Traffic Light Negotiation Using V2X(Vehicle-to-Everything) Communication with 5G

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***Abstract*—This paper demonstrates the modeling and simulation of a traffic light negotiation system using Vehicle-to-Everything (V2X) communication with 5G integration. By leveraging ultra-reliable low-latency communication (URLLC) capabilities of 5G, the system ensures efficient and safe navigation at intersections under dynamic traffic conditions. V2X communication modes, such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), facilitate the sharing of critical data, while 5G enhances the communication framework to handle high traffic densities and complex scenarios. The proposed system is tested on various scenarios to validate its performance and scalability.**

***Index Terms*—V2X Communication, 5G, Traffic Light Negotiation, Automated Driving, Simulink.**

I. Introduction

Efficient and safe navigation of intersections is crucial for autonomous driving systems. Traditional sensor-based approaches, such as radar and vision systems, often face limitations in scenarios involving low visibility, multiple dynamic actors, or complex intersections. Vehicle-to-Everything (V2X) communication addresses these challenges by providing vehicles with access to real-time data from their surroundings.

With the integration of 5G technology, V2X communication gains ultra-reliable low-latency communication (URLLC) and enhanced mobile broadband (eMBB) capabilities. These features ensure near-instantaneous data exchange, enabling vehicles to make timely and accurate decisions even in high-density traffic conditions. This work focuses on a traffic light negotiation system that integrates 5G-enabled V2X communication to optimize decision-making at intersections.

A. Traffic Light Negotiation

The system uses data from V2V and V2I communication to guide the ego vehicle through intersections. The V2V mode transmits Basic Safety Messages (BSMs) containing information about nearby vehicles, such as speed and position. The V2I mode provides Signal Phase and Timing (SPAT) messages from traffic lights, allowing the ego vehicle to anticipate light changes and adjust its trajectory accordingly.

II. System Overview

The proposed system comprises the following components:

- **Sensors and Environment**: Models the traffic light, road network, and surrounding vehicles using Simulink.
- **V2X Communication Subsystems**: Facilitates V2V and V2I communication enhanced by 5G technology.
- **Decision Logic**: Identifies the most important object (MIO) and generates actions based on traffic conditions.
- **Controller**: Uses Model Predictive Control (MPC) for generating longitudinal and lateral control inputs.
- **Visualization**: Displays real-time simulation of vehicle and traffic dynamics.

III. 5G-Enhanced V2X Communication

A. Role of 5G

5G technology enhances the communication framework by:

- Reducing latency to sub-1 ms for critical data exchange.
- Supporting high-throughput data for detailed traffic scenarios.
- Enabling seamless communication in high-density environments.

B. Integration in V2V and V2I Communication

The V2V Simulator subsystem transmits BSMs containing critical state information, such as vehicle speed, heading, and acceleration. The V2I Simulator transmits SPAT messages that provide traffic light status updates. Using MATLAB's 5G

Toolbox, the communication framework models realistic 5G channel conditions, including path loss, Doppler effects, and signal fading.

IV. Decision Logic

The Decision Logic subsystem prioritizes actions based on inputs from communication and sensor data:

1) **Lead Vehicle**: If a lead vehicle is detected, the ego vehicle adjusts its speed to maintain a safe distance.
2) **Crossover Vehicle**: For cross-traffic at intersections, the ego vehicle halts until the path is clear.
3) **Traffic Light**: SPAT messages determine whether the ego vehicle should proceed, stop, or decelerate.

V. Simulation Scenarios and Results

The proposed system was tested across several traffic scenarios to evaluate its performance in traffic light negotiation, vehicle detection, and decision-making. The simulation results were visualized using MATLAB and Simulink, and the key observations are presented below.

A. Scenario 1: Traffic Light Negotiation on Ego Lane

The simulation visualizes the state of the traffic light on the ego vehicle's lane in a detailed intersection model. The system accurately identifies the current state of the traffic signal (red, yellow, or green) and adjusts the vehicle's behavior accordingly, ensuring safety and efficiency.

