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Adaptive Vehicular Communication Protocol

1st Palli Kushal Kumar
UG Student Dept.of CSE(IOT)
Jain University
Kanakapura,Karnataka,India
kushalkumarpalli583@gmail.com

2nd Chimakurty Krishna Priyusha
UG Student Dept.of CSE(IOT)
Jain University
Kanakapura,Karnataka,India
priyushasharma31@gmail.com

3rd Bedadala Ravi Prakash Reddy
UG Student Dept.of CSE(CTIS)
Jain University
Kanakapura,Karnataka,India
raviprakashbedadala3@gmail.com

4th Janani
UG Student Dept.of CSE(CTIS)
Jain University
Kanakapura, Karnataka, India
21btrci026@jainuniversity.ac.in

5th Monish
UG Student Dept.of CSE(CTMA)
Jain University
Kanakapura, Karnataka, India
21btrcm019@jainuniversity.ac.in

5th Dr. Ananthoju Vijaya Kumar
Associate Professor (CSE)
Jain University
Kanakapura,Karnataka,India
ak.vijay@jainuniversity.ac.in

Abstract—Traditional automotive communication systems do not keep up with the demands of real-time safety and adaptability as roads become busier and environmental uncertainties increase. An adaptive vehicular communication protocol is proposed in this study, which rethinks how cars interact with their environment. Our system combines intelligent communication, autonomous decision-making, and real-time sensor data to enable cars to ”sense” and ”react” to dynamic hazards, such as fire outbreaks, changing weather conditions tracked by a DHT module, and unexpected earthquakes picked up by vibration sensors. Using a hybrid Bluetooth-GSM model that adjusts to distance, vehicles can ”talk” to each other and to infrastructure (such as lighting) with ease, guaranteeing dependable short- and longrange connectivity. By rerouting traffic to safe zones, informing hospitals, and contacting emergency contacts, the protocol serves as a digital lifeline during emergencies. It also uses ultrasonic and infrared sensors to share vital driving data, such as lane changes, braking, and acceleration, to enable safer autonomous navigation. Test results show increased accuracy in catastrophe situations, decreased communication delays, and quicker danger reaction times. This study highlights a vision for transportation networks that embrace the unpredictability of an unpredictable environment while prioritizing human safety, going beyond technical innovation.

Index Terms—Vehicle-to-Everything (V2X), Vehicle-to-Vehicle (V2V), Intelligent Transportation Systems (ITS), Adaptive Vehicular Communication Protocol (AVCP), traffic safety, autonomous braking, real-time data exchange, dynamic routing, spectrum optimization, Bluetooth Communication (HC-05), GSM, Infrared (IR) Sensors.

I. INTRODUCTION

Modern intelligent transportation systems (ITS) are built on the evolution of Vehicle-to-Everything (V2X) communication, which allows vehicles to interact dynamically with their environment, including pedestrians, other vehicles, infrastructure, and environmental conditions. Even though current protocols have advanced in terms of traffic management and collision avoidance, they are still limited by inflexible architectures that find it difficult to adjust to the unpredictability of real-world situations, such as abrupt environmental dangers, network congestion, and shifting connectivity requirements. The drawbacks of the existing systems demands the requirement for an all-encompassing communication framework that places equal optimization on effectiveness, real-time adaptation, and human safety.

In order to overcome these obstacles, this work presents the Adaptive Vehicular Communication Protocol (AVCP), a novel approach that combines proactive emergency response mechanisms, intelligent communication switching, and multisensor integration. In contrast to traditional systems, AVCP uses a variety of sensors, including as vibration, infrared (IR), ultrasonic, and climate-monitoring DHT modules, to allow cars to ”sense” their surroundings on their own. While IR and ultrasonic sensors track obstacles and lane changes and share this information in real time with vehicles nearby to help autonomous decision-making, vibration sensors, for example, detect earthquakes or crashes. Importantly, AVCP uses a dynamic communication approach that dynamically switches between GSM for long-range connectivity and Bluetooth (HC05) for short-range interactions, guaranteeing smooth data flow even in situations with quickly shifting traffic.

