IoT system architecture for monitoring and analyzing public transport data

Ihor Zakutynskyi | Ihor Rabodzei

Abstract The crucial role of public transport in the economy and modern city development is widely acknowledged. However, contemporary public transport systems are confronted with several challenges that require resolution. These challenges include real-time monitoring, data management, passengers flow optimization, and road accident prediction. The Internet of Things (IoT) presents a promising avenue for the development of modern public transport management systems. By leveraging a diverse range of technologies, such as sensors, edge devices, cloud computing, and various communication infrastructures, IoT systems can enable the creation of robust and automated public transport infrastructure. In this research, we propose an architecture for a public transport monitoring and management system. The proposed system can effectively collect, store, and monitor public transport data, thereby facilitating efficient management and timely response to risks that arise in the transport system. Implementation of such a system would enable public transport administrators to monitor and swiftly respond to potential problems such as overloaded passenger flows, emergencies, and technical issues with transport systems.

Keywords: IoT, ITS, system architecture, monitoring, NB-IoT

1. Introduction

Every year, the urban population is growing, both in Ukraine and around the world (World economic forum 2022), which leads to a significant increase in the number of vehicles on the roads. The rapid growth in the number of private vehicles causes traffic jams, deteriorating air quality, an increase in the number of road accidents, etc. The quality of public transportation often leaves much to be desired, due to problems with suboptimal routes, non-compliance with schedules, and overcrowding. The introduction of modern information technologies, in particular the Internet of Things (Kyriazis and Varvarigou 2013), can positively affect the development of public transport systems and make them more modern and attractive to the urban population.

The concept of the Internet of Things was proposed by Kevin Ashton in 1999 to describe a network of physical objects that are connected to the Internet (Kevin Ashton 2015). Since then, physical devices connected to the Internet have become part of everyday life.

The application of the IoT concept to transportation systems, including public transportation systems, is particularly promising (Sherly and Somasundareswari 2015).

Modern vehicles are equipped with thousands of sensors that allow recording information on movement, technical conditions, fuel consumption, and the number of passengers, and detecting anomalies in real-time. IoT platforms allow receiving and transmitting data to Cloud systems, which in turn allows further analysing and building predictive models based on the so-called Big Data.

The analysis of the accumulated data can be applied (Aceves and Aceves 2002; Ryley et al 2022) to solve such problems as:

1) Vehicle monitoring/tracking.
2) Passenger flow forecasting.
3) Reducing the number of road accidents.
4) Prediction and prevention of potential technical malfunctions.

The purpose of this study is to build optimal system architecture for collecting and analysing public transportation data. The system should be easily integrated into existing systems and should not require additional infrastructure. The proposed architecture should implement the following functionality:

• Provide passengers with real-time information on arrival times and routes.
• Warn drivers of potentially dangerous situations in time to avoid accidents.
• Control traffic according to a road or weather conditions.
• Monitor the number of passengers.
• Controlling vehicle speed and compliance with traffic rules.
• Monitoring the technical condition of the vehicle.
• Possibility of third-party integrations (Providing a public API).

2. Literature Review

The Internet of Things (IoT) is a system of interconnected devices that share data over the Internet. IoT has become an important technology in various industries including manufacturing, healthcare, agriculture, and smart cities. IoT is used to monitor and analyse various aspects of transportation, including vehicles, drivers, and traffic. IoT systems rely on a complex architecture that includes various components such as sensors, drives, gateways, and cloud platforms. This literature review focuses on IoT architectures for monitoring and analysing the transport sector.

The authors of this article (Radonjić 2022) propose a complex IoT architecture for determining the status of rotating machines by sound signals. Based on the information provided by this system, preventive maintenance can be more reliably planned for a specific rotary machine. This system can be used in any industrial plant with fixed rotational frequency machines.

The authors (Majid Moazzami et al 2021) propose an IoT-based smart transport system architecture that includes various components. The system is designed to monitor and analyse traffic flow, vehicle location, and driver behaviour. The proposed architecture provides real-time traffic management and reduces congestion.

In this paper (Surachet Sangkhapan 2021), the researchers studied the problem of road accidents caused by public buses and propose a smart bus management system based on NB-IoT.

The authors (Amara Adiya et al 2023) propose IoT architecture for a smart parking system that includes various components including sensors, actuators, and cloud platforms. The system is designed to monitor and analyse the availability of parking spaces and provide parking instructions to drivers in real-time. The proposed architecture reduces congestion and improves parking efficiency.

