Data Transmission via Mobile Telephony Network for an Environmental Radiation Monitoring System

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Abstract:
This paper presents the details of the adopted solution and lessons learned in the implementation of an environmental radiation monitoring system that transmits the collected data to a central computer via a mobile telephony network. The system is intended to be installed in fleet vehicles, which are not specifically dedicated to environmental radiological monitoring, and travel routes based on their own operational needs. The radiological and georeferencing data are transmitted through the mobile telephony network using the MQTT protocol.

1. Introduction

A mobile environmental monitoring system with data transmission of georeferenced information through a mobile telephony network holds significant value as it enables data collection from different vehicles simultaneously at various locations, allowing real-time tracking on a map. In this context, the distance between the sensor device and the recipients of the data becomes irrelevant. These individuals do not need to expose themselves to risks or harsh weather conditions, travel long distances, and can monitor remote locations, even in real-time, over distances of kilometers [16].

In this particular case, the system aims to monitor and survey environmental radiation along the streets, avenues, and roads of Brazil. The use of such a system can lead to a much deeper understanding of the distribution of higher levels of natural radioactivity across the country. Additionally, it has the potential to quickly identify anomalies that may not be of natural origin, such as areas contaminated by accidents or negligence [15].

2. Mobile Telephony Network Scenario in Brazil:

Regarding communication through the mobile telephony network, various technologies have been employed over the years, including CDMA, GSM, 1G, 2G, 3G, 4G, and now 5G.

First Generation:

Mobile telephony emerged in the 1980s, employing analog technology.

Second Generation - 2G:

The second generation introduced digital technology, providing a safer operation and allowing for more compact devices with lower power consumption. Initially, it supported voice communication only, later incorporating data transmission, albeit in a limited capacity.

Third Generation - 3G:

The third generation was developed to meet the growing demand for data traffic. To address data confidentiality for large companies and individual privacy, security became a significant concern. In

1990, the Global System for Mobile (GSM) was introduced, based on Time Division Multiple Access (TDMA) technology. This new technology enabled mobile devices to access broadband internet, facilitating numerous applications. In 1997, the General Packet Radio Service (GPRS) was introduced, transmitting data in the form of packets, leading to greater efficiency [1]. GPRS operates as a layer over GSM and can be seen as "GSM + Data." The theoretical maximum speed of 3G networks is up to 42 Mb/s.

Fourth Generation - 4G:

In Brazil, the 4G network already covers over 3,000 cities and utilizes LTE technology, providing data traffic speeds superior to those of 2G and 3G networks. The Brazilian 4G network utilizes frequencies of 2,600MHz, 1,800MHz, and the gradually released 700MHz band, formerly used by analog TV signals.

Fifth Generation - 5G:

The fifth generation aims to extend internet connectivity to various devices, enabling the Internet of Things (IoT) concept for security cameras, locks, cars, etc. It offers even higher speeds and allows the connection of an increased number of devices.

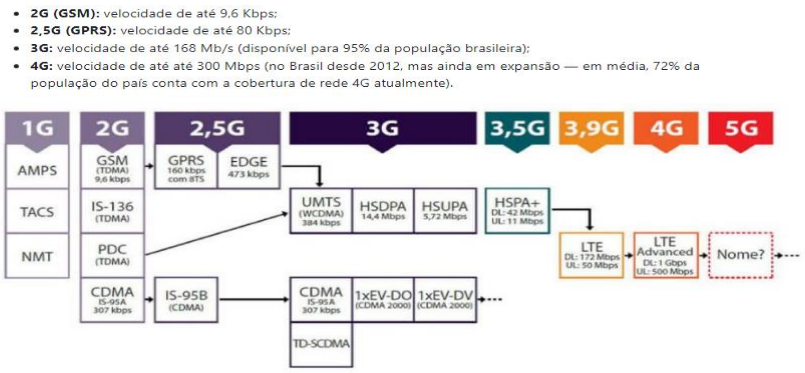

Figure 1: Evolution of Mobile Internet [17]

Coverage of Mobile Telephony Networks in Brazil

Brazil still has large areas of its territory without mobile telephony network coverage. There are three mobile telephony operators with nationwide coverage: Vivo, Claro, and Tim. Figure 1 depicts the coverage areas of these three operators - Vivo, Claro, and Tim, respectively [6]. These maps are based on measurements collected automatically by users of the nPerf application [6].