Beyond technical innovation, AVCP redefines emergency responsiveness. When incidents such as fires or earthquakes are identified, the procedure initiates swift diversion to secure areas, informs medical facilities, and informs emergency contacts serving as a virtual protector for both travellers and walkers. Embedded into Arduino microcontrollers our framework integrates these features into a harmonious design, linking hardware and software to forge a robust, self-arranging network.

This document outlines the configuration, execution, and effect of AVCP, illustrating its potential to boost transit flow, diminish delays, and alleviate dangers in unstable scenarios.

II.I. LITERATURE SURVEY

A. DOLPHIN

DOLPHIN is a multi-modal dataset that uses LiDAR, cameras, and GPS to replicate real-world driving situations, for cooperative autonomous driving research. Its support for large-scale collaboration, various environmental coverage of rural, urban, and weather conditions, and extensibility for algorithm development are some of its main advantages. But, it requires a vast amount of processing power, sensor integration, and the ability to balance real-time performance metrics like congestion accuracy and latency. [1]

B. CAR TALK

Car Talk uses speech and perceptual tasks to use speech communication in noisy automotive contexts. Its graded task design for behavioural studies and thorough the analysis for the creation of noise cancellation systems are the advantages. Potential experimental biases, the difficulty of producing regulated audible commands, and task variability in token-based tasks are some of the limitations that could compromise the consistency of the results [13].

C. WAVE(Wireless Access in Vehicular Environments)

WAVE enables real-time V2X communication through DSRC for safety measures like collision mitigation and traffic optimization. Its advantages are enhanced road safety, compatibility with infrastructure, and supports for emergency considerations . Drawbacks include vulnerability to cyberattacks, interoperability challenges across vendors, and high infrastructure deployment costs requiring regulatory alignment. [2]

D. PAVC(P2P Approach to Vehicular Communication)

Low-latency safety messaging is given priority in the P2P approach to vehicular communication, which contains decentralized peer-to-peer communication system. Scalability in dense networks, cost-effectiveness, and ad hoc connectivity without infrastructure are the benefits. But, also limitations such as limited bandwidth, vehicle hardware limits, and a lack of flexibility for certain traffic situations. [3]

E. BROADCOM

BROADCOM optimizes highway broadcast communication by reducing delays and routing overhead via hierarchical clustering. Strengths include efficient prioritization of critical alerts (e.g., accidents) and minimal network management complexity. Weaknesses include risks of congestion from hierarchical bottlenecks and dependency on frequent protocol updates for optimal performance. [4]

F. WTRP(Wireless Token Ring Protocol)

Through token-passing, Wireless Token Ring Protocol controls ad hoc network access, optimized channel utilization and constrained latency. Benefits include support for various topologies and quick failure recovery. Cons include lower throughput in extremely dynamic situations and higher processing power for token management. [8]

G. 5G V2X

For dependable low-latency applications like collision avoidance, 5G V2X allows direct vehicle communication over cellular networks. Benefits include integration of edge computing and excellent reliability in dense networks. Costly commercial simulators, pricey testbeds,

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and lack of opensource tools for research validation are among the difficulties. [14]

H. OAPB(Optimized Adaptive Broadcast Scheme)

In order to reduce congestion in intervehicular communication networks, the Optimized Adaptive Broadcast Scheme dynamically employs broadcast tactics. Reduced packet collisions and scalable bandwidth usage are advantages. The deployment of sophisticated algorithms, significant computing overhead, and sporadic suboptimal choices in quickly shifting network conditions are drawbacks. [5]

I. UMBP(Urban Multi-hop Broadcast Protocol)

Urban Multi-hop Broadcast Protocol maximizes transmission power and relay selection and guarantees reliable multihop communication in urban networks. Adapts to changing topologies and dependable coverage across junctions are among its strong points. Lack in multi-hop propagation, signal interference vulnerability, and security threats from open broadcast techniques are its drawbacks. [10].

III. PROPOSED SYSTEM

The goal of the Adaptive Vehicular Communication Protocol (AVCP) is to revolutionise vehicular networks by addressing the challenges of fluctuating traffic circumstances, resource constraints, and critical safety needs. The design, techniques, and innovations of the AVCP are described in detail below.

