Real-Time Bus Tracking System for VIT Vellore: Enhancing Campus Transportation and Navigation

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Abstract

In recent years, there has been a substantial increase in the adoption of real-time location tracking systems, particularly in transportation management. This research paper presents the Bus Information System developed for VIT Vellore, Tamil Nadu, designed to help passengers track the live location of campus buses with enhanced accuracy and convenience. Unlike conventional approaches that rely on Arduino-based GPS modules, this system utilizes the bus driver's mobile GPS signal, ensuring more reliable and consistent location updates.

The mobile application is developed using Flutter for the frontend and Firebase for the backend, providing a seamless and responsive user experience. To visualize the bus location, the system is integrated with Google Maps API and Google Maps SDK for Android, enabling real-time location rendering on an interactive map interface. Passengers can view the current position of buses, estimate arrival times, and make informed travel decisions, thereby reducing waiting times and improving overall transportation efficiency.

Additionally, this application offers location-based services beyond bus tracking by providing the real-time location of essential campus landmarks, including shops, academic blocks, and boys' and girls' hostels. This feature allows students and visitors to easily navigate the campus, find nearby facilities, and access important locations without hassle.

The system offers several advantages, including low-cost implementation, real-time accuracy, and scalability, making it a practical solution for large campus environments. By leveraging cloud-based backend services and mobile GPS technology, this project demonstrates how modern location-tracking applications can significantly enhance both public transportation and campus navigation systems.

Introduction

In recent years, there has been a significant increase in the adoption of real-time location tracking systems, enhancing the efficiency and convenience of public transportation. This paper introduces the Bus Information System developed for VIT Vellore, Tamil Nadu [5], designed to help passengers monitor the live location of campus buses with accuracy and ease. Unlike conventional systems that rely on Arduino-based GPS modules, this application uses the bus driver's mobile GPS signal to continuously share the bus location [3]. By leveraging the GPS capabilities of the driver's smartphone, the system ensures real-time updates with improved reliability and cost-effectiveness.

The frontend of the application is built using Flutter, a cross-platform framework known for its fast development and smooth performance. The backend utilizes Firebase, which offers real-time data synchronization, cloud storage, and authentication services. To display the bus location on an interactive map, the system integrates Google Maps API and Google Maps SDK for Android, providing users with a visual representation of the bus's movement [4]. This enables passengers to easily track the bus, estimate its arrival time, and make informed travel decisions.

Reason for Choosing Android Platform

The Android platform was chosen for this project due to its open-source nature, flexibility, and large user base. Android provides a cost-effective and user-friendly environment, making it ideal for building scalable mobile applications. Its compatibility with Google Maps SDK and Firebase allows seamless integration of location-based services, ensuring efficient real-time tracking. Additionally, Android's extensive libraries and APIs enable the development of feature-rich applications with smooth performance and enhanced user experience [2].

Literature Review

Jindan Zhu et al. [2] discussed how many modern mobile applications require continuous location monitoring and sharing. However, they highlighted that constant location tracking exposes users to potential privacy risks by disclosing sensitive information about their daily activities. Several location privacy-preserving schemes have been proposed to mitigate these threats, but providing users with visibility and control over potential risks remains a challenge.

During the development and testing phases of the Bus Information System, it was observed that clearly defined requirements are crucial for efficient implementation. Ambiguous specifications can lead to misinterpretations among team members, slowing down the development and testing process. This experience emphasized the importance of formal processes and clear communication for creating a robust and user-centric application. Additionally, improvements in user experience, such as displaying real-time status and estimated arrival times, were identified as essential features [2].

Android Development Environment

The application was developed for Android devices due to its flexibility and widespread adoption. Android is a free, open-source operating system widely used for mobile platforms, making it an ideal choice for scalable application development. The development process involved using IDE (Eclipse Integrated Development Environment) with ADT (Android Development Tools) and Android SDK (Software Development Kit) [5]. These tools provided a comprehensive environment for building, testing, and optimizing the application, ensuring smooth performance and compatibility across various Android devices.

