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Real-Time vehicle tracking architectures using Geolocation, IoT, and cloud-based infrastructure

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Abstract

This study adopts an exploratory and applied approach to analyze modern vehicle tracking architectures, emphasizing satellite geolocation, M2M mobile networks, and cloud computing. A structured technical literature review guided the classification of relevant technologies, including hardware, communication protocols, and cloud-based platforms. The proposed system was evaluated in laboratory and field scenarios, demonstrating accurate real-time positioning with an average error of less than five meters using GNSS modules. Data transmission via GSM, GPRS, and 4G networks proved stable, with low latency and minimal packet loss. The packets were sent at 1-minute intervals to optimize data usage from the mobile data plan. Leveraging cloud services like AWS IoT Core and Lambda enabled scalable, serverless processing, while Amazon Timestream ensured efficient time-series data storage. The web dashboard, integrated with Google Maps, provided real-time visualization and historical tracking. Results confirm the system's robustness, scalability, and applicability to fleet management, logistics, and vehicle safety in urban and semi-urban contexts.

Keywords: Vehicle Tracking, Geolocation Systems, Internet of Things (IoT), Cloud Computing, Real-Time Monitoring, Predictive Analytics

1. Introduction

Brazil ranks among the top ten countries in the global automotive industry ^[1]. This prominent position is reflected in the continuous growth of the national vehicle fleet. According to data from SENATRAN, by 2024, there were 123,974,520 vehicles in circulation across the country ^[2], encompassing private individuals, businesses, and public institutions. Regardless of the ownership profile, a common requirement across all segments is the assurance of vehicle asset security.

Data from the Brazilian Public Security Yearbook indicate that, in 2023 alone, 354,742 cases of vehicle theft and robbery were recorded nationwide ^[3]. In this context, insurance companies and vehicle protection associations play a critical role—not only in covering incidents such as collisions, accidents, and natural disasters like floods, but also through proactive strategies for preventing and responding to property crimes such as theft and robbery.

The effective operation of these institutions is largely supported by vehicle tracking technologies. These systems rely on embedded devices and integrated technological infrastructures to enable real-time vehicle positioning and continuous monitoring through specialized platforms.

Given the global expansion of vehicle fleets, the demand for increasingly efficient tracking and security systems has intensified. This growth is not only driven by urban expansion and economic development but also by the increasing incidence of theft, traffic incidents, and the need for real-time logistics management. In response to these challenges, various technologies have been employed in the development of vehicle tracking systems, notably the integration of the Global Positioning System (GPS) with mobile communication networks—such as GSM, GPRS, and 4G/5G—as well as architectures based on the Internet of Things (IoT) and cloud computing ^[6, 8, 11].

Initial solutions based on microcontrollers such as Arduino and GPS-GSM modules enabled low-cost systems for vehicle localization and SMS-based transmission of coordinates, often

integrated with Google Maps [7, 9]. While functional, these systems presented limitations in terms of scalability, energy efficiency, and data security. Subsequently, the use of long-range, low-power wireless networks—such as LoRaWAN—emerged as a promising alternative, particularly in dense urban areas. Platforms like ProIoT exemplify how such solutions can provide wide coverage with minimal energy consumption [4].

In addition to GPS-based methods, some studies have proposed alternative tracking approaches using vibration and light sensors in conjunction with real-time detection algorithms. These strategies aim to reduce the operational costs associated with satellite-based systems. A notable example is presented by Koedsaksit *et al.* [14], who developed a mobile IoT application capable of vehicle tracking through embedded sensors, demonstrating that vibration sensors can achieve accurate route monitoring in environments such as university shuttle services.

With the advancement of IoT technologies and their integration with cloud services, more robust and scalable architectures have emerged. Recent projects have incorporated platforms such as Google Cloud IoT Core, Firebase, AWS, and ThingSpeak to store, visualize, and analyze tracking data in real time. These systems also include automated theft detection mechanisms and alert notifications [8, 11]. Such architectures support not only location tracking but also predictive analysis of suspicious events and remote monitoring via web and mobile interfaces.