Figure 1: Vivo Coverage Claro Coverage TIM Coverage

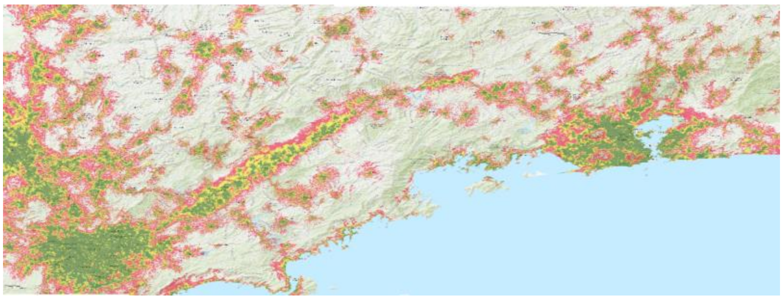

Figure 2: Claro Coverage Map in the Rio São Paulo axis, source: Claro website [7].

Figure 3: Claro Coverage Map for the Rio-São Paulo axis obtained from the nPerf website [6], and developed based on user tracking from the application.

Observing Figure 2, the Claro coverage map obtained from the operator's website [7] for the Rio São Paulo axis, and comparing it with Figure 3, obtained from nPerf [6] for the same region, it can be noticed that Claro users managed to get coverage even in some areas without the operator's coverage, probably due to the use of data roaming service. In this case, when a device is outside the coverage area of its original operator but within the coverage area of another operator, the latter identifies the device through the IMSI. If the device is eligible for data roaming, the second operator establishes a connection with the original operator. Within the national territory, there is no additional charge for data roaming, unlike voice roaming, which incurs additional charges.

The federal road network of the country extends for about 125,000 kilometers, of which nearly 58,000 kilometers are already covered [3]. Table 1 shows the percentage of road network covered by each operator [3]. However, it is essential to highlight that in 2021, Winity Telecom won the auction for the 5G spectrum, gaining the right to explore the 700MHz band to provide coverage for major Brazilian highways. Between 2023 and 2029, Winity is expected to cover nearly 36,000 kilometers of roads with 4G or superior signal [4]. Winity will then become the fifth telecommunications operator with nationwide reach, but instead of serving end consumers, the company will lease its network to other operators [5].

Cobertura da Rede de Telefonia Móvel nas Estradas Brasileiras			
	2G	3G	4G
Claro	27,20%	30,70%	28,80%
Oi	19,90%	12,70%	10,80%
TIM	17,60%	20,90%	26,70%
Vivo	26,10%	33,00%	28,20%

Table 1: Mobile Telephony Operators' Coverage of Brazilian Roads [3]

GPRS Device/Terminal Connection

A GPRS device/terminal establishes a connection to the network following these steps:

1-Upon activation, it is recognized by the network similar to a mobile phone, and a logical link, authentication, and registration to the network are established.

2-In the next step, an IP address is assigned, establishing the connection. Usually, the IP address is dynamic and provided by the mobile telephony operator.

3-To save energy, the device can assume different states: Stand-by/Idle or Ready when ready to instantly send and receive data packets.

Access Point Name (APN)

All information exchange involving different types of devices and the mobile telephony network is done through the Access Point Name (APN). APNs are established by the operator [1], which can be one of the major operators like Vivo, Tim, Claro, and Algar or a virtual operator. The APNs provided by major operators for mobile phone connections are public APNs, and there are also virtual operators offering services focused on Machine-to-Machine (M2M) communication that provide private APNs.

Due to the large number of devices connected to public APNs, there is a higher frequency of signal dropouts and transmission quality loss. In contrast, private APNs offer a more stable connection with fewer signal dropouts, enhanced security, and the ability to manage the usage of each SIM card on a monthly basis [18].

