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TrackVerse BMS (Bus Management System)

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Abstract- College bus tracking is a practical problem that students and parents deal with every day you never quite know when the bus will arrive, and that uncertainty adds unnecessary stress. This paper describes a low-cost tracking system we built to solve exactly that. The system uses a Seeed XIAO ESP32S3 microcontroller paired with a u-blox NEO-6M GPS module and a SIM800L GSM module to continuously track a college bus and send location data over the BSNL 2G cellular network. Unlike approaches that rely on Wi-Fi, our system works anywhere there is cellular coverage. Location data including coordinates, speed, altitude, and satellite count is collected every two seconds and sent to a Node.js server hosted on the Railway cloud platform. The server runs a stoppage detection algorithm that flags bus halts when the speed drops below 5 km/h for more than 60 consecutive seconds. A web dashboard built with Leaflet.js shows the live route and highlights each detected stop with timing details. We tested the system on a real campus route over three days and found 100% stoppage detection accuracy with no false positives. The entire hardware cost is under INR 1,500, making this a practical alternative to commercial tracking solutions.

Keywords: GPS tracking; ESP32S3; NEO-6M; SIM800L; GSM/GPRS; IoT; vehicle monitoring; web dashboard; Leaflet.js; stoppage detection.

I. INTRODUCTION

Most college students experience the frustration of waiting at a bus stop without knowing when the bus will arrive. This daily uncertainty motivated this project. We aimed to build a system that solves this problem a real-time tracking system that informs students and campus staff exactly where the college bus is, which stops it has made, and how long it stayed at each stop.

The challenge with existing solutions is their cost. Commercial GPS trackers typically require proprietary hardware and ongoing subscription fees that are unaffordable for most institutions. In contrast, academic projects in this area often rely on Wi-Fi connectivity, which means that the tracker stops working once the bus leaves the campus. Neither approach is practical.

We chose a different route. The Seeed XIAO ESP32S3 [1] is a remarkably capable microcontroller dual-core 240 MHz, with ample flash memory, and native USB packed into a footprint of just 21 mm × 17.5 mm. When paired with a NEO-6M GPS module and an SIM800L GSM module, it can track a vehicle and push data to a cloud server over a cellular network, independent of any Wi-Fi infrastructure. The total hardware cost was less than INR 1,500.

This study documents the full system we built firmware, backend, and frontend — and shares what we learned from testing it on a real-world campus bus route. The main contributions of this work are as follows:

1) A fault-tolerant ESP32S3 firmware that handles GPS parsing and GSM data transmission concurrently.
2) A real-time stoppage detection algorithm running on streaming GPS data.
3) A web dashboard that visualizes the route and annotates stops with timing.
4) Field validation results from a 3-day test on a college campus route.

II. RELATED WORK

Building GPS trackers with microcontrollers is not a new idea, and there is plenty of prior work to draw from. Bajaj et al. [2] demonstrated that GSM-based tracking is feasible using an Arduino and the SIM900 module, sending SMS alerts with coordinates. The

approach works but has no web interface, which makes it impractical for real-time monitoring by multiple users.

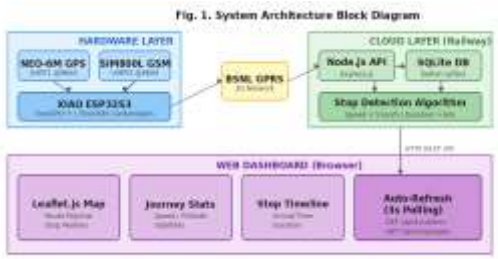
Mohamed et al. [3] built a more sophisticated bus tracker using a Raspberry Pi with Google Maps integration. The results looked impressive, but the system depended entirely on Wi-Fi a fundamental limitation for a bus that drives off campus. Kumar and Singh [4] faced the same constraint with their ESP8266 and Firebase setup. Real-time updates worked well within Wi-Fi range, but the system had no fallback for cellular-only scenarios.