This paper (Kavitha 2022) presents an architecture of network-based congestion control in a WSN-based IoT system and a mechanism for data transmission in an intelligent transportation system.

In general, IoT systems are becoming increasingly important in the transportation sector, IoT architectures are used to monitor and analyse various aspects of transportation. The proposed architectures provide real-time traffic management, reduce congestion, improve parking efficiency, and reduce fuel consumption.

In this article, we will propose the architecture of the public transport monitoring and management system.

3. Materials and Methods

This study uses experimental and analytical approaches.

Before designing the systems, a technical task was formulated, which described the functionality that the system should implement, as well as its technical characteristics.

The main requirements were:

A. Connectivity

The architecture should have a reliable and secure communication infrastructure that enables seamless connectivity between the public transport vehicles, infrastructure, and passengers.

B. Data Management

The architecture should be capable of collecting, processing, and analysing large amounts of data from various sources such as sensors, GPS, and passenger information systems. This data can then be used to optimize routes, schedules, and maintenance schedules.

C. Real-time monitoring and control

The architecture should support real-time monitoring and control of public transport vehicles, enabling operators to identify and respond to issues quickly. This helps to improve safety, efficiency, and passenger experience.

D. Interoperability

The architecture should support interoperability with existing and future systems, enabling integration with other transportation systems such as ride-sharing and bike-sharing services.

E. Security
The architecture should be designed with security in mind, incorporating measures to prevent unauthorized access to data and systems.

F. Scalability

The architecture should be scalable to accommodate future growth and changes in technology. In the process of system development, the initial step involved performing a design of the system architecture. In the next step, researchers selected basic methods of connection and communication. The fundamental technologies and communication protocols between components and services were analysed, and performance tests were conducted to facilitate decision-making. Also, the input data types and data structures were analysed, which facilitated the selection of optimal storage and databases. Various solutions and methods such as linear methods and neural networks were evaluated for data processing.

Also, best practices for microservices-based IoT software architecture were analysed using next practices:

1) Performance testing to see if the software can handle large amounts of data.
2) Security testing to check whether the software meets the requirements for data security and protection against malicious attacks.

4. System Architecture

In this paper, we propose a system for monitoring and managing public transport data based on a classic IoT architecture. The system can be divided into two parts – Hardware (Vehicle module) and Cloud. The Hardware part is an IoT device that is installed in the vehicle and performs the task of collecting and transmitting data. The cloud part is responsible for storing, aggregating, and analysing the accumulated data.

The above model (Figure 1) allows collecting large amounts of well-structured chronological data, which is used to train neural network models to predict the number of passengers on transport routes, as well as models to predict the likelihood of an accident. The application of neural networks represents a potent predictive technique that facilitates the generation of forecasts grounded on intricate interdependencies.

![Figure 1 General system structure.](https://www.malque.pub/ojs/index.php/msj)

4.1. Evaluation

4.1.1. Hardware module

A hardware module is installed directly in the vehicle and collects and transmits data via the cellular network and consists of the next components:

A. GPS module

This module would allow the transport system to track the location of each vehicle in real-time, which could help optimize routes and schedules, and provide passengers with accurate information about arrival times.

B. Communication module

A communication module would allow the transport system to transmit data between vehicles, transit stations, and other systems, such as traffic management systems or emergency services. This could help improve coordination and response times.

C. Sensor module

A sensor module could include various sensors, such as temperature, humidity, and air quality sensors, which would help monitor the conditions inside the vehicle and at transit stations. This could help improve passenger comfort and safety, as well as identify areas for improvement in the system.
D. Payment module

A payment module could allow passengers to pay for their fares using contactless payment methods, such as credit cards or mobile payment apps. This could help reduce lines and wait times at ticketing kiosks and provide a more convenient and seamless experience for passengers.

E. Driver assistance module

A driver assistance module could include features such as collision detection, lane departure warning, and adaptive cruise control, which would help improve driver safety and reduce the risk of accidents.

Information from physical devices is transmitted in real-time via cellular networks using the MQTT protocol via NB-IoT connection (Figure 2).

![Data transmitting diagram](Image)

Figure 2 Data transmitting diagram.

There are various reasons why MQTT (Message Queuing Telemetry Transport) can be an appropriate protocol for smart public transport systems using IoT technology.

F. Lightweight

MQTT is a lightweight protocol that requires minimal bandwidth and is well-suited for low-power, resource-constrained IoT devices. This makes it an ideal choice for IoT smart public transport systems that rely on battery-powered devices.

