# Coordination Control Method for Zone Boundary Traffic Signals Based on Organic Computing

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**Abstract**
The research focuses on developing a coordination control method for traffic signals at zone boundaries using organic computing principles. This study lies at the intersection of urban traffic signal control and artificial intelligence. The proposed method comprises various modules, including traffic flow monitoring, self-optimization, self-modification, evolutionary learning, self-assessment, and self-adaptation. The objective is to achieve efficient coordination between traffic signals at zone boundaries, thus preventing congestion and traffic blockages in the intersecting areas.



**Keywords: Traffic signal control, Zone boundary, Organic computing, Coordination, Traffic flow monitoring, Self-optimization, Evolutionary learning.**
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## Introduction

Urban traffic management is a complex and challenging task, particularly at zone boundaries where traffic flows from different areas converge. Efficient coordination of traffic signals at these intersections is crucial to ensure smooth traffic flow, reduce congestion, and enhance overall transportation efficiency.[1] Traditional traffic signal control methods often fall short in effectively addressing the dynamic and interconnected nature of traffic patterns at zone boundaries. As a result, traffic congestion and blockages frequently occur, leading to delays, increased travel times, and frustration among commuters.To overcome these challenges, researchers and traffic engineers have been exploring innovative approaches that leverage advanced technologies and artificial intelligence techniques. One such approach is the coordination control method for traffic signals at zone boundaries based on organic computing principles. Organic computing refers to the design of systems that can adapt, learn, and self-optimize in response to changing conditions and goals, inspired by the self-organizing capabilities observed in natural systems(Wang, Cai, and Lu 2020; Zhu and Li 2019).

The coordination control method proposed in this research aims to tackle the complexities of traffic signal management at zone boundaries. By integrating various modules, including traffic flow monitoring, self-optimization, self-modification, evolutionary learning, self-assessment, and self-adaptation, the method strives to achieve efficient coordination between traffic signals. This approach goes beyond traditional fixed-time or actuated signal control methods by enabling the traffic signal system to dynamically adapt and optimize its operation based on real-time traffic conditions and evolving patterns(Su et al. 2020).

One of the critical components of the coordination control method is the traffic flow monitoring module. This module utilizes advanced sensing technologies, such as loop detectors, cameras, and other intelligent transportation systems, to collect real-time data on traffic conditions at zone boundaries. This data serves as the foundation for decision-making and coordination strategies, allowing the system to understand the current traffic state and make informed adjustments to signal timings(Su et al. 2020; Wang et al. 2020; Zhu and Li 2019).