Moreover, more sophisticated solutions based on computer vision have been applied in urban traffic contexts. These involve vehicle detection and tracking using algorithms such as YOLOv4 and DeepSORT. Although more complex and primarily focused on traffic surveillance systems, these approaches highlight the potential of artificial intelligence for large-scale tracking in multi-object environments [5, 13].

In light of this scenario, the present study aims to present an overview of vehicle tracking architectures, emphasizing the integration of geolocation modules, mobile communication networks, and cloud services. The paper discusses the underlying technologies, the main challenges involved, and the advantages of cloud-based systems over local implementations—particularly in terms of scalability, cost-effectiveness, security, and interoperability with data analytics and AI platforms.

2. Materials and Methods

This study adopts an exploratory and applied approach, supported by a structured technical literature review. The objective is to analyze, compare, and classify different technological architectures used in vehicle tracking systems. The selection of references prioritized recent and relevant scientific articles published between 2020 and 2024, obtained from indexed databases such as IEEE Xplore, ScienceDirect, and Google Scholar.

The analysis focused on three main technological domains:

- **Geolocation and hardware:** including GPS, GSM/GPRS modules, LoRaWAN, and sensor-based systems;
- **Communication and integration:** including mobile

networks (4G/5G), M2M communication, and Internet of Things (IoT) protocols;

- **Cloud-based platforms and services:** including Firebase, Google Cloud IoT Core, AWS, and the application of artificial intelligence for monitoring and event prediction.

The proposed system was validated through practical tests conducted in controlled and real-world environments, assessing factors such as scalability, real-time capability, power consumption, cost-effectiveness, and applicability to scenarios like urban mobility, logistics, and theft prevention. This approach enabled the construction of a comprehensive overview of current vehicle tracking technologies and their evolution, highlighting the most promising configurations in terms of performance, efficiency, and integration with intelligent services.

2.1 Technical Basis for Satellite Tracking

The determination of a vehicle's position begins with satellite-based localization systems, with the Global Positioning System (GPS) being the most widely adopted in the industry. This system consists of a constellation of 24 satellites distributed across six orbital planes, with four satellites per plane, ensuring that at least four satellites are simultaneously visible from any point on the Earth's surface. In addition to the operational satellites, a number of reserve satellites are available to maintain system reliability in case of failures.

Each satellite continuously transmits radio signals containing essential data for terrestrial receivers. These signals include: (i) ephemeris data, which describe the precise orbital position of the satellite at the time of transmission; (ii) almanac data, which provide orbital information for all satellites in the constellation, enabling the receiver to quickly identify those visible in a given region; and (iii) the timestamp of the transmission, synchronized by high-precision atomic clocks onboard the satellites.

GPS receivers—such as those used in vehicle tracking systems—capture these signals and calculate the distance to each satellite by multiplying the signal travel time by the speed of light. However, a single satellite is not sufficient to determine a precise geographic position. Therefore, the trilateration method is employed, requiring at least three distance measurements to estimate the receiver's latitude and longitude. Each satellite defines a sphere around itself with a radius equal to the calculated distance; the intersection of these spheres pinpoints the location of the receiver. A fourth satellite is crucial for determining altitude and compensating for possible synchronization errors. Moreover, by analyzing temporal variations in the measurements, the system can also estimate the device's direction and velocity.

The Fig 1 shows a communication architecture of the system. A GNSS signals are received by the GPS tracker and transmitted via M2M over cellular network to a BTS. The data is processed by cloud infrastructure and accessed through a monitoring interface over WAN.