G. Low latency

MQTT supports low latency, enabling real-time monitoring and tracking of public transport vehicles. This is essential for ensuring that public transport systems are running efficiently and on time.

H. Scalable

MQTT is highly scalable and can handle a large number of IoT devices, making it suitable for smart public transport systems that may have thousands of vehicles that need to be monitored and managed.

I. Reliable

MQTT has built-in mechanisms to ensure reliable message delivery, even in unreliable network conditions. This is critical for public transport systems where reliable communication is essential for the safety and efficiency of the system.

The utilization of MQTT in an IoT-based smart public transport system can enhance the system’s dependability, efficiency, and safety by enabling real-time monitoring and tracking of public transport vehicles while minimizing bandwidth and power consumption.

Later, after the data is saved, microservice communication takes place via the HTTP protocol.

In this study, the Vehicle module is implemented based on a Raspberry Pi 2 model B with SIM7020E NB-IoT HAT module (Figure 3).

![Raspberry Pi 2 model B with SIM7020E NB-IoT HAT module](Image)
The Narrow Band-Internet of Things (NB-IoT) HAT is compatible with Raspberry Pi and can be operated using serial AT commands. It facilitates communication protocols such as LWM2M/COAP/MQTT, among others (Table 1).

Table 1 SIM7020E NB-IoT Specification.

<table>
<thead>
<tr>
<th>SIM card</th>
<th>NB-IoT specific card</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocols</td>
<td>LWM2M/COAP/MQTT/TCP/UDP/HTTP/HTTPS</td>
</tr>
<tr>
<td>Control</td>
<td>AT commands (V.25TER, 3GPP TS 27.007, and SIMCOM AT Commands)</td>
</tr>
<tr>
<td>Band</td>
<td>FDD-LTE B1/B3/B5/B8/B20/B28</td>
</tr>
<tr>
<td>Data rate</td>
<td>Uplinks62.5Kbps</td>
</tr>
<tr>
<td></td>
<td>Downlinks26.15Kbps</td>
</tr>
<tr>
<td>Baudrate</td>
<td>300bps~921600bps (115200bps by default)</td>
</tr>
<tr>
<td>Voltage</td>
<td>5V/3.3V</td>
</tr>
<tr>
<td></td>
<td>Single module current (VBAT=3.3V):</td>
</tr>
<tr>
<td></td>
<td>Idle mode: 5.6mA</td>
</tr>
<tr>
<td></td>
<td>Sleep mode: 0.4mA</td>
</tr>
<tr>
<td></td>
<td>PSM mode: 5uA</td>
</tr>
<tr>
<td></td>
<td>eDRX mode: 70uA (eDRX=655.36s)</td>
</tr>
<tr>
<td>Dimension</td>
<td>30.5mm x 65.0mm</td>
</tr>
</tbody>
</table>

NB-IoT can be a suitable technology for a smart public transport system for several reasons:

A. **Wide coverage**

NB-IoT has better coverage than traditional cellular networks and can provide connectivity even in areas with weak network coverage. This is particularly useful for public transport systems that operate in remote or rural areas where cellular coverage may be weak.

B. **Low power consumption**

NB-IoT devices require low power, which means that they can operate on battery for extended periods, making them ideal for IoT applications like public transport systems where devices may not always be connected to a power source.

C. **Low latency**

NB-IoT has a low latency, meaning that data can be transmitted quickly, which is crucial for real-time tracking and monitoring of public transport vehicles.

D. **Cost-effective**

NB-IoT technology is cost-effective, which makes it an affordable solution for public transport systems that may have limited budgets.

Overall, the use of NB-IoT technology in a smart public transport system can improve the efficiency, safety, and convenience of the system while reducing costs and increasing reliability.

4.1.2. **MQTT Broker**

The MQTT Broker acts as an intermediary entity, receiving messages from Vehicle modules (i.e., publishers) and delivering them to clients who have subscribed to receive such information (i.e., subscribers).

4.1.3. **API Gateway**

The API Gateway service functions as a means for storing and retrieving data. Serving as a central point of access, it facilitates entry to stored data, analytics, and neural network-derived forecasting outcomes. Additionally, the service offers a Public API, which enables integration with third-party systems.

4.1.4. **ML (Machine learning) Service**

ML service used for building neural network models based on stored data. Machine learning techniques can enhance the efficiency and efficacy of smart public transport systems via several mechanisms.

Predictive maintenance constitutes a pertinent approach, wherein machine learning algorithms predict maintenance requirements for public transport vehicles before they fail, reducing downtime and enhancing system reliability.
Real-time routing and scheduling is another mechanism, wherein machine learning algorithms analyse real-time traffic data, weather conditions, and passenger demand to optimize the routing and scheduling of public transport vehicles. Such optimization can reduce travel time, enhancing the overall passenger experience.

