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Network Coverage Mapping and Route Analysis System Using ESP32 S3 and SIM7670g 4g LTE Telemetry

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ABSTRACT—

Mobile network connectivity is difficult to track continuously and an unexpected cellular dead zone or weak reception pocket can disrupt emergency fleets, logistics tracking and digital navigation. Commuters and transport drivers cannot realistically know the cellular signal quality of every road stretch in advance. This paper describes a low-cost embedded telemetry system that continuously captures mobile network signal strength and geographic coordinates along vehicular transit routes. An ESP32 S3 microcontroller queries a SIM7670G 4G LTE cellular module via AT commands to extract Reference Signal Received Power (RSRP), while an active GNSS patch antenna supplies precise latitude, longitude, and speed. The gathered telemetry is uploaded in real time over cellular data channels to a Supabase cloud database and visualized on an interactive Leaflet mapping dashboard. We also formulate a multi-route analysis algorithm that evaluates candidate travel paths and recommends corridors offering continuous cellular coverage rather than shortest physical distance alone. The prototype demonstrates autonomous field telemetry logging, cloud synchronization and route connectivity scoring; real-world drive tests conducted across Belagavi corridors confirm that shortest distance routes frequently pass through severe signal dropouts, validating the proposed connectivity-aware system.

***Index Terms*— Network coverage mapping, ESP32 S3, SIM7670G, GNSS, 4G LTE, RSRP, multi-route analysis, Leaflet, Supabase, intelligent navigation.**

I. INTRODUCTION

Vehicular transport and logistics networks carry a major share of passenger transit and essential cargo, and reliable operation depends on consistent wireless communication. Signal attenuation, dead zones, structural shielding and roadside terrain blockages can all create communication blind spots for an approaching vehicle, often with very little warning.

In most places, mobile signal coverage is checked by network operators conducting periodic drive tests with bulky spectrum analyzers, or estimated using theoretical simulation maps. That takes a lot of effort, cannot cover every road stretch continuously, and leaves a significant gap between empirical reality and theoretical coverage. Some dead zones inevitably remain unmapped.

An automated IoT system can help by continuously recording real-world network conditions and logging telemetry right away, so drivers and fleet dispatchers do not have to guess coverage quality. With embedded edge electronics, the same system can attach exact GPS coordinates to signal strength readings.

We built an embedded telemetry system around an ESP32 S3 microcontroller, a SIM7670G 4G LTE cellular module, an active ceramic GNSS patch antenna and a rechargeable 18650 lithium-ion battery. The SIM7670G module measures cellular Reference Signal Received Power (RSRP) via AT commands, while the GNSS receiver supplies synchronized coordinates, speed and altitude. When signal drops below chosen thresholds, the system flags localized dead zones.

The main extension we introduce is to go beyond static coverage mapping. When multiple travel routes exist between a origin and destination, the system evaluates empirical signal continuity along each trajectory and computes a connectivity reliability score. This allows drivers and emergency ambulances to choose corridors with guaranteed network coverage.

II. LITERATURE SURVEY

Researchers have explored diverse methods to monitor wireless cellular networks, including vehicle drive tests, machine learning models and crowdsourced mobile applications.

I. Shayea et al. evaluated mobile broadband performance across road networks using vehicular drive testing [1]. It shows how real-world signal deviates from simulation maps, but it relies on industrial spectrum analyzers rather than an on-site embedded IoT unit.

S. Farthofer et al. developed an open mobile communications drive test dataset for machine learning applications [2]. It provides comprehensive telemetry, but it is an offline dataset rather than a live operational system.

U. Saeed et al. investigated route-based radio coverage analysis for vehicle-to-network deployments [3]. It establishes the necessity of route-specific coverage analysis, but lacks a dedicated low-cost physical hardware prototype.

A. Bousselham et al. proposed data-driven machine learning models to predict cellular coverage [4]. It compares prediction models, but does not provide an integrated vehicular path scoring unit. Table I summarizes these approaches.