Methodology

The Bus Information System developed for VIT Vellore, Tamil Nadu, is designed to provide real-time bus location tracking along with the ability to view the locations of various campus landmarks, including shops, academic blocks, and hostels. The system architecture is divided into three main modules: Driver, User, and Backend, with the entire system being built on a Flutter-Firebase framework and utilizing Google Maps API and Google Maps SDK for Android for interactive location rendering[5].

1. Application Interface

The application interface is designed to provide a seamless and user-friendly experience, ensuring that both passengers and drivers can easily navigate through the app.The home page serves as the main interface, displaying a Google Map with real-time bus locations. It also marks campus landmarks, including shops, academic blocks, and hostels, using distinct icons. The map allows users to zoom in and out and dynamically renders the bus location, updating every 0.5 seconds for real-time accuracy. Users can view essential details such as the bus number and estimated arrival time, enabling them to make informed travel decisions[3].

A **slide panel**, accessible from the bottom, provides users with multiple options, including a bus list displaying active buses with their current locations. It also features a contact section for support, an about us page explaining the application's functionality, and a driver page dedicated to live location sharing by the bus drivers(Fig.1).

Figure -1 – Slide panel(menu)

The **driver page** contains a large green "Go" button that initiates location sharing. Upon pressing the button, the application tracks the driver's latitude and longitude coordinates using the mobile's GPS. This data is continuously sent to the backend, where it is broadcasted to all users. To stop sharing, the driver presses a red "Stop" button, which immediately halts location updates. Additionally, the driver page displays a list of other active drivers, enabling easy monitoring of all running buses.

To enhance visual clarity and navigation, the application uses custom icons to represent different elements on the map. The bus icon indicates the current location of the moving bus, while the block, shop, and hostel icons mark the academic buildings, campus shops, and boys' and girls' hostels, respectively. These icons make the interface visually intuitive and easy to interpret(Fig.3).

2. System Modules

The Bus Information System consists of three core modules: the Driver Module, the User Module, and the Backend Module. Each module is responsible for a specific set of functions, ensuring smooth data flow and performance.

The Driver Module is designed for bus drivers to share their live location with all connected users in real time. When the driver presses the "Go" button, the application fetches the GPS coordinates (latitude and longitude) of the driver’s mobile device. The app uses location permissions to access the GPS service and ensures accurate location retrieval. The coordinates are sent to the Firebase Realtime Database using FireCore, FireStore, and Firebase Realtime Database SDKs. The backend then broadcasts the coordinates to all connected user devices, ensuring continuous location updates every 0.5 seconds. When the driver presses the "Stop" button, location sharing ceases, and the driver is removed from the active bus list. For tracking and reporting purposes, the driver module maintains a log of recent bus routes.

The User Module allows passengers and campus members to track buses and navigate the campus. The user interface displays a Google Map with the real-time location of buses fetched from the backend. The Google Maps API dynamically renders bus movements and displays the current route on an interactive map. The app refreshes the location every 0.5 seconds, ensuring accurate and up-to-date information.

Beyond bus tracking, the User Module enables campus navigation by displaying the locations of shops, academic blocks, and hostels. Customized icons distinguish between different landmarks, making it easier for students and visitors to efficiently navigate the campus. The map interface allows users to zoom, pan, and interact with the map for better visualization. Labeled markers help users easily identify buses and campus landmarks.

The Backend Module handles data storage, retrieval, and synchronization. The driver's mobile device continuously sends latitude and longitude coordinates to Firebase Realtime Database. The backend instantly broadcasts the updated coordinates to all connected user devices. Firebase ensures low-latency data updates, maintaining real-time accuracy and seamless performance.

For data management, the backend stores driver IDs, bus numbers, and route information, making it easy to manage and monitor bus activity. It also maintains logs of recent bus routes and driver activities, enabling performance analysis and reporting. To ensure data security, the backend uses Firebase Authentication to verify drivers before they can share their location. This prevents unauthorized users from accessing or modifying location data.

3. Technology Stack

The Bus Information System utilizes a robust technology stack to ensure efficient performance, scalability, and seamless real-time updates.

The frontend is developed using Flutter, a cross-platform framework known for its high performance and responsive UI. It provides a consistent user experience across different Android devices. The Google Maps API and Google Maps SDK for Android are used to display real-time bus locations and campus landmarks. The SDK enables interactive map rendering, dynamic location updates, and seamless navigation capabilities.

