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**S J C INSTITUTE OF TECHNOLOGY, CHICKBALLAPUR DEPARTMENT OF CSE (AI&ML)**

# B.E. PROJECT SYNOPSIS

SEM: VI

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| **Area of Project work:** | | Autonomous Vehicles and Intelligent Transportation Systems (ITS) | | |  |
| **Title of the Project Work:** | | "An Integrated Framework for Adaptive Path Planning, V2X Communication, and Energy-Efficient Networking in Autonomous Vehicles" | | |  |

# ABSTRACT

The proposed system introduces an integrated simulation framework designed to address critical challenges in autonomous vehicle navigation, including real-time path planning, communication reliability, energy-efficient decision-making, and passenger comfort. The framework combines Deep Reinforcement Learning (DRL), traditional algorithms (A\*, RRT\*), V2X communication protocols (groupcasting, IR-HARQ), and Wireless Sensor Network (WSN) optimization. It is designed for high-fidelity simulation in platforms like CARLA and SUMO and aims to ensure adaptive, safe, and sustainable vehicle behavior under dynamic traffic conditions. By fusing AI-driven planning, sensor feedback, and formal safety verification, the system targets enhanced performance, explainability, and deployability in real-world scenarios.

# Objective of the Project:

** Adaptive Path Planning: Develop a hybrid global-local path planning system using DRL and traditional planners (A\*, RRT\*) to respond to dynamic environments.**

** Vehicle-to-Vehicle Communication (V2X): Implement reliable 5G/6G-based communication using IR-HARQ and groupcasting for cooperative driving.**

** Real-Time Replanning: Integrate MPC for continuous trajectory adjustments in response to obstacles and route changes.**

** Comfort and Safety Control: Use Full Velocity Difference (FVD) model and feedback loops to ensure passenger stability and smooth motion.**

** Energy-Aware WSN Integration: Optimize sensor networks using reinforcement learning and clustering with MOISA for efficient energy use.**

** Formal Safety Verification: Apply Signal Temporal Logic (STL) to validate policy decisions and maintain adherence to safety constraints.**

# Literature Survey

Recent research in autonomous vehicle planning has focused on combining AI models, communication protocols, and environmental sensing for robust operation. This survey outlines key approaches and their limitations.

**1. Deep Reinforcement Learning in Path Planning**

* *Survey of DRL for Autonomous Motion Planning*: Highlights DRL's ability to handle complex scenarios but notes limitations in safety, generalization, and interpretability.
* *LfD with STL Constraints*: Combines human demonstrations and formal logic to ensure rule-compliant path generation.
  + **Limitation**: High computation time in real-time settings.
  + **Solution**: Introduce hybrid DRL-STL control pipelines with MPC.

**2. V2X Communication Reliability**

* *IR-HARQ and Groupcasting in 5G NR*: Demonstrated over 98% improvement in message reliability under delay/outage conditions.
  + **Limitation**: Lack of real-time traffic adaptability.
  + **Solution**: Integrate AI-based dynamic message scheduling and relevance prioritization.

**3. WSN and Energy-Efficient Routing**

* *Collaborative Energy-Efficient Routing (CEEPR)*: Uses RL and MOISA to enhance WSN lifespan and performance.
  + **Limitation**: Not fully integrated into vehicular decision loops.
  + **Solution**: Link sensor data directly to path planning modules via feedback APIs.

**4. Real-Time Comfort and Traffic Stability**

* *FVD Model with Feedback Control*: Enhances comfort by minimizing acceleration fluctuations.
  + **Limitation**: Not scalable to high-density urban scenarios.
  + **Solution**: Use multi-predecessor feedback and real-time replanning.

**Proposed Methodology**

**The project will be implemented as a simulation-based system integrating the following modules:**

1. **Hybrid Path Planner:**
   * **Use A\*/RRT\* for initial path estimation.**
   * **DRL (e.g., PPO/SAC) for adaptive motion planning under uncertainty.**
   * **Replanning with MPC for local obstacle avoidance.**
2. **V2X Communication Module:**
   * **Develop groupcasting protocol with IR-HARQ retry schemes.**
   * **Implement packet delay/loss scenarios in SUMO + CARLA bridge.**
3. **Comfort and Control Module:**
   * **Integrate Full Velocity Difference (FVD) model with dynamic feedback gains.**
   * **Use STL to enforce safety zones and rule compliance.**
4. **WSN Energy Management:**
   * **Apply RL-based clustering and MOISA for energy optimization.**
   * **Use NS-2/NS-3 to simulate network load and routing dynamics.**
5. **Unified Decision and Logging Layer:**
   * **Build centralized integration logic.**
   * **Use STL-based runtime monitors to verify policy actions.**

**Requirements**

1. Hardware Requirements:

 CPU: Intel i7 or Ryzen 7 equivalent

 GPU: NVIDIA RTX 2060 or higher (for DRL training)

 RAM: 16 GB minimum

 OS: Windows 11 (64-bit)

2. Software Requirements:

 CARLA (0.9.13+), SUMO (1.10+), NS-2/NS-3

 Python 3.8+, TensorFlow or PyTorch

 OpenCV, scikit-learn, Stable-Baselines3

 YAML, Flask (optional for UI)

 Graph plotting: Matplotlib / Seaborn

**Functional Requirements**

* DRL-based adaptive motion planner
* V2X communication emulator (groupcast + retry logic)
* Real-time replanning under uncertainty
* STL-based safety verification
* WSN data-driven routing adjustments

**Non-Functional Requirements**

* Real-time response latency < 100 ms
* High simulation fidelity and modularity
* Scalable from single-lane to multi-lane environments
* Configurable communication and traffic parameters
* Robust log management and explainable AI layer

**Conclusion**

The proposed system presents a comprehensive, modular framework that unifies adaptive path planning, reliable V2X communication, energy-efficient wireless sensor management, and formal safety verification for autonomous vehicles. By integrating DRL with traditional planning algorithms, real-time MPC-based replanning, and 5G/6G-enabled V2X protocols, the system ensures responsiveness and robustness in dynamic traffic environments. Reinforcement learning-enhanced WSN modules and STL-based validation layers further bolster decision accuracy and safety compliance. Simulation platforms such as CARLA, SUMO, and NS-3 will enable high-fidelity testing across mixed and constrained environments. This work contributes toward bridging the gap between simulation and real-world deployment of autonomous mobility systems through intelligent integration, explainability, and scalability.

**References**

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