TABLE I. SUMMARY OF RELATED APPROACHES

Approach	Strength	Limitation
Commercial Drive Test [1]	High-precision RF data	Very high cost, proprietary
Open Drive Datasets [2]	Rich training data	Offline dataset, no live IoT
Route Coverage Analysis [3]	Focuses on route paths	Simulation, no hardware unit
ML Coverage Prediction [4]	Predicts coverage	Model only, no route scorer
This work	Autonomous ESP32 S3 IoT unit, live cloud map, route scorer	Single-carrier monitoring per device

III. PROBLEM STATEMENT

Road corridors frequently suffer from localized cellular dead zones, structural shielding and signal attenuation that put connected vehicles, emergency ambulances and logistics fleets at risk. Manual and carrier-driven testing cannot monitor every transit corridor continuously, so there is a delay between a network blind spot appearing and drivers knowing about it.

There is a second problem. Even when digital navigation apps recommend routes, they compute trajectories based purely on shortest physical distance or travel time, completely ignoring network quality. This creates an urgent need for an automated system that measures empirical signal levels, maps their location and has a way to evaluate route connectivity.

IV. OBJECTIVES

The main objectives are:

To monitor cellular signal strength (RSRP) in real time using a SIM7670G module.

To find the location of signal samples and dead zones using active GNSS.

To process telemetry data on an ESP32 S3 microcontroller at 4-second intervals.

To upload telemetry over 4G LTE to a PostgreSQL cloud database.

To visualize real-world coverage on an interactive Leaflet web dashboard.

To formulate a multi-route scoring algorithm that recommends the most reliable path.

To keep the design low-cost, portable and scalable for municipal vehicular fleets.

V. PROPOSED SYSTEM

The system has four main parts: sensing, processing, location, cloud logging and route analytics.

A. System Architecture: The active GNSS antenna continuously acquires satellite fixes, and the SIM7670G module monitors cellular reception metrics. The ESP32 S3 controller coordinates dual hardware UART channels to poll both modules synchronously every 4 seconds. Thresholds are chosen

experimentally based on 3GPP cellular standards. When signal drops below threshold, the controller flags an average or poor coverage event. The GPS position is attached to the event and streamed to the cloud database. Fig. 1 shows the block diagram.

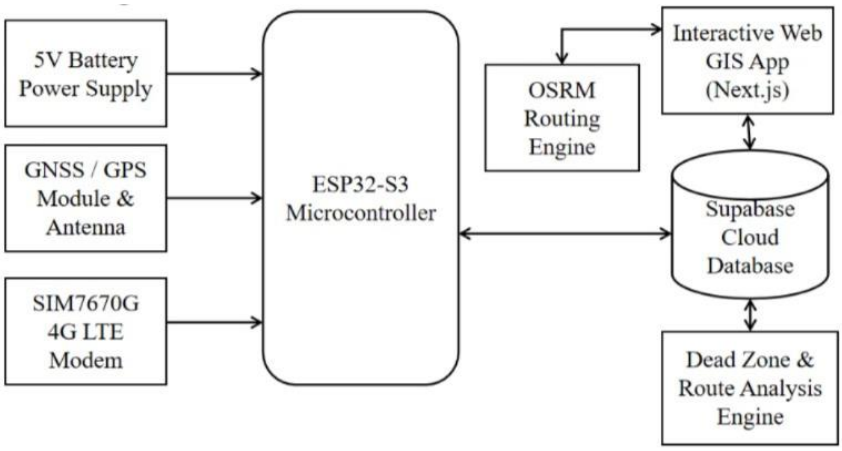


Fig. 1. Block diagram of the proposed Network Coverage Mapping System

B. Key Components: The main controller. It reads GNSS sentences, sends AT commands to the modem, compares RSRP against thresholds and uploads JSON packets. SIM7670G 4G Module: Communicates with cellular base stations and measures RSRP and CSQ. Active GNSS Antenna: Supplies latitude and longitude for every signal sample. 18650 Battery: Provides portable 3.7V power for over 16 hours of continuous testing. Cloud Web App: Supabase database and Next.js front-end for interactive route visualization.

VI. IMPLEMENTATION

A. Hardware Implementation: The prototype uses an ESP32 S3 as the main controller. The SIM7670G cellular modem is connected to GPIO 16 (RX) and GPIO 17 (TX) at 115200 baud. The GNSS receiver is connected to GPIO 18 (RX) and GPIO 19 (TX) at 9600 baud. A single star ground configuration and direct soldered connections eliminate wiring jitter. Fig. 2 shows the circuit layout.