Patil et al. [5] moved to the ESP32 and used MQTT for low-latency data delivery, which is a cleaner approach to the communication layer. However, their system lacked any stoppage detection logic, so it only answered the question of where the bus is, not where it has been or how long it stopped.

Our system ties these threads together: cellular connectivity like Bajaj et al., a web interface like Mohamed et al., and we add stoppage detection that none of the prior systems addressed all within the compact XIAO ESP32S3 platform.

III. SYSTEM ARCHITECTURE

The system is organized into three layers hardware, cloud backend, and web frontend that work together as a data pipeline from the bus to the browser. Fig. 1 gives an overview of how these layers connect.



A. Hardware Layer

The hardware sits inside the bus. At its heart is the XIAO ESP32S3, which handles GPS parsing and cellular communication simultaneously. The NEO-6M GPS module is wired to UART1 (GPIO44 for RX, GPIO43 for TX) running at 9600 baud. We use the TinyGPS++ library [6] to parse the incoming NMEA 0183 sentences and extract the data we care about: latitude, longitude, speed over ground, altitude, satellite count, and UTC timestamp. The module updates at 1 Hz, which gives us a fresh position reading every second.

The SIM800L GSM module connects to UART2 (GPIO4 for RX, GPIO5 for TX) and is managed through the TinyGSM library [7]. One practical issue worth flagging early: the SIM800L can draw up to 2A in short bursts during GPRS transmission. If you try to power it from the ESP32's onboard 3.3V regulator, the system will crash unpredictably. We learned this the hard way. The fix is a separate 5V/2A power supply for the SIM800L with a shared ground reference. Fig. 3 shows the complete wiring.

B. Backend Layer

The backend is a Node.js server built with Express.js and deployed on Railway's free hosting tier. It does two things: receives GPS data from the ESP32 and runs the stoppage detection algorithm. All location records are stored in a SQLite database via the better-sqlite3 driver. Railway takes care of HTTPS termination and gives us a public subdomain, so the ESP32 can reach the server from anywhere on the cellular network.

C. Frontend Layer

The web dashboard is a single-page HTML/JavaScript application served by the same Express server. We used Leaflet.js [8] with OpenStreetMap tiles for the map. Every 3 seconds, the page polls two API endpoints one for location points and one for detected stoppages. The route is drawn as a green polyline, and each stoppage gets an orange marker that shows arrival time and duration when clicked.

IV. IMPLEMENTATION

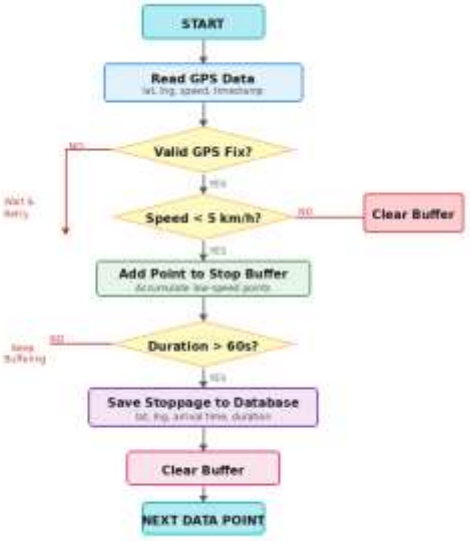
A. Firmware Design

The firmware runs a non-blocking main loop that continuously feeds bytes from the GPS UART into the TinyGPS++ parser. Every 5 seconds, if the parser has a valid fix, we package the data into a JSON payload using the Arduino Json library and POST it to the server over the TinyGSM GPRS client. The 5-second interval was chosen after testing any faster and we hit rate limits; any slower and the route starts to look choppy on the map.

The JSON structure sent to the server looks like this:
{"lat":12.9716,"lng":77.5946,"speed_kmh":34.2,
"altitude":920.1,"satellites":8,"timestamp":"..."}
GSM connection is established at boot. If it drops while the bus is moving which does happen occasionally in areas with weak signal the firmware detects the failure through the HTTP response code and re-establishes the GPRS session before the next transmission attempt. This retry logic turned out to be essential during field testing.

