile network testing and optimization.

ACKNOWLEDGMENTS

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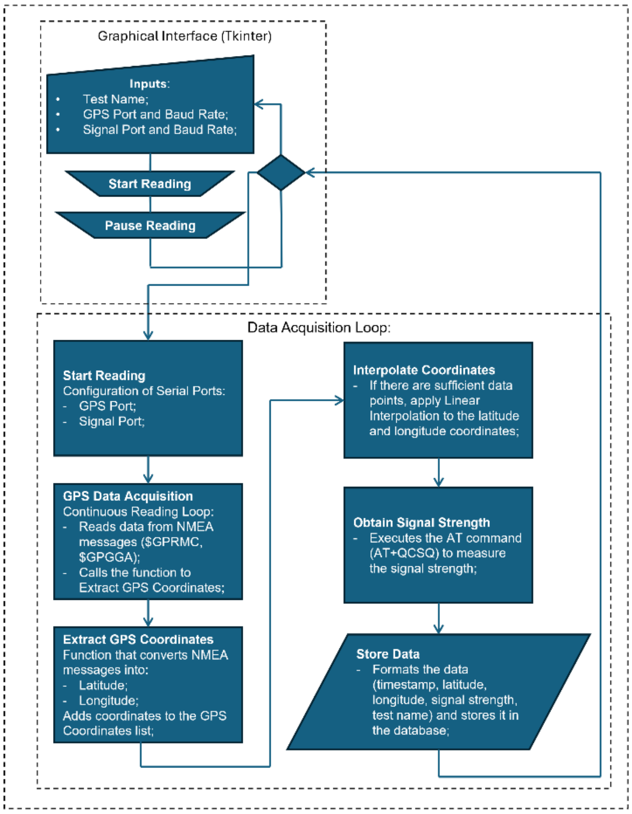
VII. APPENDICES

A. *Appendix 1 – Simplified Descriptive Diagram of the Python Script*



REFERENCES

[1] M. C. Pires. “O Brasil, o Mundo e a Quarta Revolução Industrial: reflexões sobre os impactos econômicos e sociais,” in *Revista de Economia Política e História Econômica*. 2018, v. 40, p. 5-36.

[2] Ericsson and Juniper Research, “What Will Drive Mobile Financial Services’Growth? Results from MNO Survey by Ericsson and Juniper Research”. 2024.

[3] Mané, A. Optimization of the methodology of configuration of mobile communication networks. 2018. Available online: https://repositorio.iscte-iul.pt/bitstream/10071/18750/1/master_ansumane_mane.pdf Accessed on: 28/10/2024

[4] Franco, C. D. S. S. Detecção de sectores cruzados e optimização de cobertura em redes LTE. 2014. Available online: http://hdl.handle.net/10400.21/4187 Accessed on: 29/10/2024.

[5] Martins, T. A. Métodos estatísticos aplicados a otimização de redes de telefonia móvel. 2024. Available online: https://repositorio.unb.br/jspui/handle/10482/47158

Accessed on: 29/10/2024.

[6] Lopes Neto, P. N. Desenvolvimento de um sistema de classificação e diagnóstico automático de células em redes de telefonia móvel de quarta geração. 2024. Available online: https://repositorio.unesp.br/items/72258c64-4cd4-4604-bddc-d2c86f0ddfa2 Accessed on: 28/10/2024.

[7] Wortmann, F., & Flüchter, K. Internet of Things: Technology and Value Added. Business & Information Systems Engineering, 2015. Available online:https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1338&context=bise Accessed on: 28/10/2024.

[8] Sun, Y., Wang, J., & Zhang, Z. Mobile Network Drive Testing Made Efficient with Generative Modeling. 2022. Available online: https://www.pure.ed.ac.uk/ws/portalfiles/portal/306413857/GenDT_SUN_DOA30102022_AFV.pdf Accessed on: 28/10/2024.

[9] Rappaport, T. S., et al. Millimeter Wave Wireless Communications for 5G Cellular: It Will Work!. IEEE Access, 2013. Available online: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6515173 Accessed on: 25/10/2024.

[10] Yin, S., & Kaynak, O. Big Data for Modern Industry: Challenges and Trends. Proceedings of the IEEE, 2015. Available online: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7067026 Accessed on: 21/10/2024

[11] Allion. Wireless Heat Map Analysis, the Hottest New Trend in IoT Product Verification. Available online: https://www.allion.com/article-iot-heatmap-analytic/ Accessed on:30/10/2024.

[12] Quectel. 5G-M2 EVB: User Guide. 2018, version 1.0.

[13] Heatmapper. Available online: http://www.heatmapper.ca/. Accessed on: 21/09/2024