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Cloud-Internet of Things Architectures for Smart City Public Transportation Systems

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Abstract

A smart city is a model for urban development that focuses on the quality, interactivity, and performance of infrastructure services using Information and Communication Technologies (ICTs). For example, smart public transportation is largely realized with efficient real-time data exchange and service optimization facilitated by cloud computing or the Internet of Things (IoT) devices. Benefits are realized by breaking down petroleum like bitumen/tar and raw materials using computational tools integrated into the software based on cloud computing that allows instant access to processing, storage, control & updates over the internet on our computer. Bring IoT in, and it would be an array of sensors embedded in each vehicle, coupled with Global Positioning Systems (GPS) modules that collect information about where vehicles are at all times as well as how full they (and stops) are, any congestion or environmental concerns along the way. This paper investigates the cloud and IoT convergence concerning smart city public transportation systems by proposing cloud-IoT architecture for improving urban mobility. Fundamental techniques included the design of layered architecture and moving data collection, transmission, and processing into cloud platforms to enhance service availability and timeliness. Experimental results underscore the capability of this architecture to improve public transportation efficiency and rider experience in a way that creates foundations for deployable, intelligent transit systems. This cloud-IoT integration marks a major step for future sustainable and efficient urban transit solutions.

Keywords: Smart city public transportation, Cloud-internet of things architecture, Urban mobility enhancement, Intelligent transit systems, Sustainable urban transit.

1 | Introduction

With rapid urbanization worldwide, cities are under increased pressure on infrastructure, particularly in public transportation. An efficient public transportation system is critical for sustainable urban growth, reducing congestion, emissions, and commute times [1]. The smart city model leverages Information and Communication Technologies (ICT) to enhance urban services' quality, responsiveness, and efficiency. Cloud

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computing and Internet of Things (IoT) would become significant technologies in this context since both allow flexible and scalable approaches toward a real-time analytical assessment, operational efficiency, and a user-centered approach to design.

Scalable cloud-based resources for storage, processing, and analytics for real-time monitoring and management of transportation networks. To sum up, centralized data and computation of central resources help cloud platforms accomplish key functions, including predictive maintenance, route optimization, and demand forecasting, among others. Meanwhile, the IoT connects wide-scale networks of physical devices, that is, forms such as sensors, Global Positioning Systems (GPS) modules, and Radiofrequency Identification Systems (RFID) systems that are implanted in vehicles and infrastructures.

These IoT devices continuously gather data about locations, loads of passengers, environmental conditions, and patterns in traffic, processing and analyzing it in the cloud to make informed decisions in a data-centric fashion. Integrating cloud and IoT technologies into a cohesive architecture will benefit public transportation. Such integration will ensure that cities can create responsive and adaptive transportation systems capable of adjusting dynamically to demands within cities. Passengers will have real-time information about when vehicles are due to arrive, congested routes, and service outages. Transportation authorities can make operations streamlined and cost-efficient and improve resource allocation. This paper discusses a cloud-IoT architecture designed for smart city public transportation systems. The architecture takes a layered approach to collecting, transmitting, and processing data, which enhances system reliability, scalability, and efficiency. Below is a table summarizing the core components of a cloud-IoT-based transportation system and their respective roles.

Table 1. Core components of cloud-IoT architecture in smart city public transportation systems.

Component	Description	Role in Smart Transportation	Example Technologies
Cloud infrastructure	Provides scalable resources for centralized data storage, processing, and analytics	Enables real-time analysis, predictive maintenance, and data-driven insights	AWS, google, cloud, microsoft, Azure
IoT sensors and devices	Collects continuous, real-time data on vehicle locations, passenger counts, and environmental metrics	Supports real-time tracking, passenger flow management, and environmental monitoring	GPS, RFID,temperature & humidity sensors
Data transmission network	Secure and reliable communication protocols that transfer data from IoT devices to the cloud	Facilitates real-time data exchange and ensure the system reliability	4G, 5G, LoRa, MQTT protocol

Using this architecture would allow the city to construct an intelligent and scale-able transport system that can adequately respond to existing and urgent city mobility and lay a base for futuristic progress. With cloud and IoT convergence for public transit, a viable adaptive mode of urban transportation toward future sustainable cities takes place within this city and creates even more robust, resilient infrastructure as part of cities.