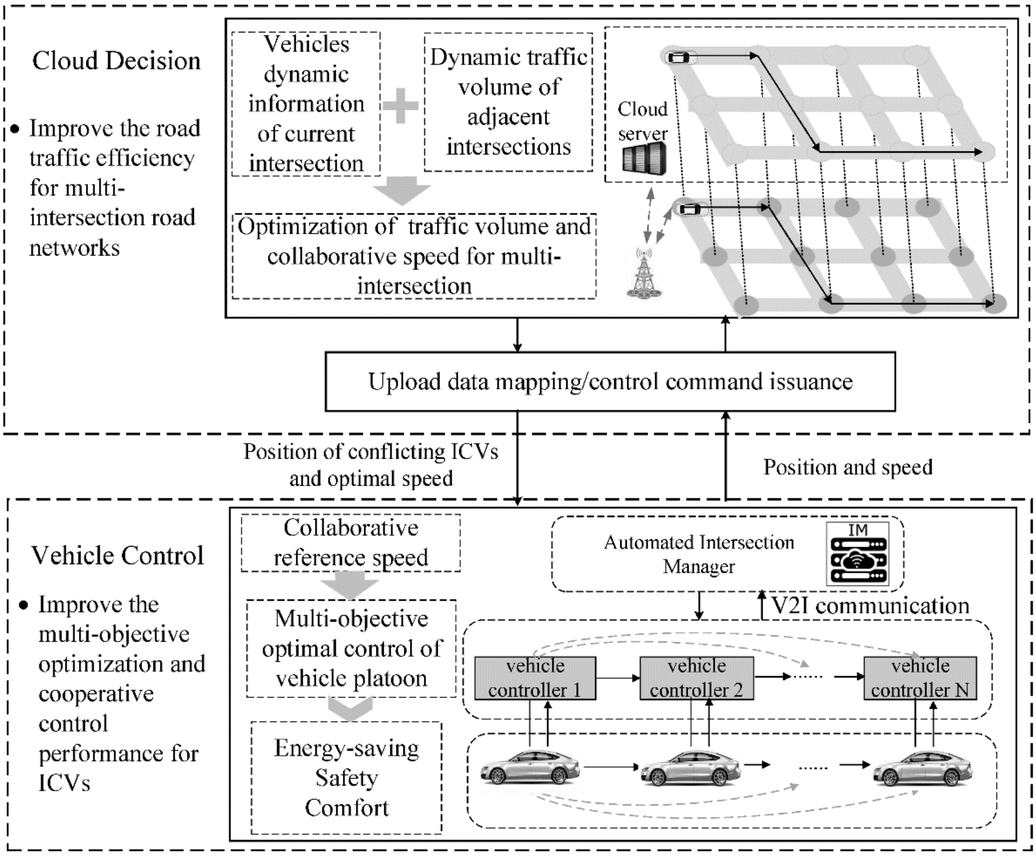




*Figure 1. Distributed and hierarchical optimal control architecture.*

The optimization problem's computational aspect is additionally minimized utilizing the DMPC technique for multi-intersection and multi-vehicle systems. This ensures that a less complex control problem with a reduced dimension can be tackled individually. The control architecture of this approach is depicted in **Figure 1,** encompassing two layers—an upper cloud decision layer and a lower vehicle control layer.The self-optimization module plays a vital role in continuously fine-tuning the traffic signal timings to maximize traffic flow and minimize delays. Optimization algorithms, such as genetic algorithms or reinforcement learning techniques, are employed to search for the optimal signal settings based on defined objectives and constraints(Gao et al. 2020; Su et al. 2020). This adaptive approach allows the system to respond to changing traffic demands throughout the day, accommodating peak periods, fluctuations in traffic volume, and varying travel patterns.Additionally, the coordination control method incorporates a self-modification module that enables the system to learn and adapt its behavior over time. By analyzing historical traffic data and observing the effectiveness of previous signal adjustments, the system can modify its coordination strategies to improve performance and address emerging traffic patterns(Rafter et al. 2020).

The evolutionary learning module further enhances the system's capabilities by enabling it to evolve and optimize its coordination strategies through a process of trial and error. By simulating various scenarios and evaluating the outcomes, the system can identify effective strategies and gradually refine its operation to achieve better traffic flow.To evaluate the effectiveness of the coordination control method, a self-assessment module is integrated into the system. This module continuously monitors the traffic performance, collects feedback from road users, and measures key performance indicators such as travel time, delay, and queue lengths. Based on this assessment, the system can make necessary adjustments and optimize its coordination strategies in real-time(Chen et al. 2020; Gao et al. 2020).

In conclusion, the coordination control method for traffic signals at zone boundaries based on organic computing offers a promising approach to address the challenges of traffic congestion and blockages. By leveraging advanced technologies and artificial intelligence techniques, the proposed method aims to achieve efficient coordination and optimize traffic flow at zone boundary intersections. This research contributes to the field of urban traffic management by providing a systematic and intelligent approach that can adapt and learn from real-world traffic conditions, ultimately improving transportation efficiency and enhancing the overall urban mobility experience(Wang et al. 2020).

**Related Work**

Currently, traffic signal control systems, both domestically and internationally, operate independently within specific regions. Each region optimizes and coordinates its intersection traffic signal plans based on the traffic information within its own area. This approach results in a lack of coordination and interference between traffic signal systems at zone boundaries(Su et al. 2020).

At zone boundaries, where different control areas meet, the traffic signal timing parameters are optimized separately by the affiliated areas based on the traffic flow rates within their respective regions. However, the population distribution, land use changes, economic development, and traffic patterns vary between different regions within a city, leading to significant traffic flow disparities at zone boundaries(Singh et al. 2021; Yang and Emadi 2013).