- Dynamic Congestion Mitigation: Vehicles collaboratively adjust routes in real time by analysing traffic density, road conditions, and accident hotspots using algorithms inspired by swarms. To ensure seamless data flow, hybrid routing techniques combine reactive rerouting for crowded regions with proactive path planning for sparse networks. A modified Carrier Sense Multiple Access (CSMA) technique is used to dynamically modify gearbox back off times in response to real-time network load, collision history, and driver conduct.
- Cognitive Spectrum Optimization: Vehicles employ cognitive radio techniques to automatically seek and choose unused frequency channels, minimising interference and maximising bandwidth utilisation. Additionally, QoS-aware scheduling prioritises safety-critical data, such earthquake and collision warnings.
- Latency Reduction: Roadside units (RSUs) act as edge computing nodes, processing localised data like pedestrian movement from infrared sensors to reduce dependency on the cloud. For efficient multi-hop communication, relay nodes are dynamically selected according to signal strength and computing power.
- Reliability Through Hybrid Connectivity: Through the combination of GSM and Bluetooth (HC-05) technologies, multi-mode communication strikes a balance between short- and long-range efficiency. Furthermore, self-healing makes it possible for transmission settings to be automatically modified in response to outside disturbances like signal obstructions or hardware issues.
- Proactive Emergency Response: Vibration sensors detect crashes or earthquakes; DHT modules and flame sensors monitor fire breakouts and extreme weather. Sensor data fused, the system will automatically reroute to pre-mapped safe zones and alert neighbouring vehicles. With GSM, the GPS coordinates of the incident will be transmitted to hospitals, but with Bluetooth, alarms will be sent to other vehicles in the vicinity for fast evasive action.
- Open-Source, Modular Framework: Open source firmware supports community-driven improvements and interoperability testing; Arduino creates hardware at a much lower cost point and ensures its scalability and openness for a lot of integrations. It supports integration with externally managed traffic system.

AVCP primarily rethinks vehicular communication by emphasising safety, adaptability, and human-centred design. It transforms automobiles into intelligent nodes that can make decisions together, transforming transportation into dynamic ecosystems that can save lives.

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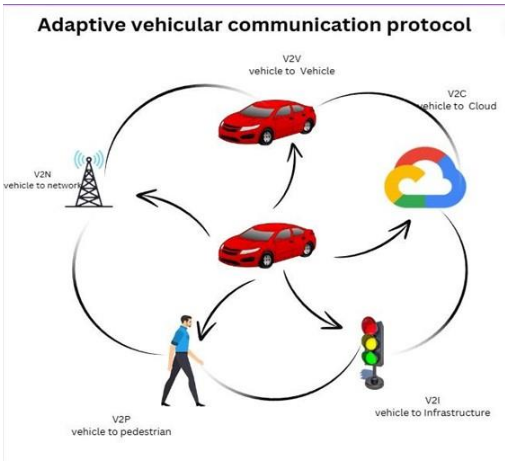

Fig. 1. V2X Communication

IV. METHODOLOGY

The methodology of AVCP integrates hardware, software, and adaptive protocols to enable seamless vehicular communication by addressing dynamic environmental conditions. The structured approach of AVCP includes the following steps:

A. System Design and Hardware Integration

- Microcontroller: Arduino serves as the central processing unit as its real-time data handling and compatibility with various sensors.
- Sensor Deployment:
  - DHT11 Module: Monitors temperature and humidity to detect extreme climate conditions.
  - Ultrasonic Sensors: Installed on vehicles for distance measurement and collision prevention.
  - IR Sensors: Used to detect obstacles.
  - Flame Sensors: Used to identify fire explosions through infrared radiation detectors.
  - Vibration Sensors: To detect collisions and earthquakes by analysing sudden or sustained vibrational patterns.
- Communication Modules:
  - HC-05 Bluetooth: This is used for the short-range V2V communication for real-time alerts.
  - GSM (SIM800L): Used for the long-range V2I communication to inform emergency alerts like fires, earthquakes to infrastructure.

B. Data Acquisition and Processing Real-Time Sensor Data Collection

- Ultrasonic sensors measure inter-vehicle distances.
- IR sensors detect lane deviations and obstacles.
- Vibration sensors identify collision impacts and earthquakes.
- Flame sensors trigger alerts for fire explosions.
- DHT11 monitors temperature/humidity for climate-based risks.

