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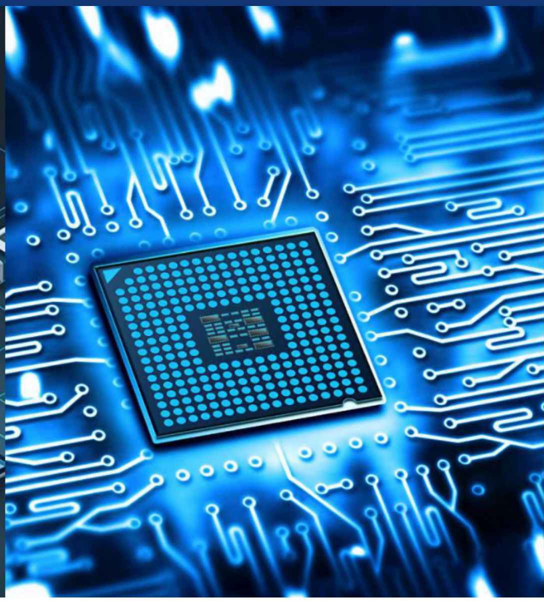

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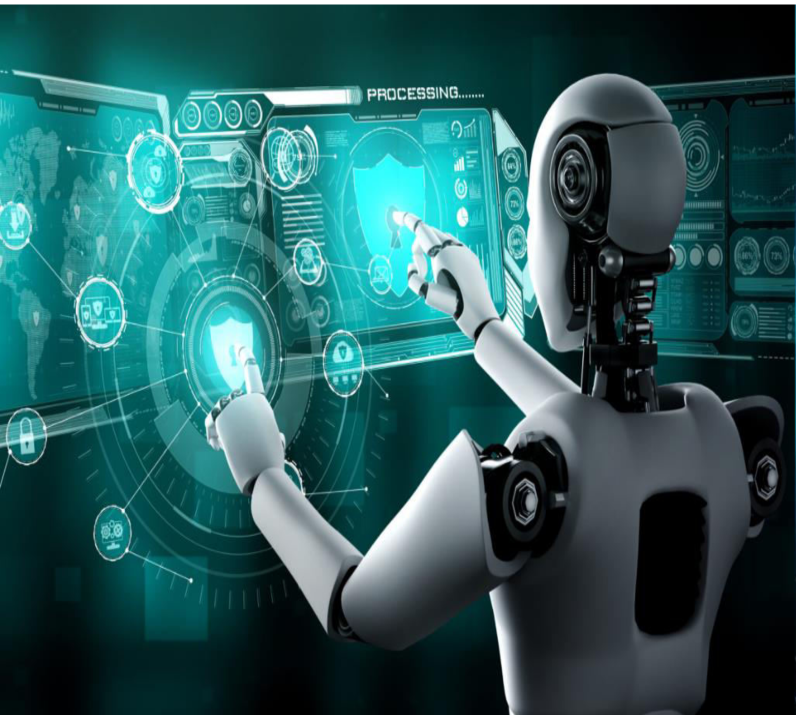