Operator	APN
oi	gprs.oi.com.br
Tim	timbrasil.br
Vivo	zap.vivo.com.br
Claro	claro.com.br ou java.claro.com.br
Algar Telecom	algar.br

Table 2: Public APNs of Major Operators

Methodology

Monitoring System

The monitoring system used aims to monitor environmental radiation along Brazilian streets and roads using a device composed of three main modules: a Geiger counter, a microcontroller integrated with a mobile network communication module with GPS, and a sensor for temperature, humidity, and atmospheric pressure. The final device is designed to be low-cost and installed in trucks, buses, and fleet vehicles that typically cover long distances in their daily routines. These vehicles would not be dedicated to this specific monitoring task [2].

While one advantage is the use of third-party fleet vehicles, which are non-dedicated and travel long distances daily, it also leads to a certain diversity of vehicles and variations in coverage quality, including areas with good coverage, poor coverage, or no coverage, as well as switching between different mobile operators during the same trip. The issue of coverage was one of the first problems identified during the development of the project. Often, when the device traveled through an area with no signal, it couldn't reconnect even after reaching an area with good coverage.

The monitoring device consists of three main components, as shown in Figure 4: a Geiger counter, a control and telecommunications module, and a sensor for humidity, temperature, and atmospheric pressure. The adopted control and telecommunications module integrate a SAMD21 microcontroller [9] with an A9G GPRS/GSM/GPS module operating at frequencies (850MHz, 900MHz, 1.8GHz, 1.9GHz) [10]. All communication with the GSM network is carried out using AT commands [11]. AT commands are a set of commands that allow GSM devices/terminals to communicate with the GSM network and follow the GSM 07.07 specification [1].

Figure-4: Modules comprising the monitoring device.

The SAMD21 microcontroller performs counting of the signals/interruptions generated by the Geiger counter and, according to a predetermined time interval (15 seconds), closes the counting. Then, through AT commands, it obtains GPS coordinates from the A9G module and assembles a package containing the date, time, counts, coordinates, temperature, humidity, and pressure. Once again, using AT commands, this package is sent by the A9G module to the mobile telephony network. The transmission of the information package is based on the MQTT protocol.

The Message Queuing Telemetry Transport (MQTT) Protocol

The choice of this protocol is due to various studies [12], [13] that have already indicated it as one of the most efficient for machine-to-machine communication, especially concerning devices with energy consumption restrictions and limited memory and processing resources, such as the IoT microcontrollers used here (SAMD21/A9G).

Figure-5: Diagram of Data Transmission through the Mobile Telephony Network

This protocol was created in 1999 by IBM initially for use in the oil and gas sector. Later, IBM released MQTT 3.1 as a free and open protocol, allowing anyone to implement it. It operates on the publish/subscribe model, where a client machine publishes information received by the broker, which then distributes it to subscribing machines. It is important to note that the same machine can act as both a publisher and a subscriber. In our case, the monitoring devices are the publishers, and the central computer that receives and processes the data is the subscribing client.

As this is equipment for environmental radiation monitoring, it was calibrated against the existing large-area planar sources at IRD.

The following are the AT commands used for communication with the GPS and the mobile telephony network. These commands are sent by the SAMD21 microprocessor to the A9G module, which handles communication and GPS tasks:

Upon powering on the microcontroller, activate the communication module:
AT command: "AT+CGATT=1"

To turn on the GPS:
AT commands:
"AT+GPS=1"
"AT+GPSRD=0"
"AT+GPS?"
"AT+GPSRD=GGA"

Connection to the GSM network, using the APN:
AT command: "AT+CGDCONT=1,"IP","APN name",0,0"

Obtaining the date and time from the mobile telephony network:
AT command: "AT+CCLK?"

Connection to the MQTT broker:
AT command:
"AT+MQTTCONN="Broker address",13486,"Instance",120,1,"Username","Password""

Obtaining GPS coordinates:
AT command: "AT+LOCATION=2"

Sending the MQTT packet:
AT command: "AT+MQTTPUB="Geiger",""+deviceID + Count....

If there is no connection loss, steps 6 and 7 are continually repeated, in this case, every 15 seconds.

