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Design and Implementation of a Hybrid IoT-Based Real-Time College Bus Tracking System Using ESP32 and GPS

Adeel Arif[1], Mohd Aarfeen[2], Mohammad Zaid[3], Mohd Hanzala Niyazi[4], Sifatullah Siddiqi[5]
Department of Computer Science, Integral University, Lucknow, India - 226026

Abstract: ***In many educational institutions, students and staff often face uncertainty regarding the arrival and departure of college buses due to traffic conditions, route variations, and lack of real-time communication. Conventional tracking methods rely on fixed schedules or manual updates, which are inefficient and do not provide accurate or timely information. To address these limitations, this paper presents a hybrid IoT-based college bus tracking system that enables real-time monitoring of bus locations through both hardware-based and smartphone-based approaches. The proposed system utilizes an ESP32 microcontroller integrated with a GPS module and GSM communication module to capture and transmit real-time location data to a cloud platform. Additionally, a software-based alternative allows the driver's smartphone to act as a GPS source, directly sending location data to the cloud. The collected data is stored and processed using cloud services, enabling seamless access through a web-based application. The web dashboard provides live tracking, estimated arrival time (ETA), and route visualization, allowing students and administrators to monitor buses efficiently. The system also supports alert notifications for delays and route changes, improving safety and operational transparency. The hybrid design ensures flexibility, cost-effectiveness, and scalability, making it suitable for deployment in educational institutions with varying infrastructure capabilities.***

Keywords: IoT, Bus Tracking System, ESP32, GPS, Cloud Computing, Web Application

I. INTRODUCTION

In recent years, the rapid development of Internet of Things (IoT) technology has enabled real-time monitoring and smart management solutions in various domains such as transportation, healthcare, and smart cities. One of the important applications of IoT is vehicle tracking, where location data can be collected and shared continuously using GPS-enabled devices and cloud-based platforms. These systems help improve efficiency, safety, and user convenience in daily operations.

In educational institutions, transportation plays a vital role in ensuring that students and staff reach their destinations on time. However, most college bus systems still rely on fixed schedules without providing real-time updates. Due to traffic congestion, route changes, or unexpected delays, buses often do not follow the planned schedule accurately. As a result, students and staff experience uncertainty, increased waiting time, and inconvenience. In addition, the absence of a centralized tracking system makes it difficult for college authorities to monitor bus movements effectively.

Traditional methods such as phone calls, manual communication, or static timetables are inefficient and do not provide accurate or real-time information. These approaches are highly dependent on human intervention and are prone to delays and errors. Therefore, there is a need for an automated and reliable system that can provide continuous updates about bus locations and improve overall transportation management.

To overcome these challenges, this paper proposes a hybrid IoT-based college bus tracking system that enables real-time monitoring of bus locations. The system integrates hardware-based tracking using an ESP32 microcontroller with a GPS module and GSM communication, along with a software-based approach where a driver's smartphone can act as a GPS source. The collected data is transmitted to a cloud platform and accessed through a web-based application.

The proposed system provides live location tracking, estimated arrival time (ETA), and notification features for delays or route changes. It enhances transparency, reduces waiting time, and improves safety for students and staff. Furthermore, the hybrid approach ensures flexibility and cost-effectiveness, making the system suitable for institutions with different infrastructure capabilities.

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II. LITERATURE REVIEW

In recent years, several research efforts have focused on developing vehicle tracking and monitoring systems using Internet of Things (IoT) technology. These systems aim to provide real-time location updates, improve operational efficiency, and enhance user safety.

One of the early approaches to vehicle tracking involved the use of GPS and GSM modules integrated with microcontrollers. These systems were capable of collecting location data and transmitting it to users through SMS or web interfaces. While effective, such systems often lacked real-time visualization and required manual data interpretation.

Recent studies have introduced cloud-based vehicle tracking systems that utilize IoT platforms for real-time data storage and processing. These systems allow continuous tracking of vehicles and provide location updates through mobile or web applications. The use of cloud services improves scalability and enables access to data from multiple devices simultaneously. However, many of these systems depend entirely on dedicated hardware, increasing the overall cost of implementation.

Several researchers have also explored smartphone-based tracking solutions, where the mobile device acts as a GPS unit and transmits location data directly to a server. These approaches reduce hardware requirements and simplify deployment. However, they may face limitations such as dependency on user interaction, battery consumption, and inconsistent data transmission in low network conditions.

In addition, web-based dashboards have been widely used for monitoring and visualization purposes. These dashboards integrate mapping services such as Google Maps to display real-time vehicle positions and routes. Such systems improve user experience by providing intuitive interfaces and enabling administrators to monitor multiple vehicles simultaneously. Despite these advantages, many existing systems lack integration between hardware-based and software-based approaches.