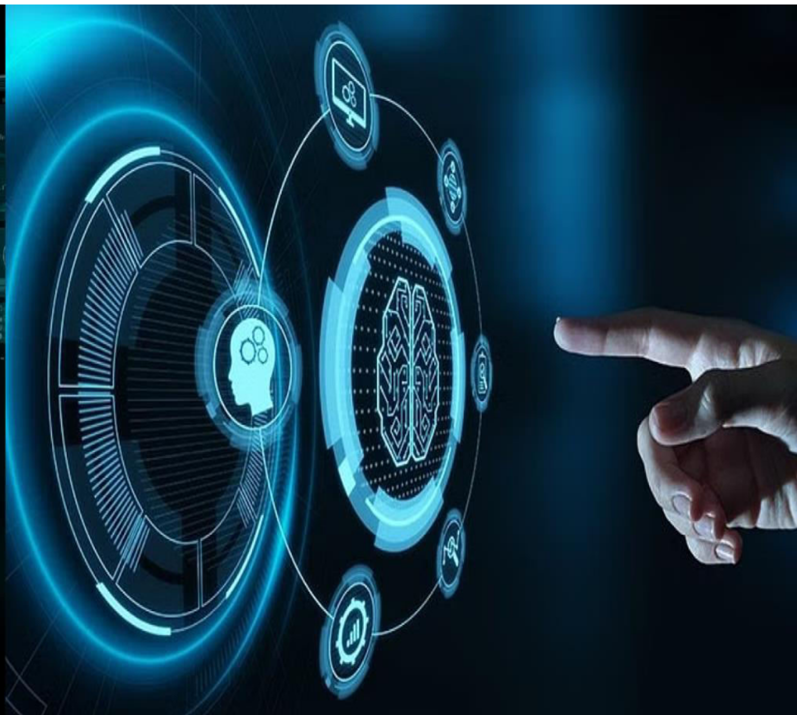

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Advanced Vehicle Communication Network Using Wireless Technology

Aditya Ranpise[1], Anuj Shah[1], Soham Sardeshmukh[1], Prof. (Mrs.) S. G. Madhikar[2]

UG Students, Dept. of Electronics & Telecommunication Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India[1]

Dept. of Electronics & Telecommunication Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India[2]

ABSTRACT: The escalating density of vehicular traffic across both urban corridors and rural thoroughfares has created a critical demand for reliable, low-latency Vehicle-to-Vehicle (V2V) communication. This paper presents the design and experimental validation of a hybrid wireless communication framework for advanced vehicular networking. The proposed architecture employs NRF24L01 radio transceivers for extended-range, low-power operation alongside ESP32-hosted Wi-Fi for high-throughput short-range data exchange. A Neo-6M GPS receiver delivers real-time geographic positioning at ±3–5 m precision, while an SW-420 vibration sensor facilitates autonomous emergency alert dispatch upon collision detection. An intelligent channel-management mechanism dynamically selects the optimal transmission medium by evaluating link range, network congestion, and interference levels, thereby reducing latency and packet loss. A two-node prototype achieves an NRF transmission range surpassing 1.8 km under line-of-sight conditions, GPS positional accuracy of ±4 m, and end-to-end emergency notification delivery within 2.8 seconds of shock onset. A browser-accessible dashboard enables centralised fleet monitoring at 5-second update intervals. The findings confirm that robust V2V communication is achievable using economical embedded hardware, forming a reproducible and scalable testbed for next-generation intelligent transportation systems.

KEYWORDS: Vehicle-to-Vehicle (V2V) Communication; NRF24L01; ESP32; Emergency Alert System; Intelligent Transportation Systems (ITS)

I. INTRODUCTION

The rapid proliferation of motor vehicles on urban streets and rural highways has intensified the demand for robust, low-latency communication between moving vehicles. Conventional cellular networks, despite their widespread availability, are prone to congestion-induced delays, coverage gaps, and non-trivial end-to-end latencies — characteristics that render them unsuitable for safety-critical use cases such as collision avoidance or emergency alert dissemination.

Vehicle-to-Vehicle (V2V) communication presents an alternative paradigm wherein adjacent vehicles exchange information directly, without relying on any fixed infrastructure. This work proposes a dual-channel V2V framework combining kilometre-scale, energy-efficient NRF24L01 radio links with ESP32-hosted Wi-Fi for short-range, high-bandwidth communication. A Neo-6M GPS module supplies continuous location data, while an SW-420 vibration sensor initiates automated emergency transmissions when sudden mechanical shock is detected.

The system addresses three core engineering challenges: (1) reliable hybrid communication that seamlessly switches between NRF24L01 and Wi-Fi channels; (2) real-time safety alerting with latency under 3 seconds end-to-end; and (3) optimised channel selection to dynamically minimise packet loss and delay.