2 | Literature Review

The concept of smart cities has gained much momentum as cities around the globe are dealing with increasing complexities, such as congestion and pollution, and the need to manage resources efficiently. The two key technologies that emerged and are central to smart city applications are cloud computing and the IoT. This review discusses seminal studies on cloud-IoT integration in smart city frameworks, research gaps, and the challenges in smart public transportation systems [2].

2.1 | Smart City Transportation through Cloud Computing

Cloud computing will enable centralized processing, data storage, and analytics required for the huge amounts of data generated by smart city transportation systems. For example, Guo et al. [3] demonstrate the applications of cloud services in route optimization, traffic management, and predictive maintenance. This is where platforms like AWS and google cloud can come in handy in the creation of scalable data solutions.

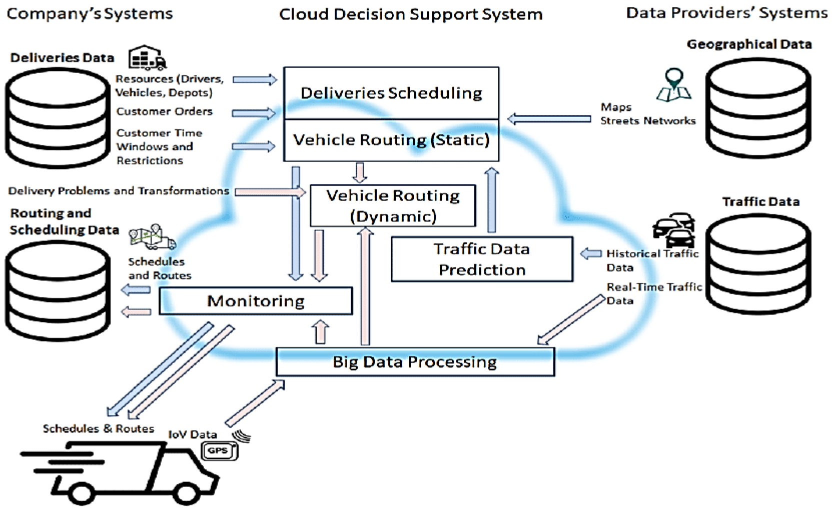

Fig. 1. Smart transportation system's architecture [1].

Fig. 1 illustrates the cloud system and its components at the core of the architectural design, on the left side with the interfaces connecting to user systems and on the right with third-party systems. Data flow is represented by arrows that indicate either entering the system, exiting it, or traveling between modules. Blue-colored arrows represent static routing and scheduling (first level), and red-colored arrows illustrate data flow for dynamic routing and rerouting (second level). The various technologies have been assessed for each part of this architecture, and selected solutions are being implemented to develop the cloud system. Detailed descriptions of these technologies are provided in the next section.

2.1.1 | Technologies or system development

The heart of the proposed architecture will comprise the cloud-based decision support system, which will benefit from the advanced technologies provided by key vendors such as Microsoft, Oracle, or Amazon. Based on the chosen technology, the system will likely utilize the IaaS or PaaS approach. Transport applications or modules will be built on the platforms mentioned above and provided to the end-user as SaaS. A foundational study by Zhang et al. [4] provides a comprehensive overview of the cloud computing architecture that this system will use. While cloud computing allows for easy hosting and service delivery online, establishing reliable, adaptable interfaces with user and third-party systems is important in successful data exchange.

A significant challenge is creating interfaces with company systems, as shown on the left side of *Fig. 1*, to facilitate data transfer to the cloud. This data will be exchanged through Application Programming Interface (API) services using the Representational State Transfer (REST) or Simple Object Access Protocol (SOAP) [5], [6]. Another way, mainly for companies with poor IT infrastructure, is the development of a web interface in ASP.NET technology where it is possible to load delivery, vehicle, and depot data without much hassle or system changes. For such purposes, Angular can generate dynamic HTML pages for mobile and desktop applications designed for data entry.

Output data from the cloud can be returned through APIs using the same or different API identifiers for input data, using REST or SOAP protocols. Geospatial data will be accessed through APIs from external providers, and delivery endpoint geocoding will use REST protocols and JavaScript libraries that allow interactive mapping capabilities.

It is expected to be programmed in Python or .NET, though C++ would also be a good choice owing to its vast numerical libraries. Big data technology is likely to play an important role in integrating the data sent from IoV devices and real-time feeds regarding traffic. Various processing techniques would Be deployed, such as a NoSQL database for unstructured data, data virtualization, integration, stream processing, and parallel processing. Therefore, the cloud framework will enable efficient infrastructure management by virtualizing big data under IaaS platforms. The next development stage in the project remains cloud infrastructure, through which the technology choices may soon be finalized.