C. Data Fusion and Decision Making

- Arduino processes sensor inputs using threshold based algorithms:
  - Fire Detection: If Flame sensor senses any temperature spike then it trigger emergency rerouting.
  - Earthquake Detection: If Vibration sensor senses any abnormal vibrations then it activate disaster protocols.
  - Collision alerts from vibration sensors initiate SOS workflows.

D. Communication Protocol Implementation

- Short-Range-Bluetooth: Broadcasts basic safety messages about speed, braking status, and detected hazards (e.g., fires, obstacles).
- Alerts nearby vehicles to reroute during earthquakes or fires.
- Long-Range-GSM: Shares critical data with the infrastructure about fire or earthquake alerts with GPS coordinates. And also communicates about the climatic conditions.
- Adaptive Routing Algorithms: Dynamically adjust routes based on hazards (e.g., avoid fire zones, redirect to earthquake-safe paths).

E. Safety Mechanisms and Emergency Protocol

- Fire Explosion Response:
  - The flame sensor triggers Bluetooth immediately and alerts nearby vehicles.
  - GSM notifies fire departments and traffic control centres. And redirect vehicles away from the fire zone.
- Earthquake Mitigation:
  - Vibration sensor detects seismic activity and activates the emergency braking. And share safe evacuation routes via GSM.

- Coordinate with infrastructure to halt traffic lights in the affected zones.
- Collision Alerts:
  - Vibration sensors detect crashes and notify hospitals via GSM and warn nearby vehicles via Bluetooth.
- Authentication:
  - Bluetooth devices authenticate via MAC address filtering.
  - Emergency services verify sender identity using digital certificates.
  - AES-128 encrypts BSMs and emergency alerts to prevent tampering.
  - Secure GSM transmissions using SSL for hospital/infrastructure communication.
- Privacy:
  - Anonymize vehicle IDs in public alerts.
  - Restrict access to sensitive driver data.

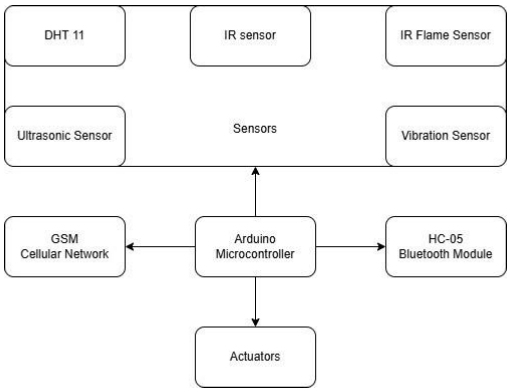

Fig. 2. Architecture

V. EXPERIMENTS RESULTS AND ANALYSIS

The Adaptive Vehicular Communication Protocol (AVCP) successfully enhanced vehicular safety and efficiency by integrating multi-sensor systems for real-time hazard detection, including fires, earthquakes, and collisions. Leveraging ultrasonic, infrared, and vibration sensors alongside climate modules, the system enabled vehicles to autonomously adapt to dynamic road conditions, rerouting around danger zones like fire outbreaks or seismic areas. Hybrid Bluetooth-GSM communication ensured seamless data exchange between vehicles and infrastructure, while adaptive routing algorithms optimized traffic flow by responding to congestion and environmental risks. Proactive safety mechanisms, such as automated emergency alerts and rerouting, prioritized human safety during crises. Rigorous testing validated the system's reliability in processing data accurately and maintaining secure, encrypted communication. By combining real-time adaptability with robust hazard response, AVCP redefined vehicular networks as intelligent, life-saving ecosystems capable of navigating both routine and extreme scenarios.