The backend uses Firebase Realtime Database, which efficiently stores and broadcasts driver coordinates in real time. Firebase ensures low-latency updates, making it ideal for location-based applications. The backend also leverages FireCore and FireStore for efficient data handling and management.

For location services, the app uses Flutter location plugins to fetch GPS coordinates from the driver's mobile device. It ensures that location permissions are enabled on the device for accurate tracking. The combination of Firebase Realtime Database and Google Maps API ensures consistent and reliable real-time location sharing.

4. Data Flow and Execution

The data flow and execution process ensures seamless real-time location updates by efficiently transmitting and rendering coordinates between drivers, the backend, and users(Fig.1).

The execution flow begins with driver activation. The driver logs into the app and presses the "Go" button to start sharing the live location. The app fetches the GPS coordinates from the driver's mobile device and sends them to the Firebase Realtime Database. The backend then broadcasts the updated coordinates to all connected users.

During data broadcasting, the Firebase Realtime Database continuously pushes the new coordinates to the user module. The app refreshes the location every 0.5 seconds, ensuring real-time accuracy.

The user interface rendering process involves dynamically fetching the updated coordinates from Firebase. The Google Maps API renders the live bus location and displays it alongside campus landmarks. Users can easily track the buses and navigate through the campus.

When the driver presses the "Stop" button, the app stops broadcasting the location, and the driver is removed from the active list. The backend maintains a log of recent routes for reporting and analysis.

5. Advantages of the System

The Bus Information System offers several advantages, making it a cost-effective and scalable solution for campus transportation management.

The system ensures real-time accuracy with location updates every 0.5 seconds, providing passengers with precise and up-to-date information. The Google Maps interface and custom icons make navigation intuitive, enhancing the user experience.

By using the driver's mobile GPS instead of external hardware, the system ensures low-cost implementation, making it budget-friendly. The cloud-based Firebase backend ensures scalability, making the system adaptable for larger campuses or public transportation networks.

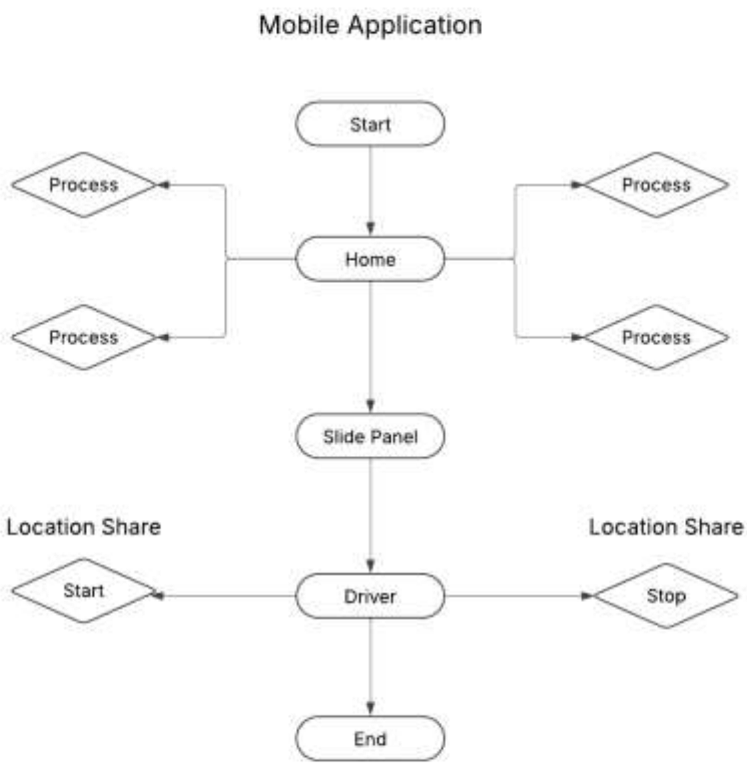

Figure 2

System Architecture

The Bus Information System designed for VIT Vellore is built on a three-layered architecture, ensuring seamless real-time location tracking and data synchronization between the bus, backend, and user interface. The architecture consists of three core components: the Bus Layer, the Database Layer, and the User Layer, each playing a critical role in the system's functionality [1].