Results:
Figures 6, 7, and 8 show the obtained results. Figure 6 displays the set of readings in the city of Rio de Janeiro, while figures 7 and 8 compare the results obtained with a commercial device and the results obtained by the developed device.

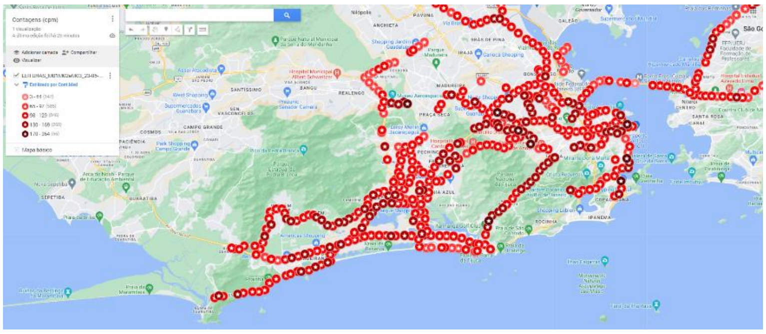

Figure 6 - Readings taken in the City of Rio de Janeiro

Figure 7 - Commercial Device
Readings obtained: 3.33 nSv/min (average)

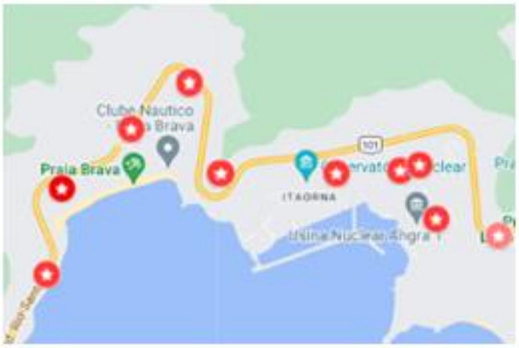

Figure 8 - Developed Device
Readings obtained: 3.41 nSv/min (average)

Initially, regular mobile telephony chips from two major nationwide operators were used. However, during the tests, it was observed that as the vehicle moved, there were frequent losses of connection with the mobile network, and reconnecting to the network was often challenging.

To overcome this difficulty, the adopted solution was to use a list of Access Point Names (APNs) composed of APNs from nationwide operators. If the microcontroller fails to establish a connection with one APN, it attempts to connect to the next one on the list, and so on. This solution showed improvement but still presented some problems.

Later, the issue of private APNs dedicated to Machine-to-Machine (M2M) or IoT communication was considered. Three types of M2M communication chips were tested, including a multi-operator M2M chip, a LinkField chip, and a chip linked specifically to one of the major operators, with the following results:

Multi-operator M2M chip: The device connected, sent a packet of readings, then lost the connection, and could only reconnect after a few minutes, resulting in unsatisfactory performance.

LinkField M2M chip: The device failed to establish communication.

M2M chip from a specific operator: This chip worked well and achieved good results.

It is important to note that these results are specific to the equipment used, and other devices may yield different results. Based on the achieved results, the decision was made to use a private APN through a chip from a virtual M2M operator.

Conclusion

The coverage of the existing mobile telephony network in Brazilian cities and roads encompasses over 2,000 cities, and approximately 50% of the federal paved road network is covered. Additionally, there are contracts in place for the installation of coverage in practically the entire remaining federal paved road network. Considering that mobile network coverage is better in densely populated areas, and the road network is denser in those regions as well, monitoring systems of this nature already present significant potential and are likely to become even more efficient. Although there are still many areas without mobile network coverage, the trend is for these areas to decrease rapidly.

The system under consideration, still in testing and not yet completed, already shows sufficient efficiency to demonstrate its full potential, with readings permeating increasingly through city streets and extending to more distant regions. Although less frequent, there are still situations in which the device loses connection and cannot reconnect. In these cases, the solution seems to be the implementation of a watchdog algorithm, which aims to monitor the system's functioning and restart it if a certain cycle takes much longer than expected. This algorithm is already under implementation.

Another aspect yet to be implemented is the retransmission of readings that were not sent due to a lack of connection. For example, if the device loses connection on a road due to coverage issues, as soon as it reconnects, it will transmit all the data that was not sent in the previous section.

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