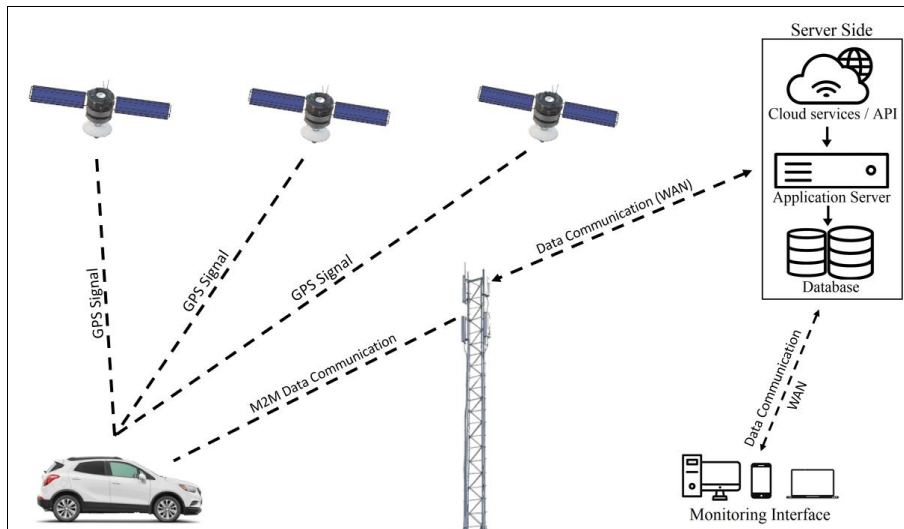


Fig 1: Communication architecture in a vehicle tracking system.

The Fig 2 shows how each satellite defines a sphere whose radius equals the distance to the receiver. The position is

calculated at the point where at least three spheres intersect, allowing accurate three-dimensional geolocation.

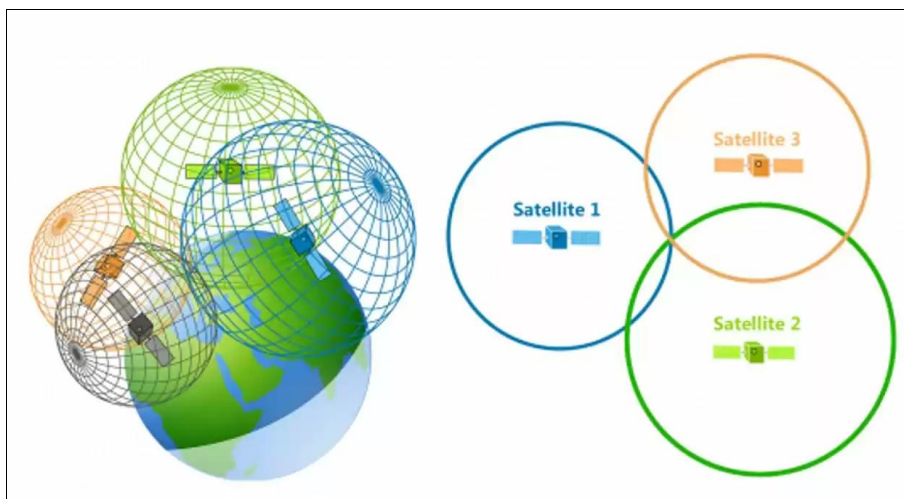


Fig 2: Illustration of GPS trilateration.

In addition to GPS, the satellite positioning system developed by the United States, it is important to highlight the existence of other Global Navigation Satellite Systems (GNSS) that operate in a similar manner and can also be used in vehicle tracking applications. Among these systems are: GLONASS, developed by the Russian Federation; Galileo, operated by the European Union; and BeiDou, developed by China. All of these systems rely on their own satellite constellations to provide positioning, navigation, and timing services.

2.1 Location Data Delivery via GSM/GPRS/4G Networks

Once the vehicle's location is obtained through the GNSS module installed in the device, the data must be transmitted to the monitoring center. At this stage, mobile telecommunications technologies play a fundamental role. Introduced in the late 1980s, the Global System for Mobile Communications (GSM) is considered the second generation (2G) of mobile networks. GSM replaced analog networks (1G) and introduced significant improvements, such as enhanced voice communication quality, more efficient use of the radio frequency spectrum, and the

adoption of time division multiple access (TDMA). Two innovations brought by GSM are particularly relevant to tracking systems: the SIM Card and the Short Message Service (SMS).

