Problem Statement Abstract

Project Title: Adaptive Mesh-based Helmet Communication System with Voice-Frequency Isolation for Retrofit Modular Use

Context and Background

Motorcycle group riding is a widespread activity for commuting, tourism, and logistics in India. However, it presents inherent safety risks due to the acoustic isolation of riders. At highway speeds (80 km/h), wind turbulence and engine noise inside a helmet can reach **95–105 dB**, effectively deafening riders to external verbal cues.

Current safety protocols rely on hand signals, which have two critical failure points:

1. **Visibility:** Hand signals are ineffective at night, in fog, or on winding roads where line-of-sight is broken.
2. **Control:** To signal, a rider must remove one hand from the handlebars, compromising vehicle stability during critical manoeuvres. There is a pressing need for a hands-free, acoustic communication channel that allows a group of 2–5 riders to maintain real-time situational awareness without relying on cellular networks, which are unreliable in remote/hilly terrains.

The Research Gap

While Bluetooth intercom systems exist in the market (e.g., Sena, Cardo), they suffer from significant limitations that create a "Market & Technology Gap":

- **High-cost barrier:** Reliable mesh systems are often priced out of reach for the average Indian commuter or student.
- **Closed ecosystems:** Proprietary pairing protocols prevent seamless communication across different brands, fragmenting rider groups.
- **Poor speech clarity in budget devices:** Inadequate signal processing leads to wind hiss/engine drone transmission, causing fatigue and distraction.
- **Rigid Integration:** Most systems require semi-permanent installation (adhesives/drilling), preventing users from transferring the unit between different helmets (e.g., swapping from a daily half-face to a touring full-face helmet).

This creates an industry-relevant R&D requirement for a **low-cost, interoperable, retrofit communication unit** that improves safety and usability.

Problem Statement

The industry partner seeks an academic collaboration to develop a **Retrofit Modular Helmet Communication Unit** that enables clear group voice communication under real-world riding noise and intermittent rider spacing.

The scope of the project includes:

- **Development of a "Self-Healing" Mesh Algorithm:** Unlike standard one-to-one Bluetooth, the system must support **multi-hop group topology**. If Rider A cannot directly reach Rider C, the audio stream should route automatically via Rider B (or other intermediate riders) to extend effective range beyond typical single-link limits.
- **Voice Frequency Isolation and Noise Rejection:** The system must prioritize human speech intelligibility by implementing a speech-focused pipeline, such as a band-pass range aligned to voice (e.g., ~300 Hz–3.4 kHz) together with voice activity detection (VAD) and wind/engine noise rejection logic.
- **Universal "Clamp-and-Go" Modular Retrofit Design:** The hardware must be a **non-destructive, transferable module** that can be attached without drilling or permanently modifying the helmet, enabling users to move it between helmets.

Potential for Innovation

This project aims to democratize high-end safety technology. The key innovation lies in the **software-defined noise cancellation** on low-cost hardware (e.g., ESP32/Nordic platforms). By shifting the complexity from expensive hardware to smart algorithms, we aim to produce a unit at a fraction of the cost of imported competitors. Furthermore, the "Open Pairing" protocol will allow the device to bridge the gap between different hardware ecosystems.

Path to Validation (Methodology) The project follows a structured progression suitable for URP funding (TRL 3 to TRL 6):

1. **Lab Validation:** simulate and benchmark mesh routing performance (packet loss, latency, re-route behavior under mobility).
2. **Controlled Audio Testing:** validate voice isolation against recorded wind/engine profiles and quantify SNR/intelligibility gains.
3. **Field Deployment:** Final validation involving a 5-rider group testing the prototype on open roads to verify range, battery life, and connection stability in real-world environments.