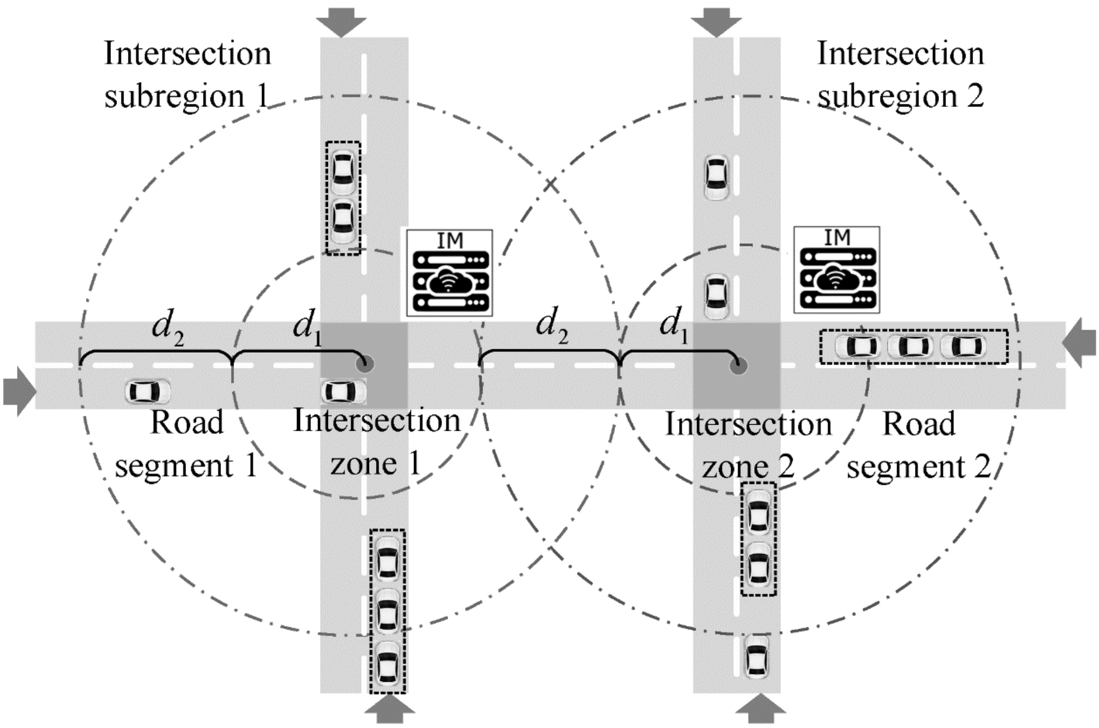


Figure 2. Studied scenarios of two intersections.

As depicted in **Figure 2,**two intersections were selected as illustrative examples, with each intersection subregion being partitioned into two distinct zones: the road segment zone and the intersection zone. Within the road segment zone, Intelligent Connected Vehicles (ICVs) were categorized based on their driving direction and car-following distance. Subsequently, ICVs were required to achieve the desired driving formation for each vehicle platoon, guided by the optimal reference velocity obtained from the cloud decision layer. Within the intersection zone, ICVs adjusted their movements to ensure conflict-free passage through the intersection zone via Vehicle-to-Infrastructure (V2I) communication [24]. Since the dynamic formation process is not the central focus of this paper, we refrain from providing an in-depth elaboration here.

During peak hours, for example, traffic from upstream regions pours into downstream areas. Unfortunately, the separate management of traffic signal systems at zone boundaries means that the traffic signals at downstream boundary intersections cannot coordinate with those at upstream boundary intersections in a timely manner. This lack of coordination results in traffic congestion and blockages at zone boundaries, which quickly propagate back to upstream regions, exacerbating regional traffic congestion.Furthermore, China has experienced frequent burst fire-disaster events in recent years, which require rapid evacuation of large numbers of people, logistics, and vehicles from affected areas to adjacent regions. If the traffic signals at the border entries of adjacent regions cannot perceive and anticipate the influx of a large volume of traffic in advance, and adjust their signal timings and cooperate with the devastated area, traffic bottlenecks can easily form at the boundary road segments. These bottlenecks hinder the rapid evacuation of affected traffic, posing threats to people's lives, property, and impeding the smooth execution of rescue and relief operations(Gao et al. 2020).

To address these challenges, there is a need for a coordinated and cooperative traffic signal control system at zone boundaries. Such a system should enable real-time information exchange and coordination between traffic signals at boundary intersections. By integrating traffic flow data, communication networks, and advanced signal control algorithms, it becomes possible to optimize traffic signal timings and coordinate the flow of vehicles between regions. This would enhance traffic efficiency, reduce congestion, and support effective disaster response and evacuation.The objective of this research is to develop a coordination control method for traffic signals at zone boundaries based on organic computing principles. The method aims to overcome the limitations of existing independent control systems and facilitate efficient coordination between traffic signals at boundary intersections. By incorporating modules such as traffic flow monitoring, self-optimization, self-modification, evolutionary learning, and self-assessment, the proposed method seeks to create a dynamic and adaptive traffic signal control system that can respond to changing traffic conditions and promote smooth traffic flow at zone boundaries(Sheikhi, Maani, and Ranjbar 2013).

