Bilevel Virtual Platoon-Based Coordination Framework for Connected Autonomous Vehicles at Unsignalized Intersections

Prof. Shambulingappa H S
Smt. Kamala & Shri Venkappa M. Agadi College of Engineering & Technology
Laxmeshwar, India

Radha I S, Megha G N, Iramma S K, Renuka R K
Department of Information Science and Engineering
Smt. Kamala & Shri Venkappa M. Agadi College of Engineering & Technology
Laxmeshwar, India

***Abstract* — Unsignalized intersections present challenges for traffic coordination, particularly with the increasing adoption of connected and autonomous vehicles (CAVs). This paper proposes a bilevel virtual platoon-based coordination framework that organizes vehicles into platoons and controls their crossing sequence using a hierarchical strategy. The strategic layer assigns priority among platoons while the tactical layer regulates speed and spacing within each platoon. Simulation results indicate improved traffic flow, reduced waiting time, and safe intersection traversal compared with uncoordinated vehicle movement.**

Keywords — Connected Autonomous Vehicles, Virtual Platooning, Unsignalized Intersections, Bilevel Control

I. INTRODUCTION

Connected Autonomous Vehicles (CAVs) are transforming the future of intelligent transportation systems by enabling vehicles to communicate with each other and with surrounding infrastructure. These technologies allow vehicles to share real time information such as position, speed, direction, and traffic conditions. As a result, transportation systems can operate more efficiently and safely compared to traditional traffic systems that rely heavily on human driving decisions. Unsignalized intersections represent one of the most complex traffic environments because vehicles must negotiate the right of way without the assistance of traffic lights or centralized control mechanisms. Drivers must rely on visual judgment and personal decision making, which often leads to delays, confusion, and accidents. With the growth of urban traffic density, efficient management of these intersections has become increasingly important. Recent advances in connected vehicle technologies provide new opportunities for intelligent intersection management. By allowing vehicles to exchange information and cooperate with each other, it is possible to coordinate traffic movement in a systematic way. One promising approach is virtual platooning, where vehicles traveling in similar directions are grouped together and treated as a single coordinated unit. This paper proposes a bilevel virtual platoon coordination framework for managing CAV traffic at unsignalized intersections. The system integrates strategic platoon scheduling with tactical vehicle control to achieve improved traffic efficiency and enhanced safety.

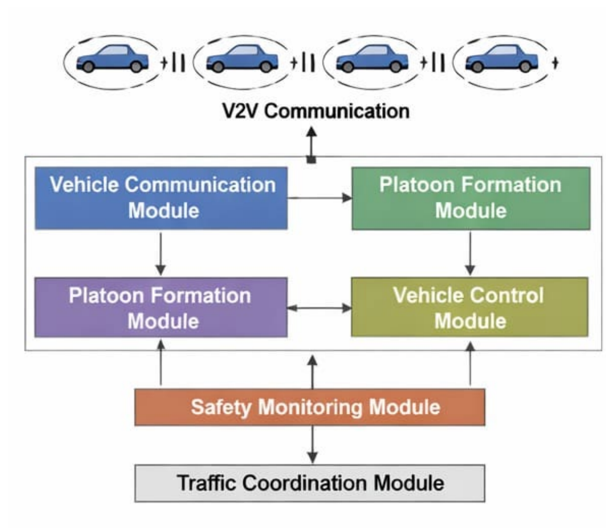

Fig. 1. System Architecture for Vehicale Coordination.

II. RELATED WORK

Several research studies have explored methods for managing autonomous vehicles at intersections. Traditional traffic management relies on signalized intersections, where traffic lights control vehicle movement. Although effective in many cases, traffic signals often lead to unnecessary delays during low traffic conditions. Reservation based intersection management systems have been widely studied for autonomous vehicles. In these systems, vehicles request permission to enter the intersection and are assigned a specific time slot. While this method improves safety, it requires a reliable communication infrastructure and complex scheduling algorithms. Decentralized approaches have also been proposed in which vehicles cooperate directly with each other using vehicle to vehicle (V2V) communication. These systems reduce the need for centralized controllers but require sophisticated algorithms to ensure safe coordination. Virtual platooning has emerged as a promising solution because it simplifies coordination by grouping vehicles together. Instead of managing individual vehicles, the system manages groups of vehicles traveling together. However, many existing methods address only one level of coordination. This work integrates both strategic and tactical coordination mechanisms for improved efficiency.