2.2 | System for Monitoring and Managing Public Transport Data

The following shows a system that can be used to monitor and manage public transportation data utilizing the traditional IoT-based architecture. This system basically constitutes two major components: first, Hardware (vehicle module) and second, the cloud. The hardware portion is comprised of an embedded IoT device in a vehicle whose purpose is to collect data and further pass it to its intended destination. The cloud is responsible for data storage, aggregation, and subsequent analysis.

This model, as depicted in *Fig. 2*, can acquire very detailed, well-organized chronological data. Data of this type can be trained in neural network models with predictions of passenger numbers at various routes and the accident likelihood. The application of neural networks offers a strong approach to generating forecasts for complex interdependencies in data [7].

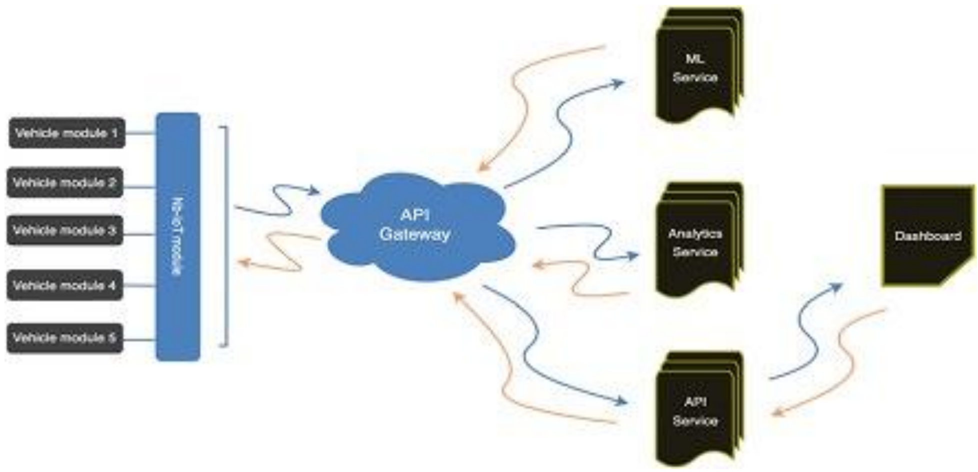

Fig. 2. IoT-based public transportation architecture showing interaction between vehicle modules, API gateway, and cloud services for data collection and visualization.

2.2.1 | Evaluation

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

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 [8].

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 improve coordination and response times.

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 and identify areas for improvement in the system.

Payment module

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

Driver assistance module a driver assistance module could include features such as collision detection, lane departure warning, and adaptive cruise control, improving driver safety and reducing the risk of accidents. Information from physical devices is transmitted in real-time via cellular networks using the MQTT protocol via an NB-IoT connection [9].

2.3 | Internet of Things-Enabled Smart Bus System with Global Positioning Systems, Radiofrequency Identification Systems, and Near field Communication Integration

The benefits of integrating the two technologies for large-scale data analysis have also been highlighted. Authors in [10] have presented a survey on the usage of smartphone-based sensing for Intelligent Transportation Systems (ITS). Smartphones' embedded sensors, such as accelerometers, gyroscopes, and GPS, have been applied to obtain traffic information, driver behavior information, and vehicle information. Solutions provided in the literature can be broadly classified into software-based solutions and hardware-enabled solutions.

Mobile application-based solutions

Mobile phone applications based on GPS have been presented in [11–14]. However, such applications are limited in that they cannot incorporate additional information, such as crowds, bus arrival times, etc.

2.3.1 | Hardware-enabled solutions

Based on the study, it has been identified that some solutions provide only location tracking based on GPS signaling and usage of GSM for information alert to the user, whereas others employ RFID technology. RFID are automatic technology that aids machines or computers in identifying objects, recording metadata, or controlling individual targets through radio waves. Connecting the RFID reader to the internet terminal, the readers can identify, track, and monitor the objects attached with tags globally, automatically, and in real-time, if needed. RFID is often seen as a prerequisite for the IoT [15].

In addition to location tracking, RFID has been used in bus information systems to obtain information such as bus IDs, crowds, etc. Authors in [16–18] have used RFID for the proposed solutions. Nowadays, we prefer NFC payments, which are similar to RFID technology. This NFC technology is simpler and easier for transactions. Previous works provide some insights into a smart bus system, but none of them proposed/demonstrated a complete system. Through this work, we propose a new IoT system that will track the vehicle with a GPS, people with an NFC system, and the ambiance in the vehicle through a temperature and humidity system. In the following sections, we will discuss our system architecture and components for a smart bus, followed by our idea to integrate multiple smart buses to make an efficient IBTS.