The SIM Card (Subscriber Identity Module) is a subscriber identification module that stores network information and authenticates the device with the mobile operator. In tracking applications, a special type of chip known as M2M (Machine to Machine) is commonly used. Designed for communication between machines and Internet of Things (IoT) devices, these chips operate autonomously, allowing continuous data transmission. For proper functionality, M2M chips must be configured with a specific Access Point Name (APN) provided by the carrier, along with authentication parameters. This configuration ensures a secure and stable communication channel between the tracker and the network infrastructure. It is worth noting that most M2M chips purchased by tracking companies are already SMS-enabled, allowing remote configuration of the devices via text messages.

With the GSM infrastructure in place, the General Packet Radio Service (GPRS) was introduced in 1998, regarded as an evolution of 2G (sometimes referred to as 2.5G). GPRS

implemented packet switching, a method in which data is divided into smaller units and transmitted over multiple radio channels that may be shared among different users. This technique enables an "always-on" connection, usage-based billing, and higher transmission speeds compared to GSM. It became a viable solution for transmitting vehicle location data to the operators' Base Transceiver Stations (BTS), also known as cell towers.

Although still used in simpler devices, GPRS is gradually being replaced by more advanced technologies. Beginning in 2001, third-generation (3G) networks were introduced, promoting the concept of mobile broadband and enabling higher data throughput and improved network performance. In 2009, the launch of fourth-generation (4G) networks - also known as Long-Term Evolution (LTE) - further increased data transmission speed and quality. 4G also simplified network architecture by adopting IP-based communication for all data types, unifying voice and data transmission. Currently, most modern vehicle trackers use 4G, as 5G coverage has yet to become fully widespread in many regions.

These transmission technologies enable the location data captured by the GNSS module to be sent to the mobile network through BTS units - commonly referred to as cell towers. These towers are strategically positioned in geographic regions known as cells, and together they form the mobile coverage network. The vehicle tracker detects the strongest available BTS signal and modulates the data into radio frequency signals, transmitting them through its antenna.

The BTS units, in turn, contain transceivers that convert the radio signals into digital data. This information is then forwarded to the Mobile Switching Center (MSC) of the operator, which is responsible for routing the data to its final destination - in this case, the servers of the vehicle monitoring platform. Once stored and processed, the location data can be accessed in real time by the end user through web interfaces or mobile applications.

2.3 Cloud-Based Architectures for Vehicle Monitoring

Cloud computing plays a fundamental role in the modernization of vehicle tracking systems by providing scalability, continuous availability, and advanced capabilities for processing, storage, and data visualization. Leading cloud service providers—such as Amazon Web Services (AWS), Google Cloud Platform (GCP), Microsoft Azure, and Huawei Cloud—offer specialized solutions for IoT device management and applications focused on vehicle telemetry.

2.3.1 Platforms

Amazon Web Services (AWS): offers services such as AWS IoT Core for data ingestion via MQTT or WebSocket, Amazon Timestream for time series data storage, AWS Lambda for serverless processing, and Amazon SageMaker for deploying machine learning models.

Google Cloud Platform (GCP): provides Cloud IoT Core, BigQuery for large-scale analytics, Vertex AI for predictive modeling, and integration with Google Maps Platform for geolocation services.

Microsoft Azure: offers Azure IoT Hub for secure communication between devices and the cloud, as well as Time Series Insights for temporal data analysis, Azure Digital Twins for fleet simulation, and Azure Maps for

location-based services.

Huawei Cloud: delivers solutions such as IoT Device Management and FunctionGraph (comparable to AWS Lambda), with a strong presence in emerging markets and compatibility with open standards.

The following sections present examples of how cloud computing can be applied at different stages of the vehicle tracking process.

2.3.2 Real-Time Data Reception and Ingestion

The data transmitted via the cellular network are routed by mobile operators and delivered to the monitoring center. This center, hosted in the cloud, can leverage services such as AWS IoT Core or Azure IoT Hub, which support the simultaneous reception of data from thousands of devices and utilize lightweight communication protocols such as MQTT.

Practical example: The tracker sends its location via a 4G connection; the data are received by AWS IoT Core and immediately routed to real-time visualization services.