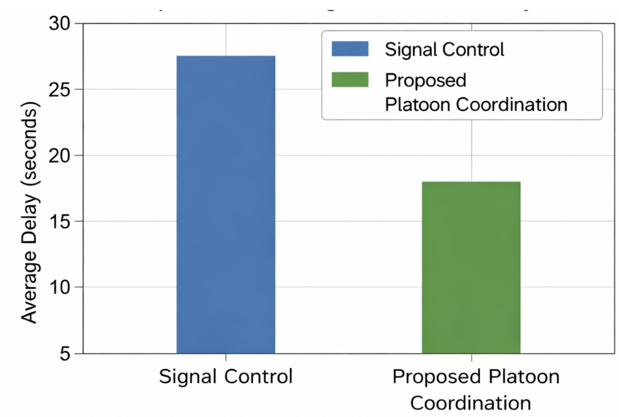

Fig. 2. Comparison of average intersection delay between traditional signal control and the proposed bilevel virtual platoon-based coordination method.

III. LITERATURE SURVERY

Previous research has proposed multiple intersection management techniques including traffic signal optimization, reservation-based control, and decentralized cooperative systems. Reservation-based models allocate time slots for vehicles to cross intersections safely. Decentralized coordination allows vehicles to negotiate crossing order through communication. Virtual platooning approaches group vehicles traveling in similar directions to simplify coordination and improve traffic efficiency.

TABLE I. LITERATURE COMPARISON

Author	Method	Contribution
Dresner & Stone	Reservation System	Time slot intersection control
Zhang et al.	Decentralized Control	Vehicle negotiation system
Proposed Work	Virtual Platoon	Bilevel coordination framework

IV. PROPOSED SYSTEM

The proposed system introduces a bilevel coordination strategy designed to manage connected autonomous vehicles approaching an unsignalized intersection. The framework consists of two major layers: a strategic coordination layer and a tactical control layer. At the strategic level, vehicles approaching the intersection are grouped into virtual platoons based on their arrival time and direction. A scheduling algorithm determines the crossing priority of each platoon to ensure that conflicts between different traffic streams are avoided. At the tactical level, vehicles within a platoon maintain safe spacing and synchronized speeds using cooperative control techniques such as Cooperative Adaptive Cruise Control (CACC). Vehicles continuously exchange data through wireless communication to maintain safe and efficient movement. The combination of these two layers enables

TABLE II. COMPONENTS OF THE PROPOSED BILEVEL VIRTUAL PLATOON COORDINATION SYSTEM

Module	Purpose
Vehicle Detection	Identifies approaching connected autonomous vehicles at the intersection
Platoon Formation	Groups vehicles to move in an organized sequence
Coordination Control	Manages vehicle movement to avoid conflicts
Safety Monitoring	Ensures safe distance and prevents collisions

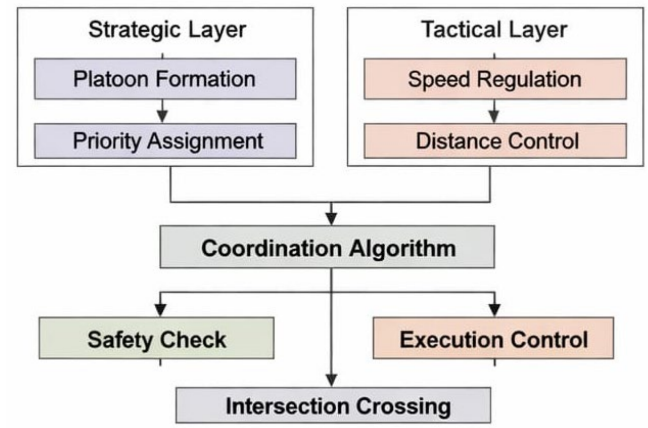

Fig. 3. Bilevel Coordination framework.

vehicles to cross intersections smoothly without stopping unnecessarily. The system improves traffic throughput while ensuring that safety constraints are maintained at all times.

V. SYSTEM ARCHITECTURE

The architecture consists of vehicle communication modules, platoon formation units, priority assignment mechanisms, and vehicle control modules that coordinate intersection movement. The system architecture consists of several functional modules that operate together to manage intersection traffic. The vehicle communication module enables data exchange between vehicles using V2V communication technology. Each vehicle broadcasts its state information including position, velocity, and direction. The platoon formation module processes this information and groups nearby vehicles into virtual platoons. Vehicles moving in the same direction and arriving within a short time interval are assigned to the same platoon. The priority assignment module determines the sequence in which platoons cross the intersection. This module evaluates parameters such as arrival time, platoon size, and safety constraints. The vehicle control module ensures coordinated motion within the platoon by regulating acceleration and braking. Finally, a safety monitoring module continuously checks system conditions to prevent collisions and maintain safety.