II. LITERATURE SURVEY

A review of existing research reveals several complementary contributions that collectively motivate this work.
Sharma et al. [1] (2018) developed an accident detection platform using Arduino, GPS, and GSM modules to relay SMS-based location alerts to emergency services. Their methodology guided the integration of vibration sensing and GPS for real-time incident detection in the current system.

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Patel and Singh [2] (2019) demonstrated peer-to-peer vehicular warning communication using NRF24L01 modules and Arduino boards, establishing a foundation for NRF-based short-range V2V messaging adopted in this work.

Gupta et al. [3] (2020) built an IoT-based vehicle monitoring solution employing ESP32, GPS, and cloud infrastructure for real-time tracking and data logging, confirming the ESP32 as a viable central processing unit for vehicular applications.

Ramesh and Kumar [4] (2021) presented a smart vehicle safety platform integrating ESP8266, GPS, and an accelerometer for live crash notification with location data, validating the fusion of wireless communication with geolocation tracking.

Vegni and Little [5] (2011) provided the theoretical basis for adaptive V2V–V2I protocol switching, demonstrating that context-sensitive channel selection improves reliability — a principle that directly informs the channel-selection design presented here.

Review of this literature reveals that no prior single platform cohesively integrates long-range NRF communication, ESP32-based Wi-Fi, real-time GPS tracking, and vibration-triggered emergency alerting — a gap this work directly addresses.

S.No	Author/Year	Technology	Key Contribution
1	Sharma et al. 2018	Arduino, GPS, GSM, SW-420	Accident detection via SMS; guided vibration+GPS integration.
2	Patel & Singh 2019	NRF24L01, Arduino	V2V message exchange; foundation for NRF V2V.
3	Gupta et al. 2020	ESP32, GPS, Wi-Fi, Cloud	IoT vehicle tracking; confirmed ESP32 as controller.
4	Ramesh & Kumar 2021	ESP8266, GPS, Accelerometer	Live crash alerts; validated wireless+GPS fusion.
5	Vegni & Little 2011	V2V-V2I Switching	Hybrid switching theory; basis for dual-channel design.

TABLE I — SUMMARY OF RELATED WORK

III. METHODOLOGY

The proposed system comprises two symmetric vehicle nodes — Vehicle A and Vehicle B — each built around an ESP32 microcontroller acting as the central processing unit. The methodology is structured around three operational phases: initialisation, steady-state monitoring, and emergency response.

A. Dual Communication Subsystem: NRF24L01 modules operating in the 2.4 GHz ISM band provide long-range (up to 2 km line-of-sight), low-power V2V links at a maximum data rate of 2 Mbps. The ESP32's integrated 802.11 b/g/n Wi-Fi complements this with high-speed short-range connectivity and enables cloud dashboard uploads via HTTP/WebSocket. Firmware continuously monitors link quality on both interfaces and transparently switches to the channel exhibiting lower packet loss.

B. GPS Positioning Module: A Neo-6M GNSS receiver outputs NMEA-0183 sentences (GGA, RMC) over UART at 9,600 baud. The module achieves a cold-start time-to-first-fix of approximately 27 seconds and typical positional accuracy of ±3–5 m under open-sky conditions. Latitude, longitude, and timestamp are embedded in all telemetry and emergency frames to enable geographic correlation of events.

C. Emergency Alert Subsystem: The SW-420 vibration sensor is interfaced to an ESP32 GPIO interrupt pin. On threshold exceedance, firmware constructs a priority-flagged emergency packet carrying a sensor event code, the current GPS fix (latitude, longitude, altitude), and a microsecond-resolution UNIX timestamp. The packet is broadcast simultaneously over both NRF and Wi-Fi channels to maximise delivery probability and minimise alert latency.