2.3.3 Intelligent Processing with Serverless Functions

Raw data such as latitude, longitude, speed, and timestamp can be automatically processed using serverless functions. Services like AWS Lambda, Azure Functions, or Huawei Function Graph execute specific routines as soon as new data are received, eliminating the need for dedicated servers. Practical example: A Lambda function performs geocoding to convert coordinates into human-readable addresses, checks for speed limit violations, and generates alerts to notify the user.

2.4 Efficient and Scalable Storage

The continuous transmission of data by multiple vehicles requires robust and queryable storage. Services such as Amazon Timestream, Google BigQuery, and Azure Data Explorer are optimized to handle large volumes of time-series data with high performance.

Practical example: All location records generated by a vehicle are stored over extended periods, enabling route reconstruction, behavioral analysis, and report generation.

2.5 User Interface and Data Visualization

The presentation layer can be fully hosted in the cloud using services such as Firebase Hosting (GCP), Azure App Services, or AWS Amplify. APIs like the Google Maps Platform enable real-time geolocation functionality and interactive map integration within user interfaces.

Practical example: The user accesses a web dashboard to visualize real-time vehicle location, historical routes, and event-based alerts such as speeding violations or entry into restricted areas.

2.6 Security, Auditing, and Operational Continuity

Data protection is a critical concern, especially considering the sensitive nature of location information. Cloud platforms provide a comprehensive set of security and reliability mechanisms, including: Encryption of data in transit and at rest, ensuring confidentiality during transmission and storage; Identity-based access control combined with multi-factor authentication (MFA) to restrict unauthorized access; Automated auditing and monitoring through services such as AWS CloudTrail and Azure Monitor, enabling traceability and compliance; and, automated backup and

geographic replication to ensure disaster recovery and maintain operational continuity.

2.7 Artificial Intelligence and Predictive Analytics

With the data already centralized in the cloud, it becomes feasible to apply machine learning models for predictive analysis and pattern recognition.

Tools such as Google Vertex AI, AWS SageMaker, and Azure Machine Learning allow the development of custom

models based on fleet behavior and historical data.

Practical example: the system detects areas with high vehicle theft rates and recommends safer alternative routes, based on spatiotemporal analysis and usage history.

Table 1 presents a comparative overview of the main cloud service providers used in vehicle tracking solutions. The table highlights key features related to IoT device management, data storage, processing, real-time visualization, and machine learning capabilities.

Table 1: Comparison of Cloud Platforms for Vehicle Tracking

Cloud Provider	IoT Platform	Data Storage	Processing	Visualization	Machine Learning
AWS	AWS IoT Core	Amazon Timestream	AWS Lambda	AWS Amplify / QuickSight	Amazon SageMaker
Google Cloud	Cloud IoT Core	BigQuery	Cloud Functions / Vertex AI	Firebase Hosting / Maps API	Vertex AI
Microsoft Azure	Azure IoT Hub	Azure Data Explorer	Azure Functions	Azure App Services / Maps	Azure ML
Huawei Cloud	IoT Device Management	TSDB (Time Series DB)	FunctionGraph	Cloud UI + Open APIs	ModelArts