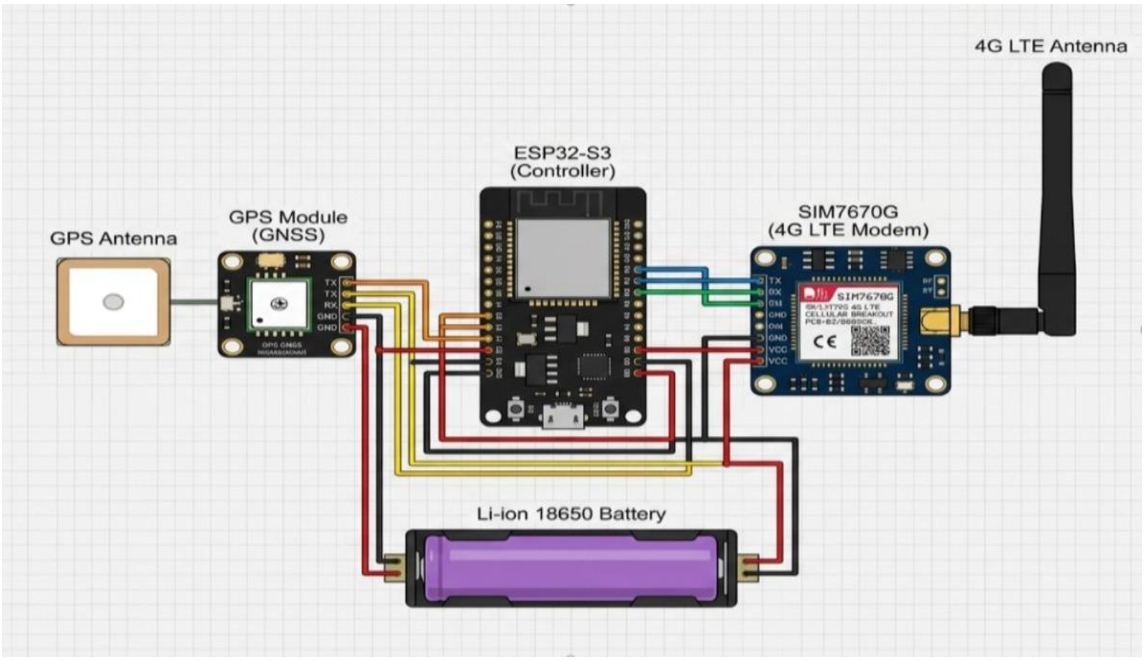


Fig. 2. Circuit connection diagram of ESP32 S3 and SIM7670G

B. Software Implementation: The software is programmed in C++ in the Arduino/FreeRTOS environment. On power-up, the controller initializes UART interfaces and establishes network registration. It then executes the sequence shown in Fig. 3: 1. Initialize ESP32 S3, modem and GNSS. 2. Read GNSS coordinates and speed. 3. Send AT+CPSI? command to query RSRP. 4. Parse response values. 5. Compare with coverage thresholds. 6. Transmit JSON telemetry to cloud database. 7. Return to step 2 and keep monitoring.