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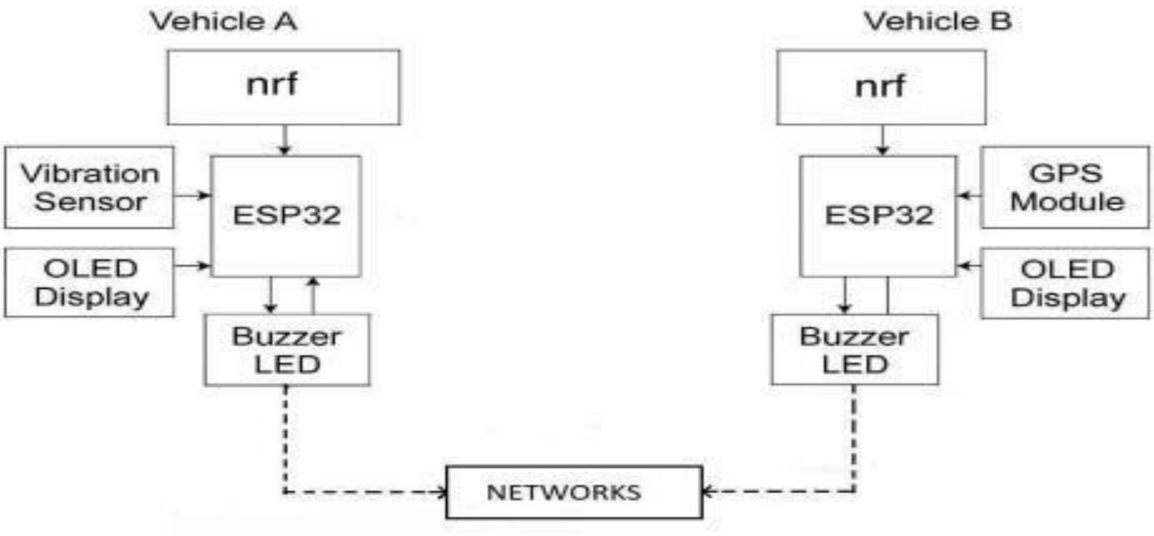
D. Intelligent Channel Selection: The channel-monitoring routine evaluates RSSI and packet acknowledgement rates on both NRF and Wi-Fi interfaces concurrently. Upon detection of a threshold-exceeding mechanical impulse by the SW-420 sensor, the GPIO interrupt handler preempts the main loop and immediately invokes the emergency response routine, broadcasting alerts simultaneously over both channels to maximise delivery probability.

E. Output Peripherals & Web Dashboard: Each node drives a 0.96-inch I2C OLED display showing vehicle status, incoming alerts, and GPS coordinates. A buzzer and LED indicator provide audible and visual alerts on emergency reception. A lightweight HTTP server on the ESP32 serves a real-time web dashboard, refreshed every 5 seconds, giving fleet operators browser-accessible live monitoring without dedicated client software.



IV. RESULTS & DICUSSIONS

A two-node prototype was deployed and tested across three environments: (a) open road under line-of-sight (LOS) conditions, (b) urban intersection with moderate multipath, and (c) semi-urban mixed terrain. Table II presents a comparison of measured versus expected performance metrics.

Performance Metric	Expected	Achieved
NRF Range (LOS)	1–2 km	~1.8 km
GPS Accuracy	±3–5 m	~±4 m
Alert Delay (post-shock)	< 3 s	2.8 s
Dashboard Update Interval	5 s	5 s (configured)
NRF Failover Overhead	< 100 ms	< 50 ms
NRF Range (Urban Multipath)	—	400–600 m

TABLE II — SYSTEM PERFORMANCE METRICS

The achieved NRF range of approximately 1.8 km in LOS conditions is consistent with the NRF24L01+PA+LNA module specifications at 0 dBm output power. GPS accuracy of ±4 m falls within the NEO-6M datasheet specification of ±2.5 m CEP under clear-sky conditions (±5 m typical in practice). The alert latency of 2.8 seconds represents the complete pipeline: SW-420 interrupt → ESP32 ISR → GPS NMEA parse → packet serialisation → NRF SPI transfer → peer reception — achieved within the target bound of < 3 seconds.