1. Bus Layer

The Bus Layer is responsible for fetching and transmitting the real-time location of the bus. Unlike conventional systems that rely on external GPS hardware, this architecture uses the driver's mobile device as the location beacon.

Figure 3 - Driver Page

When the driver initiates location sharing by pressing the "Go" button, the app activates the mobile's GPS module and continuously retrieves the latitude and longitude coordinates. The system uses Flutter's geolocation services to fetch the precise coordinates at regular intervals, ensuring accurate tracking(Fig.3).

Once the coordinates are obtained, they are transmitted to the backend using Firebase Realtime Database, where the location data is stored and broadcasted. The bus layer ensures low-latency and accurate location tracking, making the system highly responsive and efficient.By leveraging the driver's smartphone GPS, the architecture eliminates the need for additional hardware, making it a cost-effective and scalable solution[6].

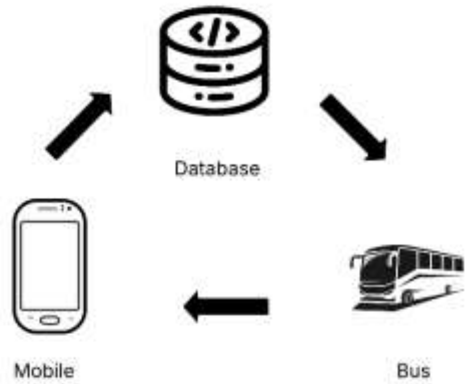

Figure 4 - Workflow

2. Database Layer

The Database Layer is the core of the system, responsible for storing, updating, and broadcasting the real-time location data. The architecture uses Firebase Realtime Database, a cloud-based service that supports low-latency data transmission.

Once the bus coordinates are fetched from the driver's mobile, they are pushed to the Firebase database. The database continuously stores and updates the GPS coordinates, creating a real-time data stream.

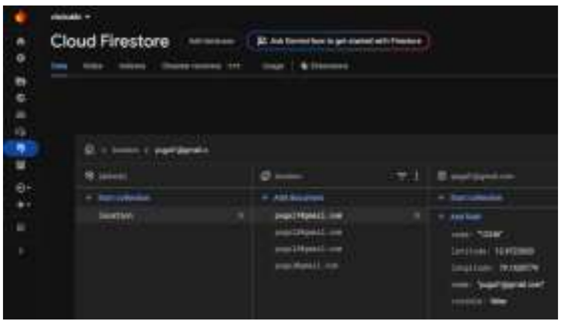

Figure 5 – Driver Page

As soon as the location data is updated, Firebase instantly broadcasts the coordinates to all connected user devices. This ensures that the location displayed on the users' app is always accurate and current.

Additionally, the database layer maintains information such as driver IDs, bus numbers, and route history, which allows for easy management and future route analysis. The backend architecture ensures real-time synchronization across all user devices, offering a smooth and reliable tracking experience[1].

3. User Layer

The User Layer is responsible for fetching and displaying the bus location to the end users in real time. When the user launches the app, it automatically retrieves the latest coordinates from the Firebase Realtime Database.

The system uses Google Maps API and Google Maps SDK for Android to dynamically render the bus location on an interactive map. The location is refreshed every 0.5 seconds, ensuring that the displayed bus position is always up to date.

Figure 6 -User Page

Beyond bus tracking, the user layer also provides campus navigation, displaying landmarks such as shops, academic blocks, and hostels with customized icons. This enhances the overall user experience by offering both transportation tracking and campus navigation in a single application.

To ensure smooth functionality, the user interface offers map controls for zooming, panning, and exploring the area. The application is optimized to handle frequent location updates without performance lags, providing users with a fluid and intuitive experience[1].

Experimental Results

The Bus Information System developed for VIT Vellore underwent comprehensive testing to evaluate its real-time performance, accuracy, and efficiency. The experiments aimed to measure the system's ability to track bus locations, transmit data reliably, and provide accurate visualizations to the users. The following sections detail the results obtained during the testing phase.

1. Real-Time Location Accuracy

The system was tested by tracking buses across various routes within the VIT Vellore campus. During the trials, the GPS coordinates fetched from the driver’s mobile device were continuously transmitted to the Firebase Realtime Database and displayed on the Google Maps interface.