4. Results and Discussion

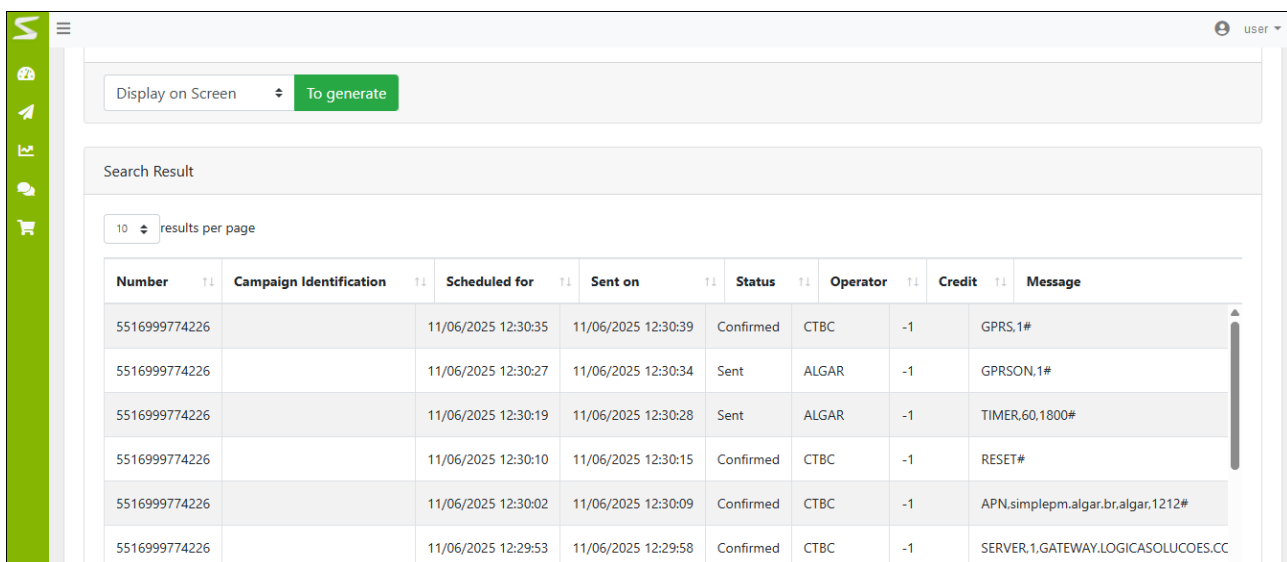
The tests conducted with the proposed vehicle tracking system yielded positive results regarding geolocation accuracy, data transmission stability, and the performance of the cloud-based architecture. The evaluations were carried out both in controlled environments and in the field, including urban and semi-urban travel scenarios.

Regarding GNSS module accuracy, an average positioning error of less than 5 meters was observed in areas with good sky visibility, utilizing simultaneous reception from GPS and GLONASS constellations. The reception of signals from at least four satellites enabled real-time trilateration, allowing for continuous and reliable vehicle localization.

Data transmission was evaluated using M2M SIM cards

operating on GSM, GPRS, and 4G networks. During testing, location data was transmitted at 60-second intervals without significant packet loss, even in areas with only 2G coverage. Under 4G connectivity, the system achieved latency below 50 milliseconds, enabling its use in time-sensitive applications such as fleet management and real-time logistics monitoring.

In addition to the monitoring interface, the platform allows for the remote configuration of trackers through the automated sending of SMS messages. This mechanism is used to set parameters such as APN, timers, and reset commands, ensuring the proper operation of M2M SIM cards. Fig 3 illustrates the SMS sending platform used for this purpose.



Number	Campaign Identification	Scheduled for	Sent on	Status	Operator	Credit	Message
5516999774226		11/06/2025 12:30:35	11/06/2025 12:30:39	Confirmed	CTBC	-1	GPRS,1#
5516999774226		11/06/2025 12:30:27	11/06/2025 12:30:34	Sent	ALGAR	-1	GPRSON,1#
5516999774226		11/06/2025 12:30:19	11/06/2025 12:30:28	Sent	ALGAR	-1	TIMER,60,1800#
5516999774226		11/06/2025 12:30:10	11/06/2025 12:30:15	Confirmed	CTBC	-1	RESET#
5516999774226		11/06/2025 12:30:02	11/06/2025 12:30:09	Confirmed	CTBC	-1	APN,simplem.algar.br.algar,1212#
5516999774226		11/06/2025 12:29:53	11/06/2025 12:29:58	Confirmed	CTBC	-1	SERVER,1,GATEWAY.LOGICASOLUCOES.CC

Fig 3: SMS sending platform for remote configuration of tracker SIM cards. The phone number has been blurred to preserve privacy.

The adoption of cloud platforms such as AWS IoT Core and AWS Lambda enabled scalable data ingestion and processing through a serverless architecture, reducing the need for infrastructure management. Furthermore, the use of time-series databases such as Amazon Timestream allowed for efficient storage of high-volume data, supporting retrospective analysis and the generation of operational reports.