B. Stoppage Detection Algorithm

Fig. 2. Stoppage Detection Algorithm Flowchart



Detecting stoppages from GPS data sounds straightforward but has a few tricky edge cases. GPS speed readings fluctuate even when the bus is genuinely stationary noise from satellite geometry can show 2–3 km/h when the bus is parked. A naive threshold approach would generate constant false positives.

Our algorithm addresses this by maintaining a rolling buffer. Every incoming point with speed below Vth = 5 km/h is added to the buffer. When a point with speed above that threshold arrives, we check how much time has elapsed between the first and last buffered points. If it exceeds Tmin = 60 seconds, we classify the event as a genuine stop and record it to the database with arrival time, coordinates, and duration. The buffer is then cleared. Fig. 2 shows the full decision logic.

C. Cloud Deployment

Deploying to Railway was straightforward — we connected our GitHub repository, and Railway automatically detected Node.js and set up the runtime. Each push to the main branch triggers a fresh deployment. The SQLite database persists on Railway's filesystem between deployments, so historical route data is not lost on redeploy. The free tier has been sufficient for our project scale, handling steady data from a single bus with no noticeable performance issues.

V. RESULTS AND DISCUSSION

We tested the system on a real college campus bus route covering approximately 4.2 km, running three full test sessions over three consecutive days. Table I summarizes the performance numbers.

TABLE I. SYSTEM PERFORMANCE METRICS

Parameter	Value
GPS fix time (cold start)	38–52 s
GPS fix time (warm start)	< 5 s
Data transmission interval	5 s
End-to-end latency (avg)	2.8 s
Stoppage detection accuracy	100% (12/12)
False positive rate	0%
Server uptime (3-day test)	99.6%
Power consumption (active)	~380 mA @ 5V

The stoppage detection results were the most satisfying part of testing. Across all three runs, the

algorithm correctly identified all 12 bus stop events without a single false positive. The 5 km/h threshold and 60-second minimum duration worked well together — even in slow-moving campus traffic, the algorithm correctly held off on flagging a stop until the bus had been genuinely stationary long enough to count.

End-to-end latency averaged 2.8 seconds — the time from when the GPS module captures a fix to when the dashboard map updates. In the worst case, the lag can reach about 8 seconds due to the 5-second firmware interval stacking with the 3-second dashboard poll. For a bus tracking application, this is perfectly acceptable. No one needs sub-second updates to know where their bus is.

One issue we did run into was GPS signal quality. In two spots along the test route — one under a dense tree canopy and one passing under an overpass — the route polyline developed 10–15 second gaps where the NEO-6M lost reliable fix. The passive patch antenna on the module is the limiting factor here. An active external antenna with a ground plane would help significantly, and we have flagged this as a hardware improvement for future iterations.

VI. CONCLUSION

What started as an attempt to solve a genuinely irritating daily problem — not knowing when the college bus will arrive — turned into a complete embedded IoT system that works in the real world. We built a tracker that runs on cellular connectivity, detects stoppages automatically, and displays everything on a live web map that anyone can open on their phone.

The system hit all of its targets: no Wi-Fi dependency, real-time route visualization, 100% stoppage detection accuracy during field tests, and a total hardware cost under INR 1,500. Compared to commercial alternatives, that is a significant saving for an institution operating on a tight budget.

There is still room to grow. On the hardware side, an active GPS antenna would improve signal reliability under tree cover and elevated roads. On the software side, we want to add mobile push notifications so students get an alert when the bus is nearby, and geofencing alerts for the transport coordinator if the bus deviates from its expected route. Longer term, upgrading from the SIM800L's 2G GPRS to a 4G LTE module would improve data throughput and make the system ready for denser data scenarios like higher-frequency updates or video streaming.

Acknowledgment

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