Furthermore, research in IoT-based transportation systems highlights the importance of real-time alerts and notifications. Some systems incorporate features such as delay alerts, route deviation warnings, and emergency notifications to improve safety and communication. However, these features are not consistently implemented across all existing solutions.

From the reviewed literature, it is evident that while significant progress has been made in vehicle tracking systems using IoT, most existing solutions focus either on hardware-based tracking or smartphone-based tracking independently. There is a lack of flexible systems that combine both approaches to provide a cost-effective and scalable solution.

Therefore, the proposed system aims to bridge this gap by introducing a hybrid IoT-based college bus tracking system that integrates both hardware and smartphone-based tracking methods, along with a cloud-based web application for real-time monitoring and management.

III.PROPOSED SYSTEM AND METHODOLOGY

The proposed system is a hybrid IoT-based college bus tracking solution designed to provide real-time location monitoring using both hardware-based and smartphone-based approaches. The system integrates sensing devices, communication modules, cloud infrastructure, and a web-based application to ensure efficient tracking and management of college buses.

A. System Overview

The system is designed to collect real-time location data from buses and transmit it to a centralized cloud platform, where it is processed and displayed through a web application. The architecture ensures continuous data flow from the bus to the end user, enabling students and administrators to track bus movement accurately.

The system operates in two modes:

1) Hardware-Based Mode: In this mode, an ESP32 microcontroller is connected to a GPS module to capture real-time location coordinates. A GSM module is used to transmit this data to the cloud server using mobile network connectivity.

2) Smartphone-Based Mode: In this mode, the driver's smartphone acts as a GPS device and sends location data directly to the cloud through internet connectivity. This approach reduces hardware dependency and provides flexibility.

B. System Architecture

The proposed system follows a layered architecture consisting of the following components:

1) Sensing Layer: This layer is responsible for collecting location data. In the hardware-based approach, a GPS module (such as NEO-6M) is used to obtain latitude and longitude coordinates. In the software-based approach, the smartphone's built-in GPS performs the same function.

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2) Processing Layer: The ESP32 microcontroller acts as the central processing unit in the hardware-based system. It reads data from the GPS module, processes it, and prepares it for transmission. In the smartphone-based approach, data processing is handled by the mobile application.
3) Communication Layer: This layer is responsible for transmitting data to the cloud. In the hardware-based system, a GSM module (such as SIM800L) is used along with a SIM card to send data over the mobile network. In the smartphone-based system, internet connectivity (Wi-Fi or mobile data) is used for data transmission.
4) Cloud Layer: The cloud platform (such as Firebase or Node.js server) stores and manages the received location data. It ensures real-time synchronization and allows multiple users to access updated information simultaneously.
5) Application Layer: This layer consists of a web-based application that provides an interface for users. The application displays live bus locations on a map using mapping services such as Google Maps API. It also provides features such as estimated arrival time (ETA), route tracking, and notifications for delays or route changes.

C. Working Principle

The system works by continuously collecting GPS coordinates from the bus and sending them to the cloud platform at regular intervals. The cloud server processes and stores this data, making it available to the web application. Users can access the web interface to view real-time bus locations and related information. In case of delays or route deviations, the system can generate alerts to notify users. The hybrid approach ensures that even if hardware is unavailable or fails, the smartphone-based system can continue providing tracking functionality.

D. Advantages of the Proposed System

The proposed system offers several advantages:
• Real-time tracking of buses with high accuracy
• Reduced waiting time for students and staff
• Improved safety and transparency
• Flexibility through hybrid implementation
• Cost-effective deployment using existing devices
• Scalable architecture for multiple buses and users
Thus, the proposed hybrid IoT-based system provides a reliable and efficient solution for college bus tracking and management.

IV. IMPLEMENTATION AND SYSTEM DESIGN

The implementation of the proposed hybrid IoT-based college bus tracking system involves the integration of hardware components, software modules, and cloud-based services. The system is designed to ensure accurate real-time data collection, efficient communication, and user-friendly visualization.

A. Hardware Components

The hardware-based system consists of the following main components:
1) ESP32 Microcontroller: The ESP32 serves as the central processing unit of the system. It is responsible for reading data from the GPS module, processing it, and transmitting it to the cloud server. The ESP32 is chosen due to its low cost, built-in Wi-Fi capabilities, and high processing efficiency.
2) GPS Module (NEO-6M): The GPS module is used to obtain real-time geographical coordinates (latitude and longitude) of the bus. It communicates with the ESP32 using serial communication and provides continuous location updates.
3) GSM Module (SIM800L): The GSM module enables communication between the ESP32 and the cloud server using a SIM card. It transmits location data over the mobile network, ensuring connectivity even in areas without Wi-Fi access.
4) Power Supply: A stable power source is required to operate the ESP32 and other components. This can be provided using a battery or a regulated power supply connected to the vehicle.