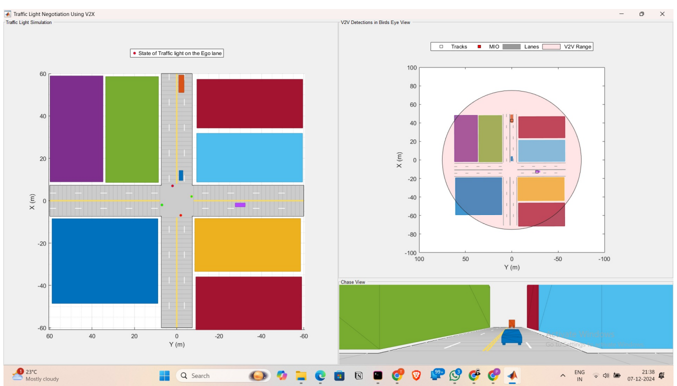

Fig. 1. State of the traffic light on the ego vehicle's lane. The system ensures the vehicle follows appropriate actions based on the signal state.

B. Scenario 2: Bird's Eye View of V2X Communication Range

This scenario demonstrates the V2X communication range and its interactions with other vehicles. The bird's eye view highlights the communication range (V2V and V2I), tracks the vehicles within the range, and dynamically updates the traffic light states in real-time.

C. Scenario 3: Chase View of Ego Vehicle

The chase view provides a rearward perspective of the ego vehicle navigating the intersection. The traffic light state, road lanes, and surrounding environment are visualized to depict real-time decision-making.

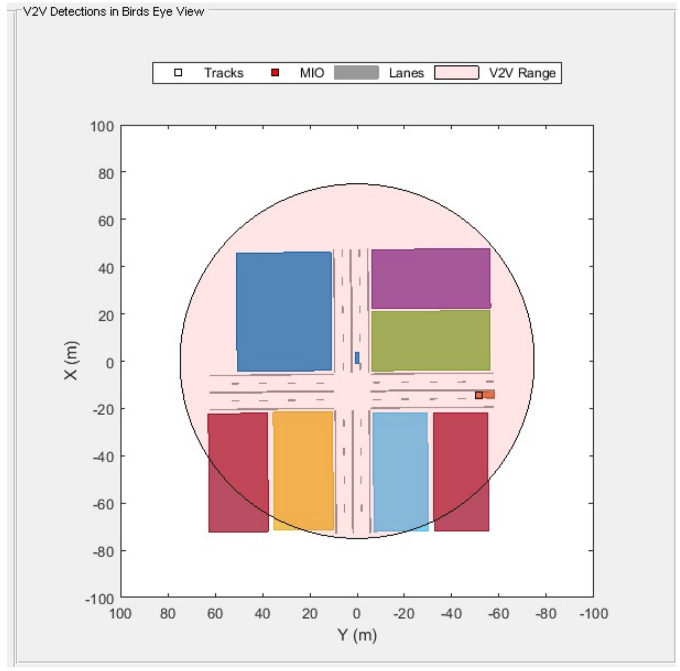

Fig. 2. Bird's eye view showing the V2X communication range and interaction with surrounding vehicles and infrastructure.

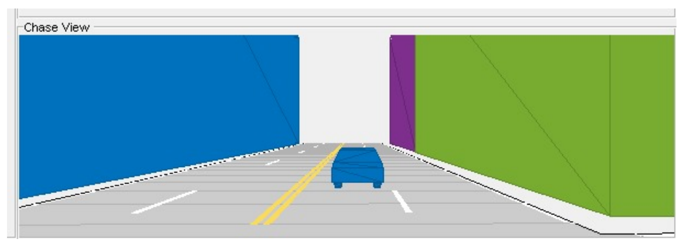

Fig. 3. Chase view of the ego vehicle approaching the intersection, showcasing its interaction with traffic lights and lanes.

D. Scenario 4: Enhanced Bird's Eye View with Traffic Interaction

An enhanced bird's eye view focuses on the interaction between vehicles and traffic lights within the V2X communication range. This simulation validates the system's ability to handle complex traffic conditions with multiple actors.

E. Scenario 5: Traffic Light State and Ego Vehicle Metrics

The simulation results include time-series data of the traffic light state, V2X detections, and ego vehicle metrics (e.g., acceleration, yaw angle, and relative distance). These graphs demonstrate the system's decision logic in varying traffic conditions.