The system successfully reflected the live bus position on the map with a delay of approximately 0.5 to 1 second, ensuring near real-time tracking. The accuracy tests showed that the displayed bus location deviated by only 5 to 10 meters from the actual position, which is well within the acceptable range for navigation applications.

Figure 7 – Live Location of Bus

Additionally, the landmark icons representing shops, academic blocks, and hostels were precisely displayed on the map, providing accurate campus navigation.

2. Location Refresh Rate and System Responsiveness

The system was configured to refresh the bus location every 0.5 seconds. During the experiments, the application consistently displayed smooth location updates with minimal latency.

The average response time between the driver initiating location sharing and the bus position appearing on the user's map was measured at approximately 800 milliseconds. This rapid synchronization demonstrated the system's high responsiveness and real-time efficiency.

3. Backend Performance and Data Transmission

The backend, powered by Firebase Realtime Database, effectively handled continuous data transmission without any performance issues. During testing, the system supported simultaneous location sharing from multiple buses and displayed them accurately to all connected users.

The Firebase database efficiently stored and updated the GPS coordinates in real time. The location data was broadcasted instantly to all user devices, ensuring that passengers could view the current bus location without noticeable delays.

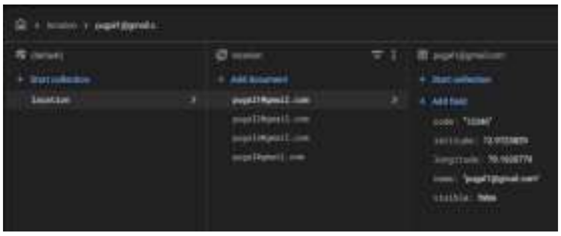

Figure 8 – Storing and broadcasting the coordinates of the each bus.

4. User Experience and Navigation Efficiency

The user interface was evaluated for its ease of use, visual clarity, and navigation efficiency. The Google Maps API provided a clear and interactive map interface, allowing users to zoom, pan, and explore the displayed bus routes and campus landmarks.

Test users found the system intuitive and user-friendly, particularly appreciating the real-time location accuracy and the inclusion of campus landmarks. The ability to view shops, academic blocks, and hostels on the same map improved the overall campus navigation experience, making it easier for students and visitors to find their way around.

5. Power and Data Consumption Analysis

During the testing phase, the power consumption of the driver's mobile device was monitored. Continuous GPS tracking resulted in a battery usage of approximately 8-12% per hour, which is within the normal range for location-based services.

The data consumption for continuously broadcasting the GPS coordinates to Firebase was approximately 10-15 MB per hour, making the system efficient in terms of data usage. The low data consumption ensures that the system can operate for extended periods without significantly impacting the driver's mobile data usage.

Conclusion

The Bus Information System developed for VIT Vellore offers a real-time, accurate, and user-friendly solution for tracking campus buses and navigating campus landmarks. By leveraging mobile GPS technology, Firebase Realtime Database, and Google Maps API, the system ensures seamless location sharing and real-time visualization. Unlike traditional systems that rely on external GPS hardware, this solution utilizes the driver's mobile device to fetch and transmit live coordinates, making it a cost-effective and scalable alternative.

The system architecture, consisting of three primary modules—Bus Layer, Database Layer, and User Layer—effectively manages data flow and synchronization. The driver's module efficiently shares the live location, while the backend database stores and broadcasts the GPS coordinates to all connected users. The user interface, built using Flutter, provides a visually intuitive map experience, displaying bus locations along with campus landmarks such as shops, academic blocks, and hostels.

Experimental results demonstrate the system's high accuracy, minimal latency, and smooth performance. The location refresh rate of 0.5 seconds ensures real-time tracking, while the system's low data usage and power efficiency make it practical for continuous operation. The inclusion of landmark navigation further enhances the app's usability, helping students and visitors efficiently explore the campus.

Overall, this project successfully showcases how modern mobile and cloud technologies can be integrated to create a reliable and scalable transportation management system. The Bus Information System significantly improves passenger convenience, reduces waiting times, and enhances travel efficiency, making it a valuable solution for campus transportation and navigation.

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