B. Software Components

The software-based system includes the following elements:
1) Cloud Platform (Firebase / Node.js): The cloud server is responsible for storing and managing real-time location data. It ensures synchronization between multiple devices and allows users to access updated information instantly.

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2) Web Application: A web-based application is developed to display bus locations and related information. It provides a graphical interface where users can view live tracking on a map, check estimated arrival times, and receive notifications.
3) Google Maps API: The Google Maps API is integrated into the web application to visualize real-time bus positions and routes. It enhances user experience by providing accurate mapping and navigation features.

C. System Workflow

The overall working process of the system is described as follows:
1) The GPS module continuously captures the location coordinates of the bus.
2) The ESP32 reads and processes the GPS data.
3) The GSM module transmits the processed data to the cloud server using mobile network connectivity.
4) In the smartphone-based approach, the mobile application directly sends location data to the cloud.
5) The cloud platform stores and updates the data in real time.
6) The web application retrieves the data from the cloud and displays the live location of buses on a map.

D. Component Summary Table

TABLE I

Component	Function	Description
1. ESP32	Processing Unit	Controls system and handles data transmission
2. GPS Module	Location Tracking	Provides real-time coordinates of the bus
3. GSM Module	Communication	Sends data to cloud via mobile network
4. Cloud Platform	Data Storage	Stores and manages real-time data
5. Web Application	User Interface	Displays tracking information to users

E. Implementation Advantages

The implementation provides:
• Continuous real-time tracking of buses
• Reliable communication through GSM and internet
• Easy access through web-based interface
• Flexibility with hybrid hardware and software approach
• Scalable system design for multiple vehicles
Thus, the implemented system ensures efficient tracking, improved communication, and better management of college transportation.

V. RESULTS AND DISCUSSION

The proposed hybrid IoT-based college bus tracking system was evaluated based on its real-time tracking capability, communication efficiency, and overall usability. The system was tested under normal operating conditions using both hardware-based and smartphone-based approaches. The system was tested on a moving vehicle within college routes.

A. Performance Analysis

The system demonstrated reliable real-time tracking of bus locations. The GPS module provided location data with an average accuracy of approximately 5–10 meters under open-sky conditions. The data transmission from the ESP32 through the GSM module showed consistent performance, with an average update delay of 2–5 seconds depending on network availability.
In the smartphone-based approach, location updates were slightly faster due to direct internet connectivity, providing near real-time synchronization with minimal latency. The hybrid system ensured that tracking functionality remained operational even if one method experienced temporary issues.

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B. System Reliability

The system maintained stable performance during continuous operation. The cloud platform successfully handled real-time data updates and allowed multiple users to access the system simultaneously without significant delay. The overall reliability of the system was observed to be approximately 90–95% under normal network conditions.

However, minor delays were observed in areas with weak mobile network signals, which affected the frequency of location updates. Despite this limitation, the system was able to recover automatically once network connectivity was restored.

C. User Interface and Usability

The web-based application provided a user-friendly interface for tracking bus locations. The integration of Google Maps allowed accurate visualization of routes and positions. Users were able to easily monitor live bus movement, view estimated arrival times (ETA), and receive notifications for delays or route changes.

The system improved convenience for students and administrators by reducing uncertainty and providing transparent information about bus movement.

D. Discussion

The results indicate that the proposed system is effective in providing a practical and scalable solution for college bus tracking. The hybrid approach enhances system flexibility by combining hardware-based and smartphone-based tracking methods.

While the system performs well under normal conditions, its performance depends on network availability and GPS signal strength. Future improvements can focus on enhancing network reliability, optimizing data transmission intervals, and integrating additional features such as predictive arrival time estimation and route optimization.

Overall, the system achieves its objective of delivering real-time tracking, improving operational efficiency, and enhancing safety in college transportation systems.

VI. CONCLUSION AND FUTURE WORK

A. Conclusion

This paper presented a hybrid IoT-based college bus tracking system designed to provide real-time monitoring of bus locations using both hardware-based and smartphone-based approaches. The system integrates ESP32 microcontroller, GPS module, GSM communication, cloud services, and a web-based application to deliver an efficient and user-friendly tracking solution.

The proposed system successfully addresses the limitations of traditional bus tracking methods by providing continuous location updates, estimated arrival times (ETA), and notification features. The hybrid approach enhances flexibility and ensures system reliability even in cases where one method is unavailable. The implementation demonstrates that the system is cost-effective, scalable, and suitable for deployment in educational institutions.