F. Discussion of Results

The simulation results validate the proposed system's efficiency in managing traffic light negotiation. Key observations include:

- Reliable detection of traffic light states and their transitions.

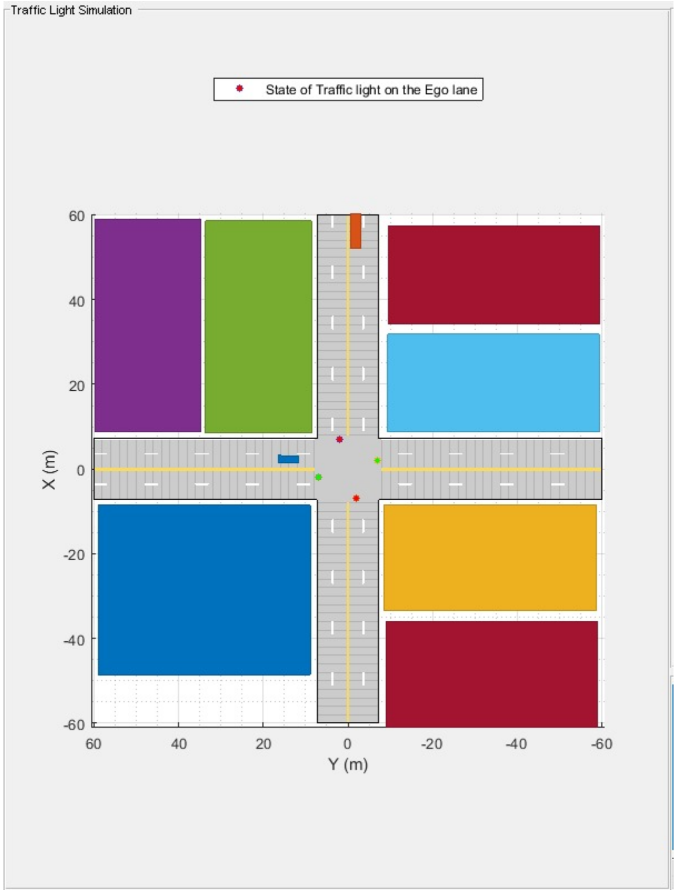

Fig. 4. Enhanced bird's eye view of the intersection, depicting V2X interactions and traffic flow dynamics.

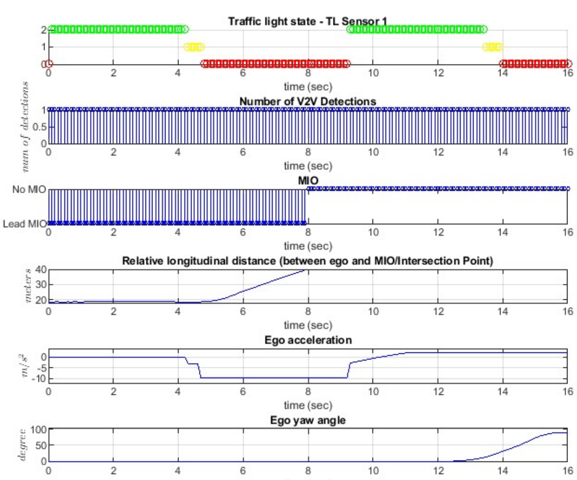

Fig. 5. Time-series analysis of traffic light state, number of V2X detections, and ego vehicle metrics, including acceleration, yaw angle, and relative distance.

- Accurate interaction with other vehicles through V2X communication.
- Efficient decision-making, leading to safe and timely navigation through intersections.
- Scalability in handling dense traffic scenarios without loss of communication performance.

VI. Conclusion

This paper demonstrates how integrating 5G technology with V2X communication enhances traffic light negotiation systems for autonomous vehicles. The 5G-enabled framework ensures ultra-low latency and high reliability, enabling efficient navigation of complex intersections. Future work will focus on extending the system to handle pedestrian interactions and multi-modal traffic scenarios.

Resources

- **GitHub Repository:** Access Here
- **Demonstration Video:** Watch Here

Acknowledgment

The authors would like to acknowledge [Institutions or Funding Agencies] for their support.

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