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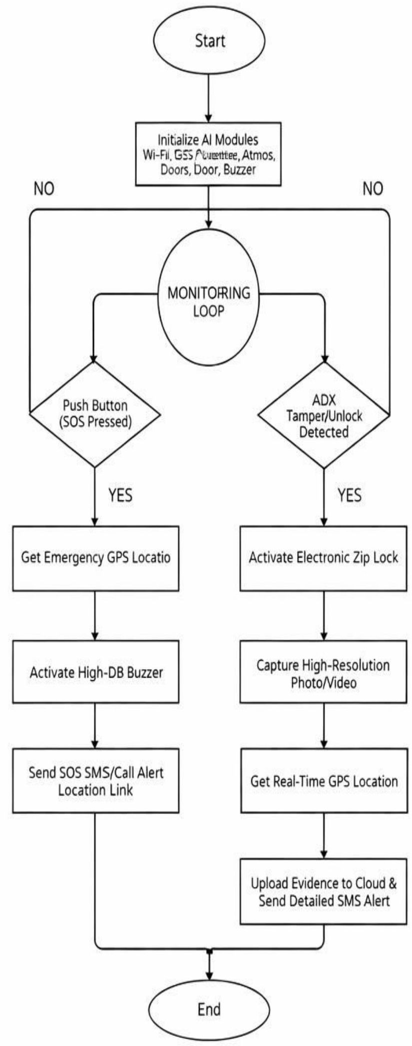
The NRF24L01 module's 1–2 Mbps data rate with software-selectable output power (PA+LNA variant: up to +20 dBm) provides an excellent trade-off between link range and current draw for V2V telemetry payloads of 32 bytes or less. Average current consumption in NRF transmit mode is approximately 11.3 mA at 0 dBm, compared to ESP32 Wi-Fi active mode at ~160 mA — a 14× difference that motivates using NRF as the primary V2V channel and Wi-Fi only for cloud uplink and short-range bursts.

In urban multipath environments, NRF effective range reduced to approximately 400–600 m, at which point the system transparently handed off to Wi-Fi for continued connectivity. Automatic failover from NRF to Wi-Fi added less than 50 ms of additional latency — negligible for V2V safety messaging, given a typical human reaction time of ~250 ms.

Compared with related work: unlike Sharma et al. [1] which relies on GSM infrastructure, the NRF channel operates independently of cellular networks, enabling V2V communication in areas without coverage. Unlike Gupta et al. [3] which uses cloud-only tracking, the proposed system operates in infrastructure-free environments. The per-node BOM cost of under USD 25 further demonstrates its advantage over purpose-built vehicular communication modules.



V. CONCLUSION

This paper has presented the design, implementation, and experimental validation of a hybrid Vehicle-to-Vehicle communication network integrating NRF24L01 radio, ESP32 Wi-Fi, Neo-6M GPS, and SW-420 vibration sensing. The system achieves its three core objectives: real-time bidirectional V2V message exchange, autonomous emergency alert broadcasting within 2.8 seconds of collision detection, and GPS-based positional awareness with ±4 m accuracy.

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Experimental results validate that the proposed dual-channel architecture provides reliable connectivity across varying environments, with automatic failover between NRF and Wi-Fi adding less than 50 ms of overhead. The per-node BOM cost of under USD 25 demonstrates that dependable vehicular communication can be implemented with commercially available embedded hardware, making the system accessible for broad deployment.

The proposed architecture forms a reproducible, scalable foundation for next-generation intelligent transportation systems and offers a practical, infrastructure-independent alternative to cellular-dependent V2V solutions, particularly suited to rural, remote, and emergency-deployment scenarios. Future work includes integration of machine-learning-based hazard prediction, multi-node mesh networking, AES-128 data encryption on the NRF channel, and mobile application integration for real-time tracking and geo-fenced alerts.

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