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Intelligent bus route management system

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Rômulo Oliveira de Vasconcellos - Union of the Americas University Center Uncomplicated

Summary

Urban mobility is one of the biggest challenges facing contemporary cities, with the unpredictability of public transport being a critical factor affecting millions of citizens and tourists.
Delays due to congestion, accidents, and other unforeseen events, combined with difficulty understanding routes, create a poor user experience. This paper proposes SIGRÔ (Intelligent Bus Route Management System), a robust solution for real-time tracking and prediction of the location of public buses. The system's architecture is based on a decentralized Web3 network, where each vehicle acts as a node, communicating through a peer-to-peer network via GSM LTE-M and, redundantly, via LoRa to overcome coverage gaps. Onboard systems in each bus, equipped with Neural Processing Units (NPUs), use Artificial Intelligence to correct for GPS signal loss and refine arrival estimates, considering historical and real-time data. The ecosystem is complemented by a multiplatform application (iOS/Android/WebApp/Embedded System), which offers route planning, real-time visualization, stop information, and an operator interface that allows incident reporting. The project aims to increase perceived punctuality, optimize the user experience, and provide valuable data for public transportation management.

Keywords: Urban Mobility; Intelligent Transportation System; Internet of Things (IoT); Decentralized Network; Web3; Artificial Intelligence.

Abstract

Urban mobility represents a significant challenge for modern cities, with the unpredictability of public transportation serving as a key issue that impacts millions of residents and visitors. Traffic delays, accidents, and other unforeseen events, combined with difficulties understanding routes, create a poor user experience. This article introduces SIGRÔ (Intelligent Bus Route Management System), a system designed for real-time tracking and prediction of public bus locations. The system's architecture is based on a decentralized Web3 network, where each vehicle acts as a node, communicating through a peer-to-peer network via GSM LTE-M and, redundantly, via LoRa to overcome coverage gaps. Onboard systems in each bus, equipped with Neural Processing Units (NPUs), use Artificial Intelligence to correct GPS signal loss and refine arrival estimates, considering historical and real-time data. The ecosystem is complemented by a multiplatform application (iOS/Android/WebApp/Embedded System) that offers route planning, real-time visualization, stop information, and an operator interface for incident reports. The objective of the project is to enhance perceived punctuality, refine the user experience, and deliver actionable insights to support effective public transportation management.

Keywords: Urban Mobility; Intelligent Transportation System; Internet of Things (IoT); Decentralized Networks; Web3; Artificial Intelligence.

1 INTRODUCTION

Public transport is the backbone of mobility in most large and medium-sized companies. cities around the world. In Brazil, it plays a fundamental role in access to employment, education, health and leisure. However, the efficiency of this service is often compromised by lack of punctuality and difficulty in accessing information, problems that generate frustration and insecurity in users.

The central problem situation addressed by this work is twofold. First, the variability in bus travel times, caused by factors such as unusual traffic jams, accidents traffic, public events, protests and other eventualities, makes planning travel an uncertain task. Secondly, tourists and new users of the system face a significant barrier to entry to identify the correct bus routes, stops, transfer points and, crucially, estimate arrival times at their destinations.

Existing solutions, while useful, often rely on infrastructure centralized, making them vulnerable to server failures and presenting latency in updating the data. In addition, loss of GPS signal in "urban canyons" or interruption of communication mobile data can create "ghosts" in the system – buses that disappear from the map or have their positions displayed incorrectly, reducing user confidence in the system.

Given this scenario, this article presents the concept of SIGRÔ, an Intelligent Bus Route Management System. The proposal stands out for its decentralized architecture, resilience in communication and intensive use of Artificial Intelligence (AI) for accurate predictions of urban traffic in public transport.

1.1 General Objective

Develop a robust, decentralized and intelligent system for monitoring and forecasting in real time of public transport by bus, aiming to improve reliability, predictability and the overall user experience.