Demand prediction is another application, where machine learning algorithms predict public transport demand based on historical data, weather conditions, and city events, enabling transport authorities to adjust service frequency and avoid overcrowding or empty vehicles.

Machine learning can also be used to optimize fares by analysing fare data from public transport systems, the adjusting pricing based on demand and supply, time of day, and other factors to increase revenue. Finally, passenger behavior analysis using machine learning can enable transport authorities to analyse travel patterns and preferences of passengers, facilitating the design of improved services that cater to passenger needs and enhancing the overall experience.

In this study, researchers used AWS services to build, train and deploy models. The general architecture is shown in Figure 4 (Amazon Web Services 2022).

4.1.5. Analytics Service

Service involves utilizing data-driven techniques and tools to gather, process, and analyse data from various sources, such as vehicles, ticketing systems, and passenger feedback. The primary goal is to extract valuable insights and intelligence to optimize the system's performance, improve passenger experience, and enhance operational efficiency.

4.1.6. Management Dashboard

Control panel and data visualization. Allows real-time tracking of the location of vehicles, number of passengers, technical condition, etc. This dashboard consists of the following parts:

Login page: This is the first page users see when they want to access the dashboard. It has a form for entering user credentials such as username and password and a submit button to submit the form (Figure 5).

Dashboard Home Page (Figure 6): This page allows select the desired transport unit and gets the necessary information on it. It contains such information as the current number of passengers, aggregated number of passengers (by hours), geolocation, etc.

Settings Page: This page allows users to manage buses in the system. It will include features such as adding new buses to the system and routes, editing bus information, and deleting buses. Users can also view the status of each bus, such as its location and whether it is running or not.

Analytics Page: This page provide for users performance reports of the system, including critical metrics like bus utilization, ridership, and revenue. Users can apply filters and export the reports to diverse formats like PDF or CSV.

https://www.malque.pub/ojs/index.php/msj
Public transport management system

Figure 6 Public transport management system - Dashboard page.

The deployment of the server infrastructure is fast and can be realized with the help of such systems as Terraform or CloudFormation.

5. Discussion

The proposed system architecture has the potential to provide numerous benefits for transportation operators, passengers, and city planners. A data management system can provide real-time information on the location and timing of vehicles. This can help passengers plan their trips more efficiently, reducing wait times and increasing overall satisfaction. Also such systems can improve efficiency by collecting and analysing data, transportation operators can identify patterns and optimize routes to reduce congestion and improve service quality. With data on passenger demand, transportation operators can allocate resources more efficiently, ensuring that there are enough vehicles on the road to meet demand without wasting resources. Also data management system can monitor vehicle conditions and identify potential safety hazards before they become a problem, ensuring the safety of passengers and drivers alike. By optimizing routes and resource allocation, transportation operators can reduce costs and increase profitability.

Overall, proposed system can help improve the efficiency, safety, and sustainability of public transportation, benefiting both transportation operators and passengers.
6. Conclusion

The proposed architecture allows for the rapid realization of efficient collection, monitoring, and analysis of data generated in public transport systems.

The implementation of such a system will allow public transport administrations to track and therefore respond in a timely manner to potential problems, such as overloaded passenger flows, emergencies, problems with the technical condition of transport systems, etc. It also makes it possible to provide passengers with information about the time of arrival and vehicle load in real-time, which will allow them to plan their time more accurately and thus make public transport more attractive. By collecting and analysing traffic data, smart public transport systems can optimize traffic flow and reduce congestion in urban areas. This reduction in traffic congestion also reduces greenhouse gas emissions, improving air quality and contributing to sustainable development.

The system uses publicly available cellular networks to transmit information, which makes it easy to integrate into the city's existing infrastructure.

Acknowledgment

This paper and the research behind it would not have been possible without the exceptional support of the Faculty of Air-navigation, Electronics, and Telecommunications and the Faculty of Cyber Security, Computer and Software Engineering of National Aviation University.

Ethical considerations

Not applicable.

Declaration of interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

References


Amara Aditya, Shahina Anwarul, Rohit Tanwar, Sri Krishna Vamsi Koneru (2023) An IoT assisted Intelligent Parking System (IPS) for Smart Cities.


World Economic Forum (2022) How has the world’s urban population changed from 1950 to 2020?

https://www.malque.pub/ojs/index.php/msj