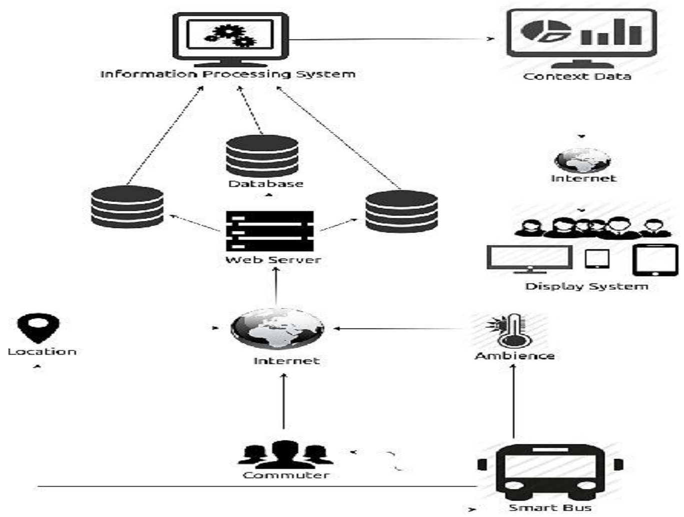

Fig. 3. Proposed architecture diagram [3].

The system architecture is classified as sensing, monitoring, and displaying systems. All operations are performed using the internet as the backbone. Different sensors are used in this system. All these sensors produce raw data, which will be stored in a central database, as shown in *Fig. 1*. This raw information needs to be carefully monitored, analyzed, and made into a meaningful context. If there are any issues, the system automatically takes action. At last, the meaningful context is displayed to the public.

3 | Challenges

Infrastructure to 2030 telecom has proven that the changing geography of infrastructure and the growing internationalization of the economy and its impact on infrastructures where the challenges arise first of all from the fact that demand patterns for infrastructure services will change between and across countries as well as within countries. At the same time, the nature of infrastructure is likely to change as technology and user requirements evolve. Finally, financing the maintenance of existing infrastructure, deploying new ones, and managing change holistically across separate albeit interrelated facilities will raise challenges of their own [19].

In 2002, Kirikova et al. [20] reduced the challenge by implying a need for knowledge development in these areas. Still, most of all, there is a need for people who can integrate knowledge from these areas. There are specialists in GIS Geographic information systems, transport modeling, and information systems development, but few people can integrate knowledge from different areas. This is a major problem because knowledge and systems integration will be a key factor in developing ITS, and he ignored some effective criteria, for example, IBM Institute for business value is based on several factors, including the city's stage of development, physical characteristics, existing levels of transport infrastructure, and citizen preferences. For example, Amsterdam and Chicago are both mature cities but have very different characteristics that will shape their transport ambitions: in Amsterdam, over 50 percent of daily trips are on foot or by bicycle, whereas in Chicago, just under 90 percent are by private car [19].

On the other hand, Dr. Tom V. Mathew summarizes the problem and solution ITS in a table that compares the problem, possible solution, and approach of ITS.

Table 2. Relationship between problems, conventional approach, and ITS approach.

Problem	Possible Solutions	Conventional l Approach ITS	ITS Approach
Lack of mobility and accessibility	Provide user-friendly access to quality transportation services	Expand fixed route transit and para transit service radio and TV traffic reports	Multi-modal pre-trip and en-route traveler information personalize public transportation enhance fare card
Traffic congestion	Increase roadway capacity reduce demand	New roads carpooling flex-time program	Advanced traffic control, advanced real-time vehicle systems real-time ride matching personalized public transport telecommuting transportation pricing

In the same way, Dr. Tom V. Mathew is interested in user services and their requirements, where several functions are needed to accomplish the user services. These functional statements are called user services requirements. The requirements for all the user services have been specified. If any new function is added, new requirements are to be defined. *Table 2* illustrates user service requirements for Traffic Control (TC) user service. TC provides the capability to manage the movement of traffic on streets and highways efficiently. These functions are provided as follows:

Traffic flow optimization

This will also include control of network signal systems with integration of freeway control. The specified user service requirements for TC shall consist of a traffic flow optimization function to provide the capability to optimize traffic flow.