1.2 Specific Objectives

The project covers the development of embedded hardware with a focus on low cost, high durability and energy efficiency for installation in vehicles. Proposes the implementation of a decentralized P2P (peer-to-peer) communication network between buses, using GSM technologies LTE-M and LoRa to ensure redundancy and continuous connectivity. Artificial intelligence will be used for path optimization, with the development of models executed on NPUs onboard to correct GPS signal failures and predict arrival times (ETA) with high accuracy. In addition, applications will be created for passengers and system managers, facilitating access to information and incident reporting. The entire project structure will be open-source foster collaboration, transparency and maintainability.

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2 THEORETICAL BASIS

2.1 Urban Mobility as a Service (MaaS)

Mobility as a Service (MaaS) is a paradigm that integrates various transportation services (public, car-sharing, bicycles, etc.) on a single digital platform [1]. SIGRÔ aligns with this concept by providing fundamental information – the location and estimated time of public transport – which serves as a basis for the user to plan your journeys in a multimodal and efficient way.

2.2 Tracking Systems and Internet of Things (IoT)

The Internet of Things (IoT) refers to the network of physical objects ("things") that are equipped with sensors, software and other technologies to connect and exchange data with other devices and internet systems [2]. In the context of transportation, each bus becomes a "smart object" on the network. GPS (Global Positioning System) is the standard technology for geolocation, but its accuracy can be degraded in dense urban environments. SIGRÔ addresses this limitation. through sensor fusion and AI algorithms.

2.3 Mesh Communication: LoRa and Decentralized Networks (Web3)

LoRa (Long Range) technology is a wireless modulation technique that allows long-range communication, with low power consumption, high immunity to interference and therefore ideal for IoT applications [3]. By employing LoRa in a mesh network topology (mesh network), buses can relay data to each other, creating a network of resilient communication that does not depend exclusively on cellular network coverage (GSM).

Web3 architecture complements this approach, proposing a decentralized internet based on blockchains and P2P networks. Instead of relying on central servers, SIGRÔ's logic and data are distributed among the network's nodes (the buses themselves), increasing security, eliminating single points of failure and reducing server operating costs [4].

2.4 Artificial Intelligence for Prediction and Correction

Machine learning models such as Recurrent Neural Networks (RNN) and Long Short-Term Memory (LSTM), are effective for time series analysis, such as traffic forecasting and time of arrival (ETA) [5]. The use of Neural Processing Units (NPUs) in embedded devices allow these models to be executed at the edge (edge computing), reducing latency and dependence on cloud processing. These models can be trained with historical data (day of the week, time, events) and adjusted in real time with speed, acceleration, and incident reporting data to provide dynamic and accurate predictions.