In terms of user interface, the dashboard developed with Google Maps integration performed effectively, offering real-time location updates, route history tracking, and event-based alerts (e.g., speeding or entry into restricted zones). The interface was accessed via web browsers on various devices without any loss in functionality.

In addition to the map-based interface, a control panel was also developed to enable real-time monitoring of vehicle

communication status. Fig 4 shows a practical example of this dashboard, highlighting the number of vehicles with active communication and the elapsed time since their last data transmission.

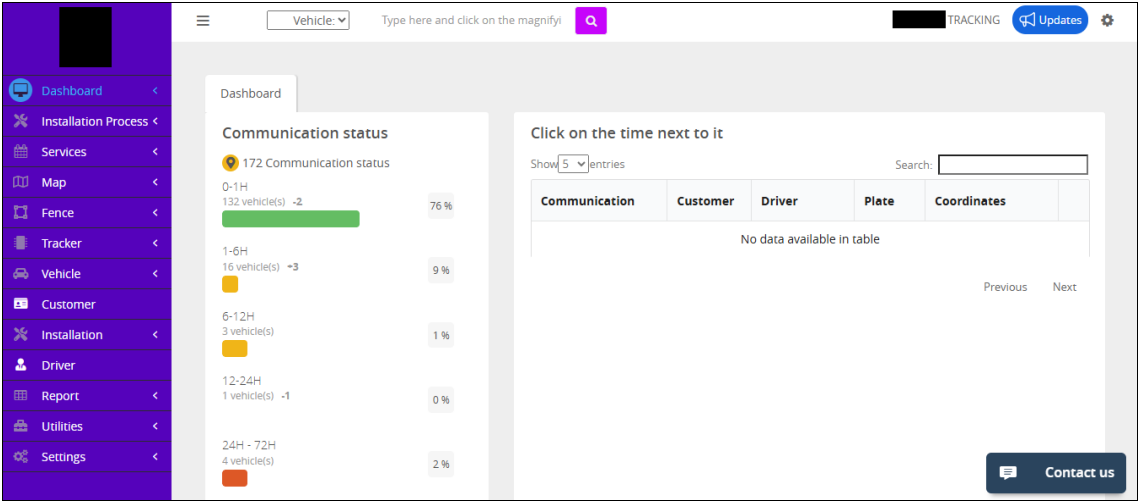


Fig 4: Real-time monitoring dashboard displaying the communication status of tracked vehicles, categorized by time elapsed since the last data transmission. The company name and logo have been omitted for privacy reasons.

In addition to the communication panel, the system also features real-time geographic visualization dashboards. These dashboards allow users to monitor the distribution, movement, and status of tracked vehicles using different map styles and interface elements. Figures 5 and 6 illustrate different views of the tracking interface, including clustering of vehicles, individual identifiers, and satellite imagery overlays for improved spatial awareness.