I. Traffic flow optimization shall employ control strategies that seek to maximize traffic-movement efficiency.

II. Traffic flow optimization shall include a wide area optimization capability, including several jurisdictions.

III. Wide area optimization shall integrate the control of network signal systems with the control of freeways.

IV. Wide area optimization shall include features that provide preferential treatment for transit vehicles.

4 | Solutions to Challenges in Cloud-Internet of Things Architecture for Smart Public Transportation Systems

Creating a cloud-IoT architecture for smart public transportation holds great promise but comes with various technical and operational hurdles. The following key solutions tackle the main challenges in implementing this architecture to achieve security, scalability, efficiency, and reliability.

4.1 | Data Security and Privacy

To safeguard sensitive information in public transportation systems, robust security measures such as end-to-end encryption, secure communication protocols (like HTTPS and TLS), and role-based access controls are crucial. Regular security audits and penetration testing further bolster defenses, while data anonymization helps meet privacy standards, ensuring user safety and compliance with regulations.

4.2 | Interoperability and Data Management

With the diverse range of IoT devices and data sources, ensuring compatibility and smooth communication between devices is vital. Adopting open standards like MQTT and RESTful APIs fosters interoperability across various devices and systems, while middleware solutions standardize data formats and improve cross-device communication. Scalable cloud platforms and edge computing minimize latency, allowing for local data processing when necessary and managing large data volumes more effectively.

4.3 | Real-Time Data Processing and Network Reliability

Real-time insights are crucial for route optimization and congestion management tasks. Cloud-based data processing frameworks like Apache Kafka and Spark and edge computing facilitate immediate data analysis and response. Establishing reliable, low-latency networks, such as 5G, ensures consistent communication between vehicles and cloud servers, while redundant network configurations offer backup options in case of connectivity problems.

4.4 | Efficient Maintenance and Cost Management

Effectively maintaining IoT devices while keeping costs in check is vital for the success of smart transportation systems. Predictive maintenance, powered by machine learning algorithms, anticipates device failures and helps reduce downtime. To manage costs, utilizing serverless and pay-as-you-go models, along with edge computing, can lower data processing expenses by handling data efficiently at its source. Also, choosing cloud providers based on their pricing structures and performing regular cost-benefit analyses can enhance resource allocation.

4.5 | User Experience and System Reliability

Applications that are user-friendly and offer real-time transit information are crucial for ensuring a positive experience for the public. Implementing redundancy in cloud-based systems and failover protocols guarantees reliable access to data, even during peak demand or network issues. These strategies help maintain a consistent user experience and build public trust in the system's reliability.

Together, these solutions tackle the main challenges of implementing a cloud-IoT architecture in smart public transportation. By focusing on security, interoperability, data efficiency, cost management, and user reliability, these approaches create a strong foundation for a resilient and scalable system that can meet the demands of modern urban transit.

5 | Conclusion

Integrating cloud and IoT technologies in public transportation systems presents an innovative approach to tackling urban mobility challenges. This paper introduces a cloud-IoT architecture designed to enhance public transit's quality, efficiency, and sustainability in smart cities. By utilizing cloud computing, public transit networks can centralize data processing and storage, enabling scalable analytics, predictive maintenance, and real-time decision-making. Concurrently, IoT devices installed in vehicles and infrastructure collect and transmit vast amounts of data, which aids in optimizing traffic flow, facilitating real-time monitoring, and improving passenger experiences. Implementing these systems comes with challenges, including data security, interoperability, real-time processing, and maintenance. Solutions such as end-to-end encryption, open standards for interoperability, scalable cloud platforms, predictive maintenance, and cost-effective models have been proposed to tackle these concerns. Collectively, these strategies ensure that the architecture remains resilient, adaptable, and effective in addressing the needs of growing urban areas. As urbanization continues, cloud-IoT-enabled public transportation systems will play a crucial role in developing sustainable, efficient, and user-centric smart cities. This cloud-IoT architecture provides a solid foundation for immediate improvements in transit efficiency and future advancements in urban mobility. By creating adaptive and intelligent transit systems, cities can enhance the quality of life for residents, reduce environmental impact, and establish a standard for sustainable development in smart city initiatives.

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Author Contribution

I am the sole author of this research and responsible for all aspects of the study.

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Data Availability

No new data were generated in this research.

Conflicts of Interest

The author indicates no conflicts of interest, and no financial supporters were involved in this research.

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