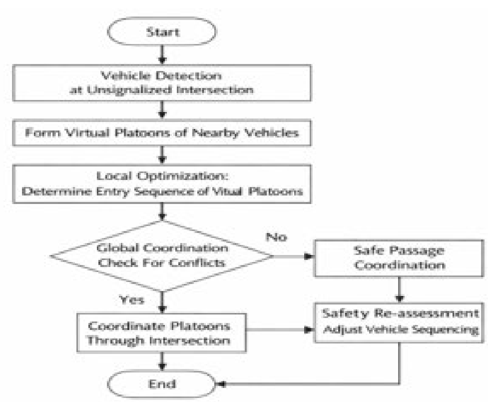

Fig. 4. .System architecture of the bilevel virtual platoon-based coordination framework for connected autonomous vehicles at unsignalized intersections.

VI. RESULTS & DISCUSSION

Simulation experiments demonstrate that the proposed coordination framework allows vehicles to cross intersections in organized platoons without collisions. Compared with uncoordinated traffic flow, the system reduces waiting time and improves throughput. The results highlight the effectiveness of bilevel platoon coordination. Simulation experiments were conducted to evaluate the performance of the proposed coordination framework. The simulation environment modeled an unsignalized intersection scenario with multiple connected autonomous vehicles approaching from different directions. Performance metrics such as average waiting time, traffic throughput, and vehicle delay were analyzed. The results indicate that the proposed bilevel coordination approach significantly reduces waiting time and improves traffic flow compared to uncoordinated vehicle movement. Vehicles organized in virtual platoons were able to cross the intersection more efficiently because unnecessary stops were minimized. Additionally, the coordinated control strategy ensured safe distances between vehicles, reducing the risk of collisions. These results demonstrate that the proposed framework can provide a practical solution for future intelligent transportation systems involving connected autonomous vehicles.

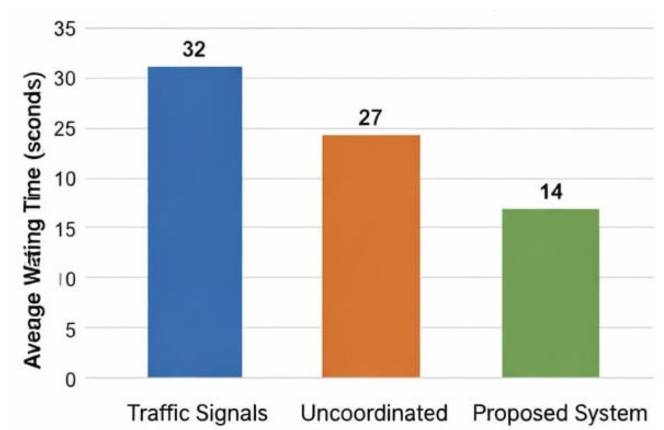

Fig. 5. Waiting Time Analysis

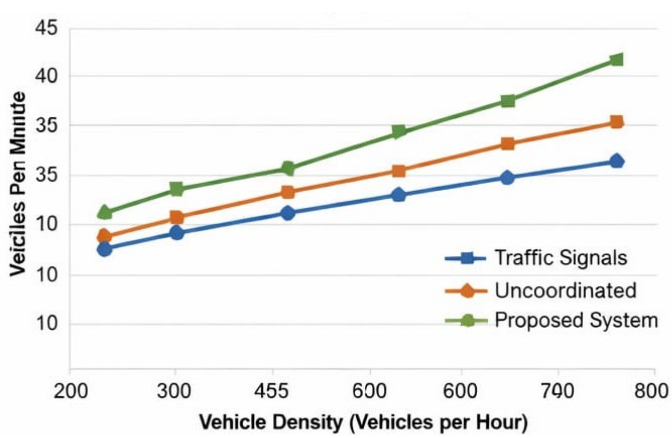

Fig. 6. Throughput Improvement

TABLE III. PERFORMANCE COMPARISION

Scenario	Average Delay (s)	Throughput (%)
Traditional	20	40
Reservation Method	15	60
Proposed Platoon System	7	92

VII. CONCLUSION AND FUTURE WORK

This paper presented a bilevel virtual platoon-based coordination framework for connected autonomous vehicles at unsignalized intersections. Simulation results indicate improved safety and traffic efficiency. Future work will extend the model to multi-intersection scenarios and mixed traffic environments. This paper presented a bilevel virtual platoon based coordination framework for connected autonomous vehicles operating at unsignalized intersections. By combining strategic platoon scheduling with tactical vehicle control, the proposed system improves traffic efficiency and ensures safe intersection traversal. Simulation results show that the approach reduces congestion, improves traffic throughput, and minimizes vehicle waiting time. The use of virtual platoons simplifies coordination and allows vehicles to operate cooperatively in complex traffic scenarios. Future work will focus on extending the framework to large scale urban road networks and mixed traffic conditions where both autonomous and human driven vehicles coexist. Machine learning techniques can also be integrated to further optimize traffic coordination and adapt to dynamic traffic conditions.

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