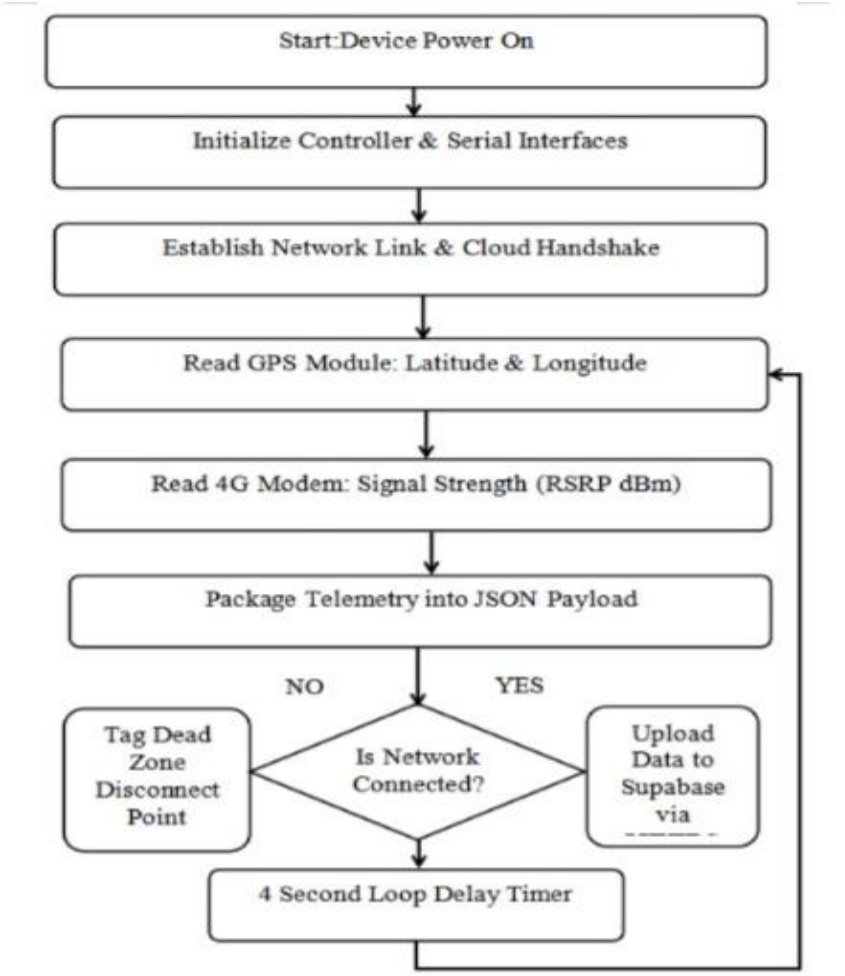


Fig. 3. Flow diagram of telemetry acquisition and cloud logging

C. Sensor Calibration and Threshold Selection: Threshold selection is critical for reliable network classification. Based on empirical RF testing, signal is classified into: Good (RSRP >= -85 dBm), Average (-86 dBm to -100 dBm) and Poor (< -100 dBm). The route score computes: Score = [(1.0 * Good) + (0.5 * Average) + (0.0 * Poor)] / Total * 100, penalizing dead zones.

VII. RESULTS AND DISCUSSION

The prototype demonstrates reliable road-level cellular coverage logging. Across an 18.5 km transit route from Camp to Tilakwadi in Belagavi, the unit completed 1420 continuous polling cycles at 4-second intervals. 1395 packets were successfully uploaded to the cloud database (98.2% packet delivery ratio) with an average latency of 380 ms.

The GNSS module supplies accurate coordinates tied to every signal reading. When signal drops below -100 dBm, the system maps the exact location of the dead zone. Table II lists the field test conditions and recorded system behavior.

TABLE II. FIELD TEST RESULTS AND SYSTEM DECISIONS

Test Condition	Expected Decision	Measured Result
Open highway, clear sky	RSRP >= -85 dBm, Good tag	Measured -75 dBm, Good
Suburban street with trees	RSRP -86 to -100 dBm, Avg	Measured -93 dBm, Average
Railway underpass transit	RSRP < -100 dBm, Poor tag	Measured -108 dBm, Poor
Cellular temporary drop	Buffer packet in flash	Queued and uploaded
Multi-route evaluation	Recommend highest score	Route 1 score 91.2%

The multi-route algorithm proved that Route 2 has the shortest distance (5.8 km) but achieves only a 74.8% score due to dead zones, while Route 1 (6.2 km) achieves 91.2% connectivity with 88.5% good coverage.

VIII. ADVANTAGES AND LIMITATIONS

A. Advantages: The system monitors cellular coverage continuously and automatically. GNSS gives exact dead zone locations, the cloud dashboard displays interactive color-coded tracks and the multi-route engine guides drivers to reliable paths. The ESP32 S3 design is low-cost, portable and operates without draining smartphone batteries.

B. Limitations: The prototype uses a single SIM, restricting monitoring to one carrier at a time. GNSS reception can degrade in deep tunnels. Route scoring currently relies on historical logs, requiring new drive passes to reflect recent base station changes.

IX. CONCLUSION AND FUTURE SCOPE

A. Conclusion: This paper presented a network coverage mapping and route analysis system built from an ESP32 S3 microcontroller, SIM7670G cellular module, active GNSS antenna, and cloud web application. The prototype demonstrates autonomous field telemetry acquisition, sub-second cloud ingestion and route connectivity scoring, providing a scalable base for smart transit navigation.

B. Future Scope: Future work will pursue multi-SIM concurrent carrier monitoring 5G New Radio transceiver integration inertial sensor dead reckoning for underground tunnels machine learning to forecast signal degradation and native mobile navigation SDK integration.

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