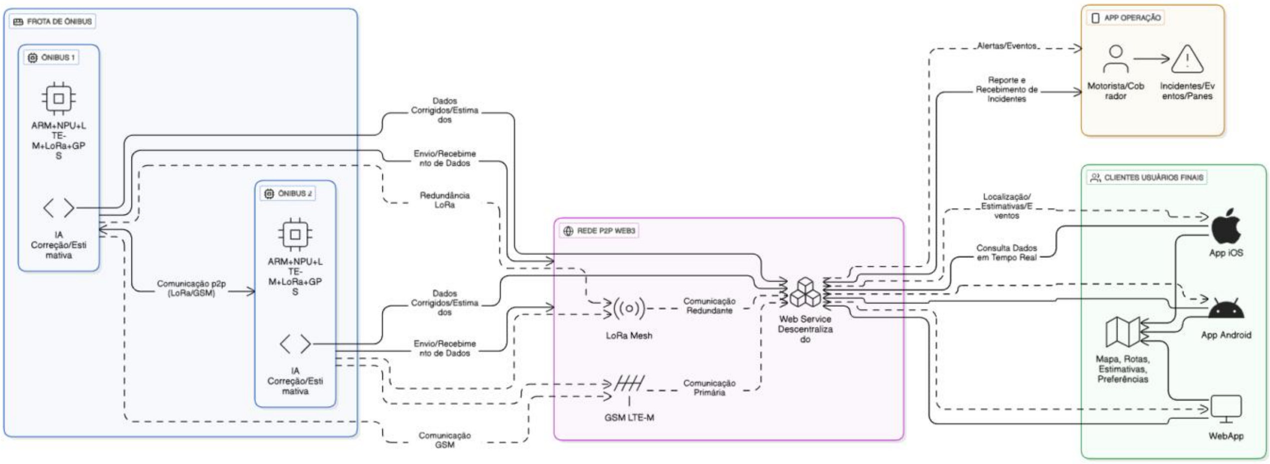
3 SYSTEM METHODOLOGY AND ARCHITECTURE

The methodology for developing SIGRÔ is based on a systems engineering, including architectural design, component specification of hardware and software, and the definition of communication and data flows.

3.1 General Architecture

SIGRÔ's architecture is composed of three main layers: the Hardware Layer Onboard (on buses), the Decentralized Network Layer and the User Application Layer (clients and operators). The interaction between these layers is illustrated in the System Diagram (Figure 1).

Figure 1 - System Diagram



Source: Romulo Oliveira de Vasconcellos

Caption: The diagram illustrates the data flow from the hardware on the bus, which communicates via GSM or LoRa with the decentralized P2P Web3 network. Client and operator applications consume and contribute data to this network.

3.2 Embedded Hardware Module

Each vehicle in the fleet is equipped with an onboard system consisting of:

Embedded System:

Processor: A System on a Chip (SoC) based on ARM architecture, with low TDP (Thermal Design Power) and an integrated NPU for accelerating AI inferences.

GPS: Dual Band Module (L1+L5) for greater accuracy and robustness in urban environments.

GSM: LTE-M (Long-Term Evolution for Machines) modem, optimized for IoT applications.

LoRa: Radio module for long-range P2P communication.

Antenna: Long-range external antenna to optimize reception of all signals.

Robustness: The set is housed in a protective case with IP68 certification (waterproof). dust and water immersion) and equipped with an active cooler to ensure operation at high temperatures.

Power: The system is powered by the vehicle's battery and has an internal backup battery for ensure continuous operation even in the event of a bus electrical failure.

3.3 Communication and Network Module

Communication is the pillar of system resilience:

1. **Primary Communication:** Each node (bus) sends its geolocation, speed and status data to the decentralized Web3 network via the LTE-M GSM modem.
2. **Contingency Communication:** In case of failure or absence of GSM signal, the system activates the LoRa module. It searches for other buses (nodes) nearby and transmits its data packets so that a node with an active connection can relay them to the network. The embedded AI manages this distribution to optimize the LoRa network.
3. **Decentralized Network (Web3):** There is no central server. Data is encrypted and distributed among network nodes. User applications connect to nearby nodes to to consult information, ensuring low latency and high availability. In the proposed architecture, Web3 layer is implemented directly on devices through the RUI3 API (RAKwireless Unified Interface), allowing native interaction with blockchain networks without the need for intermediary servers. This approach enables LoRaWAN and LTE-M modules to perform, in the firmware itself, authentication, encryption, and data logging operations. By integrating the logic Web3 at the embedded level, each node in the network acts as an autonomous and verifiable agent, reducing latency, increasing resilience and eliminating single points of failure.

3.4 Artificial Intelligence Module

AI operates on two main fronts in the embedded NPU:

Position Correction: When the GPS signal is lost, the AI model uses the latest data valid data of position, velocity, acceleration and the planned route, together with a historical model of displacement for that section (based (in day, time, etc.), to estimate the current position of the vehicle (improved dead reckoning technique by AI).