Overall, the system improves transportation management, reduces waiting time, and enhances safety and convenience for students and staff.

B. Future Work

Although the proposed system performs effectively, there are several areas for further improvement and enhancement. Future work may include:

1) Integration of machine learning algorithms for more accurate prediction of arrival times (ETA) based on traffic conditions
2) Development of a dedicated mobile application for improved accessibility and user interaction
3) Implementation of route optimization techniques to improve operational efficiency
4) Enhancement of data security and privacy mechanisms to protect user information
5) Integration with college management systems for automated attendance tracking and reporting
6) Use of advanced communication technologies such as 4G/5G for faster and more reliable data transmission

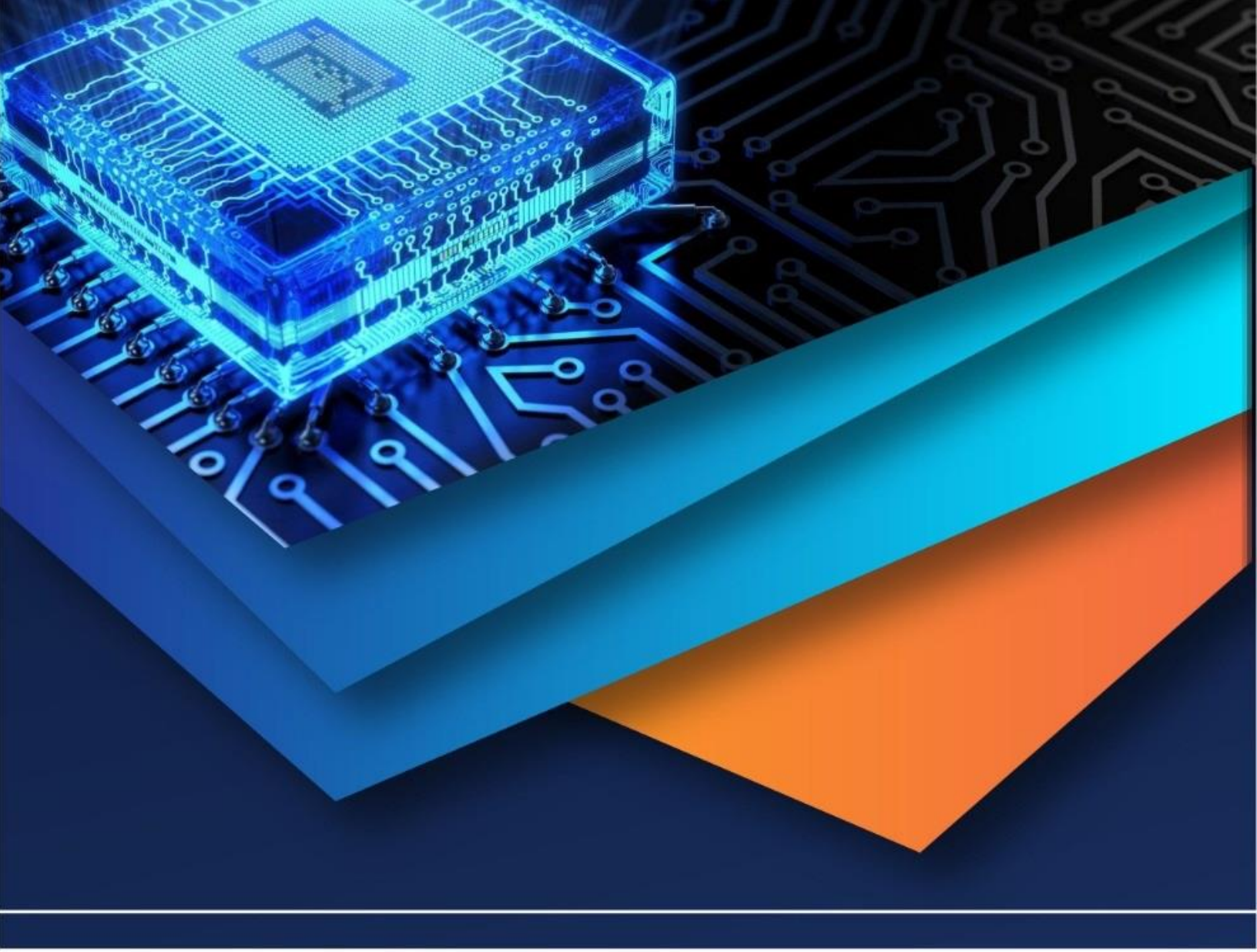
These improvements can further enhance the performance, usability, and scalability of the system, making it more suitable for large-scale smart transportation applications.

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