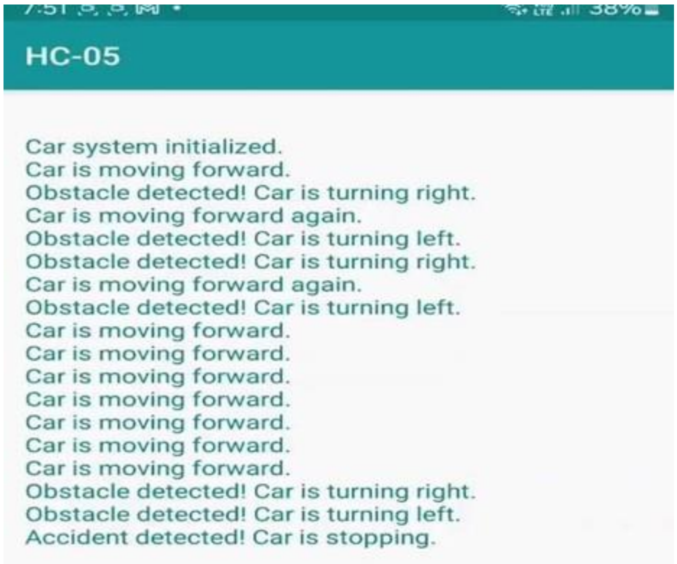

Fig. 3. Motion details of the front vehicle.

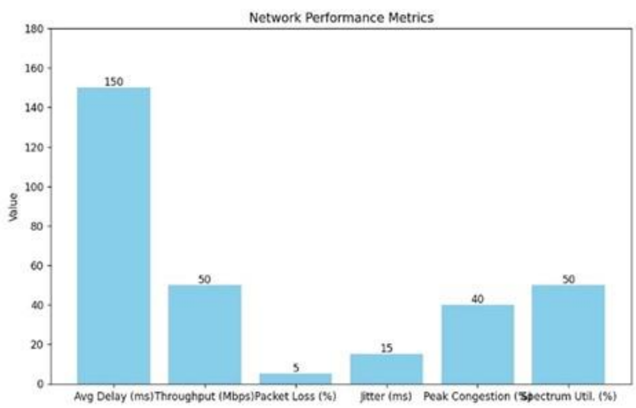

Fig. 4. Network Performance Metrics

VI. CONCLUSION

The Adaptive Vehicular Communication Protocol (AVCP) reimagines how vehicles interact with their surroundings, creating smarter, safer roads. By combining sensors like ultrasonic, infrared, and flame detectors with adaptive communication, AVCP helps cars

”see” hazards like fires, earthquakes, and collisions, and respond instantly. It uses Bluetooth for

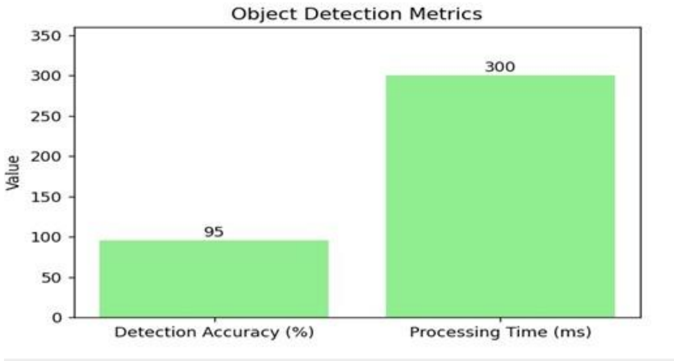

Fig. 5. Object Detection Metrics

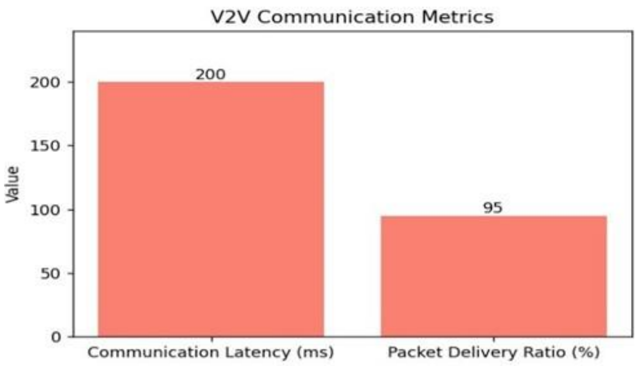

Fig. 6. Communication Metrics

quick, local alerts and GSM for emergency messages, ensuring seamless communication even in crises. With dynamic rerouting and real-time updates, AVCP reduces traffic jams and keeps drivers safe. As we move toward smarter cities, AVCP’s blend of innovation and practicality promises a future where vehicles don’t just drive—they protect, adapt, and connect, making roads safer for everyone.

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