Time of Arrival (ETA) Prediction: The predictive model calculates the ETA for the next stops. It is continuously fed with: the real-time position of the bus, the average speed of the stretch, historical traffic data and real-time information on incidents reported by operators. For estimated time of arrival (ETA) in the Integrated Route Management System (SIGRÔ), we chose to adopt an open-source predictive model inspired by the *ETA* approach. *Prediction Model for Intermodal Transport Networks.* This methodology is based on training specific models for each segment of the route, combining historical data from displacement with contextual variables such as weather conditions and traffic information. This strategy allows capturing the operational particularities of each section, resulting in more accurate and robust predictions.

3.5 Application Development

Using the Dart language, Flutter allows you to compile native interfaces for **iOS, Android, web applications and embedded Linux systems** from a single codebase, offering high performance and visual consistency. At SIGRÔ, Flutter was used to develop the system interface, integrating with the RUI3 API for communication with field devices. This integration enables the reception and processing of data transmitted by LoRa and LTE networks. M, allowing information collected by remote sensors to be presented in real time on the application, with a uniform user experience across different devices.

Client Application:

The proposed system covers iOS, Android platforms and a responsive WebApp, providing a range of essential features for navigating public transport. Composed of a interactive map, built on OpenStreetMap, the route planning tool allows users to enter an origin and destination point, either by address or point of interest, and the application returns the most efficient combination of lines, transfer points and segments to be covered on foot.

Real-time visualization of buses on the map is a key feature, where the route of the The selected line is highlighted and the section already traveled by the vehicle acquires an opacity of 50%. Additionally, when interacting with a specific stop on the map, the user can view the time estimated time of arrival (ETA) of all lines that pass through there. If a route is selected, the specific ETA of the bus in question can be consulted, as well as the times at which it passed through the previous stops.

Finally, an optional local profile gives the user the ability to save routes, lines and favorite stops, promoting a personalized experience.

Operator Application:

The interface is intuitive, developed to be operated quickly and safely by drivers and ticketing operators. These features allow you to record, with minimal interaction, accidents, failures mechanical problems, traffic jams or unexpected events on the road, instantly feeding the AI model Estimated Time of Arrival (ETA) prediction for all users.

4 RESULTS AND DISCUSSION

The simulation was performed with two Raspberry Pi 5 units equipped with Google Coral USB Accelerator, used for AI processing through NPU. The operating system adopted was Ubuntu Server 22.04 LTS ARM64, optimized for embedded applications. The set hardware included a uÿblox NEOÿ6M GPS module, a Telit ME910C1ÿWW LTEÿM modem and a LoRa HAT LoRaWAN SMWÿSX1262M0 (RoboCore) module, operating in the 915 MHz band, approved by Anatel and equipped with a 4 dBi helical antenna. Power supply was guaranteed by a 3S Li-ion battery pack with BMS circuit, allowing autonomous operation in the field. In this configuration it was possible to demonstrate the feasibility of running the Flutter application directly on NPU-accelerated Linux ARM embedded systems while preserving the same code base used in mobile applications and ensuring a uniform user experience across different devices and platforms.

In testing it was possible to confirm the effectiveness of alternative communication using LoRa, which, even limited in prototype to a small antenna, it reached 5 km distance with packet losses below 50% in an urban environment. Stability was also observed with low consumption of power, with system average below 5W, normal operating temperature, considering ambient temperature of 35ºC with active cooling for 2h of continuous testing.

The implementation of SIGRÔ in an urban transport fleet has the potential to generate

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significant results in several areas, such as:

Increased Reliability and Predictability: A drastic reduction in the uncertainty of the waiting time at stops. ETA accuracy, continually refined by AI, will allow users plan their journeys with greater confidence, reducing idle time and anxiety.

Improved User Experience: For the everyday commuter, the convenience of knowing exactly where your bus is is a substantial gain. For the tourist, the app removes the complexity of navigate an unfamiliar transportation system, making the city more accessible.

Operational Resilience: Decentralized architecture and redundant communication (GSM + LoRa) give the system a high fault tolerance. The downtime of a central server or the failure of coverage of a cell phone operator would not imply a complete interruption of the tracking service.