The current independent control of traffic signal systems at zone boundaries results in a lack of coordination and inefficiencies. The occurrence of traffic congestion, blockages, and difficulties in disaster response further highlight the need for a coordinated traffic signal control system. The proposed research aims to develop a coordination control method that integrates organic computing principles and advanced algorithms to optimize traffic signal timings and facilitate efficient coordination at zone boundaries. By addressing these challenges, the research contributes to improving urban traffic management, reducing congestion, and enhancing the overall transportation system's performance(Chen et al. 2020).

**Research Objective**

The primary objective of this research is to develop a coordination control method for traffic signals at zone boundaries, leveraging the principles of organic computing. The specific research goals include:

1. Designing a traffic flow monitoring module to collect real-time data on traffic conditions at zone boundaries.
2. Developing a self-optimization module that utilizes optimization algorithms to adjust signal timings for improved traffic flow.
3. Creating a self-modification module to allow the system to adapt and improve its performance based on feedback and observed traffic patterns.
4. Implementing an evolutionary learning module to enable the system to learn and evolve its coordination strategies over time.
5. Incorporating a self-assessment module to evaluate the effectiveness of the coordination control method and make necessary adjustments.
6. Ensuring efficient coordination between traffic signals at zone boundaries to prevent congestion and traffic blockages.

**Coordination Control Method for Zone Boundary Traffic Signals**

This method for coordinating traffic signals at zone boundaries uses a step-by-step process. Here is a simplified explanation of each step:

1. Traffic flow monitoring: Traffic data is collected and calibrated to account for fluctuations and variations in traffic flow. The calibration considers factors like vehicle detection errors and spatial variations.
2. Setting: Parameters related to traffic flow, such as inflow and average travel time, are determined based on data collected from adjacent intersections. This helps describe the traffic flow patterns in the local area.
3. Traffic flow analysis: The running rate of traffic at zone boundaries is estimated by extracting historical traffic data and using statistical methods like clustering and principal component analysis. This helps understand the current traffic flow situation.
4. Building a time-space distribution mapping model: A model is created to map traffic parameters and flow data from different sources to specific monitoring points at zone boundaries. This helps analyze and visualize the traffic patterns.
5. Convergence analysis: Multiple decision-making methods are used to analyze and determine the traffic flow running rate at zone boundaries. This helps make informed decisions about traffic control.
6. Traffic behavior analysis: Current traffic flow conditions are evaluated based on factors like speed, flow, and occupancy rate. The behavior of traffic at the present time is determined by comparing it to different traffic patterns.
7. Traffic flow operation estimation: The traffic flow operation situation is estimated based on the running rate of traffic flow. This helps understand the overall traffic situation and make appropriate adjustments.
8. Self-optimization: Based on real-time traffic information, local traffic signal controllers optimize their control schemes. They consider factors like delay, stop frequency, and traffic capacity to improve traffic flow.
9. Self-adaptation: The intelligent traffic signal controller gathers traffic behavior and control variables from different zone boundaries. This information is used to construct a matrix representing the state of each crossing. It helps understand the traffic conditions at different locations.
10. Coordinated optimization: Zone boundary intersection groups are coordinated based on global optimization. Traffic signalization patterns and control objectives are

optimized to improve overall traffic flow.

11. Evolutionary learning: The traffic flow running rate of zone boundary intersection groups is dynamically analyzed, and the best traffic signalization patterns and control objectives are identified. This helps improve the efficiency of traffic signal control.
12. Coordination with adjacent areas: The coordination process between zone boundary intersection groups and adjacent areas is established. This allows for collaborative decision-making and optimization of traffic signal control strategies.
13. Traffic signal control scheme optimization: The traffic signal control schemes for each signalized intersection within the zone boundary intersection groups are optimized based on coordination with adjacent areas. This ensures efficient traffic flow management.
14. Evolutionary optimization: An evolutionary algorithm is applied to optimize the traffic signal control schemes. This involves iterative steps of state transition, updating pheromones, crossover, and mutation. The goal is to find the optimal solution for traffic signal control.

Overall, this method aims to improve traffic flow at zone boundaries by monitoring, analyzing, and optimizing traffic signals in a coordinated and adaptive manner.

**Conclusion**

In conclusion, the coordination control method for traffic signals at zone boundaries based on organic computing presented in this research offers a promising approach to improve urban traffic flow. By integrating various modules such as traffic flow monitoring, self-optimization, self-modification, evolutionary learning, and self-assessment, the proposed method enables efficient coordination and avoids congestion at zone boundary intersections. The research contributes to the field of artificial intelligence and urban traffic signal control by providing a systematic and intelligent approach to address the challenges of traffic congestion in urban areas.

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