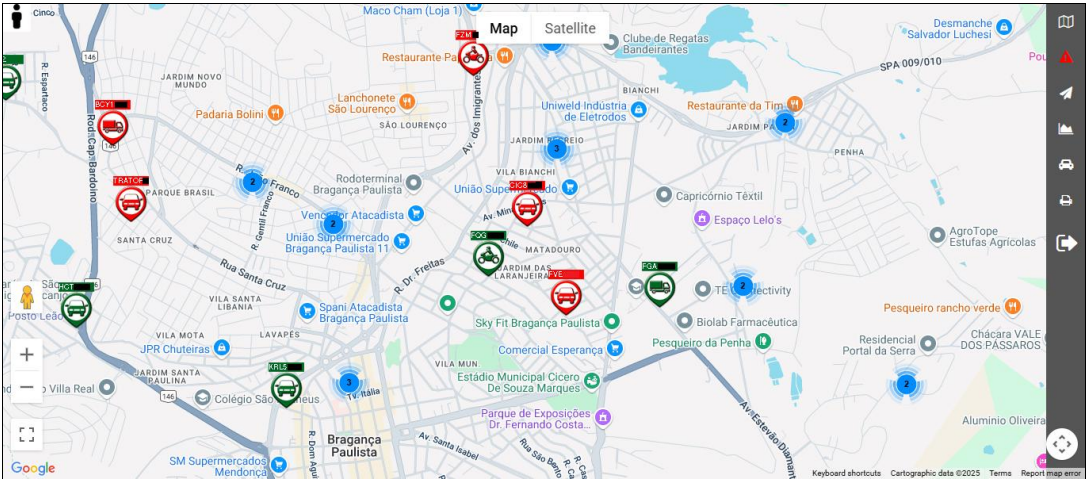


Fig 5: Web-based monitoring map with vehicle clustering and individual identification, using a Google Maps base layer. Vehicle license plates have been omitted to protect individuals' privacy.

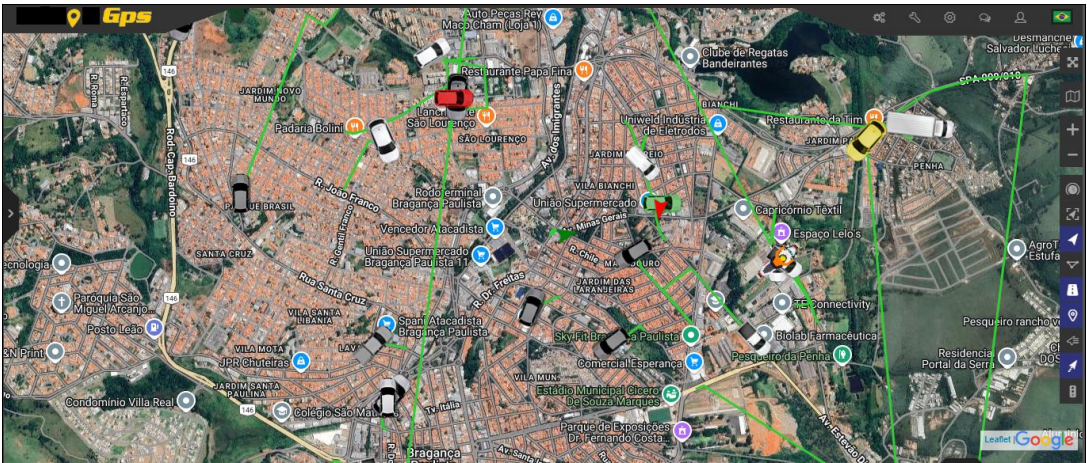


Fig 6: Satellite map interface with real-time vehicle icons and route paths visualized for operational monitoring.

Finally, the system demonstrated potential for integrating artificial intelligence techniques. Tools such as AWS SageMaker and Google Vertex AI open up possibilities for implementing predictive analytics, identifying high-risk patterns, detecting anomalies, and optimizing vehicle routes using machine learning models.

These results confirm the technical feasibility of the proposed solution, combining accurate geolocation, efficient communication, and a scalable architecture. The system proved robust for both light and heavy vehicle tracking applications, with potential for customization in diverse contexts, including logistics, urban mobility, and asset protection.

5. Conclusion

This study presented an in-depth analysis of integrated vehicle tracking architectures based on satellite geolocation systems, mobile telecommunications networks, and cloud computing platforms. The proposed system architecture demonstrated high reliability in geolocation accuracy, data transmission efficiency, and real-time monitoring capabilities, supported by a scalable and secure cloud-based infrastructure.

The integration of GNSS modules with M2M communication technologies (GSM, GPRS, and 4G) ensured consistent transmission of location data across various coverage areas. The implementation of cloud services, such as AWS IoT Core, AWS Lambda, and Amazon Timestream, enabled the real-time ingestion, processing, and storage of telemetry data, providing a robust solution for continuous monitoring and historical analysis.

The use of web-based interfaces integrated with Google Maps allowed for effective visualization and user interaction, enhancing the usability of the system in both operational and strategic contexts.

Overall, the proposed architecture proves to be a viable and adaptable solution for vehicle tracking in urban and semi-urban environments. The flexibility and scalability offered by cloud computing technologies position this system as a modern and efficient alternative for companies seeking to enhance their fleet management, asset protection, and logistical optimization.

6. Acknowledgements

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