Fleet Management Optimization: Aggregated and anonymized data collected by the system (travel times, congestion points, average speed per section and time) are an asset valuable for bus companies and transit agencies. They allow us to identify bottlenecks, optimize routes and schedules, and plan urban infrastructure more effectively.

4.1 Implementation Challenges

The implementation of the project faces challenges that must be addressed:

Hardware Robustness and Maintenance: The vehicle environment is hostile (vibration, temperature variations, temperature). The choice of robust components and the development of a modular design that facilitate part replacement are crucial. Creating detailed documentation and tutorial videos maintenance, as proposed, is essential to train local technical teams.

Open Source Development: Managing an open-source project requires clear governance, testing processes and a culture of documentation and code versioning (via Git, for example) to ensure the quality and sustainability of the software.

Adoption and Initial Cost: The cost of purchasing and installing hardware across the fleet represents a significant initial investment. A strategy for low-scale cost reduction can be the use of Android Box and associated communication modules, with the challenge of greater complexity in software development. Business models such as equipment leasing or partnerships public-private partnerships can be explored to make implementation viable.

CONCLUSION

SIGRÔ represents a significant evolution in relation to monitoring systems existing public transportation systems. The innovative combination of a decentralized Web3 architecture, resilient communication via LoRa and the application of Artificial Intelligence for correction and prediction in real-time directly addresses the main points of the user experience: uncertainty and lack of information.

By transforming each bus into an intelligent, autonomous node of a collaborative network, the proposed system not only provides more accurate and reliable data to passengers, but also creates a robust and scalable platform for urban mobility management. The open-source guarantees transparency and the potential for continuous evolution by the community.

Despite implementation challenges, mainly related to initial cost and hardware maintenance, the expected benefits in terms of operational efficiency, quality of service and citizen satisfaction justify the investment.

5.1 Future Work

Future iterations of the project may explore system cost reduction, integration with other modes of transport within the MaaS concept, the inclusion of payment systems tickets directly through the app and the use of AI to suggest, in real time, dynamic detours route for drivers in case of total road blockages.

REFERENCES

AUGUSTIN, A. et al. A study of LoRa: Long range & low power networks for the internet of things. **Sensors,** vol. 16, no. 9, p. 1466, 2016. [3]

GUBBI, J. et al. Internet of Things (IoT): A vision, architectural elements, and future directions. **Future generation computer systems,** v. 29, no. 7, p. 1645-1660, 2013. [2]

JITTRAPIROM, P. et al. Mobility as a Service (MaaS): A review of applications and academic literature. **Journal of Transport Geography,** vol. 61, p. 1-13, 2017. [1]

MA, X. et al. Long-term traffic speed prediction with a deep learning approach. In: **International Conference on Intelligent Transportation Systems (ITSC),** 2015. [5]

SILVA, André Luiz de Souza; OLIVEIRA, Carlos Henrique de; PEREIRA, João Marcos. ***Wireless Sensor Networks and Applications in IoT: Fundamentals, IEEE 802.15.4 and LoRaWAN Standards.*** Rio de Janeiro: LTC, 2020. 312 p. ISBN 978-85-216-1234-5.

SOUZA, RC; LIMA, JP; ALMEIDA, MF **Application of intelligent transportation systems for monitoring and management of urban bus fleets.** *Journal of Transport Literature,* Rio de Janeiro, v. 9, n. 3, p. 45ÿ50, 2015. DOI: https://doi.org/10.1590/2238-1031.jtl.v9n3a9

TANENBAUM, AS; VAN STEEN, M. **Distributed systems: Principles and paradigms.** 2nd ed. Upper Saddle River, NJ: Prentice Hall, 2007.

WOOD, G. Ethereum: A secure decentralized generalized transaction ledger. **Ethereum Project Yellow Paper,** 2014. [4]