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A real-time adaptive signal control method for multi-intersections in mixed connected vehicle environments

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Key words:

Adaptive traffic signal control; Connected vehicle (CV); Travel delay; Arterial road control

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Motivation

The traditional traffic signal control methods, such as actuated signal control or the maximum bandwidth method, fail to leverage the advantages of real-time information sharing in a mixed traffic environment with Connected Vehicles (CVs) to enhance signal control efficiency. This is particularly evident in mixed traffic flows consisting of CVs and Human Driven Vehicles (HDVs). Therefore, It is especially important to develop real-time adaptive signal control strategies for signalized arterials under low CV penetration rate conditions.

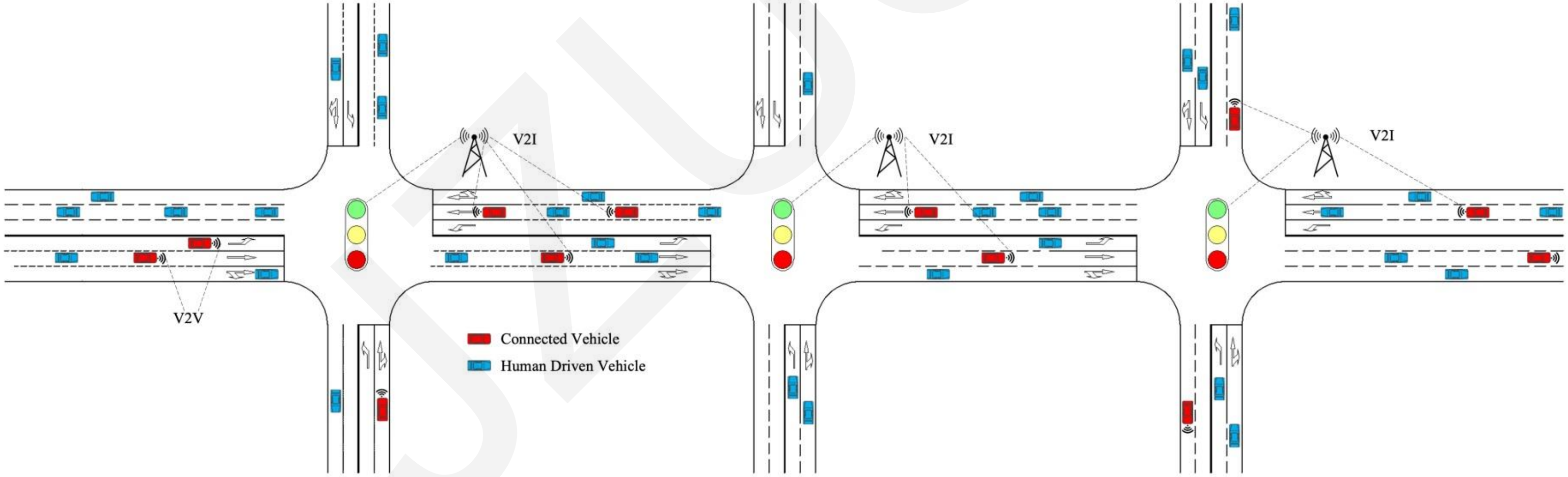

Fig. 1 Illustration of adaptive signal control for an arterial with three signalized intersections.

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Main Idea

1. Leveraging CVs in mixed traffic flows to detect the real-time operational status of surrounding HDVs.
2. A pre-time horizon is designed for the proposed adaptive signal control method to pre-allocate the Signal Phase and Timing (SPaT) based on real-time traffic flow information collected by CVs.
3. Different CV detection ranges and penetration rates are tested to evaluate their effects on the performance of the proposed adaptive signal control method.

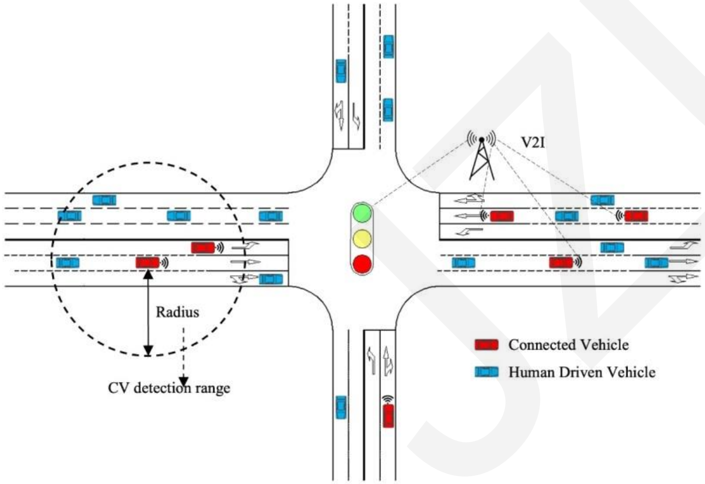

Fig. 2 The schematic of CV detection range.

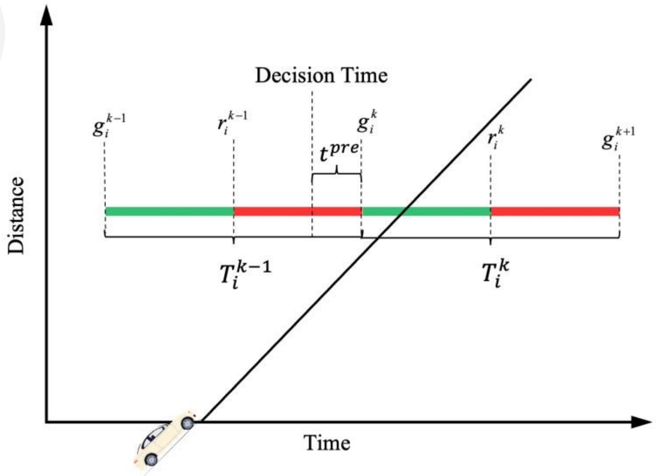

Fig. 3 The schematic of pre-time horizon.

Framework

The rolling optimization process of the proposed adaptive signal control method.

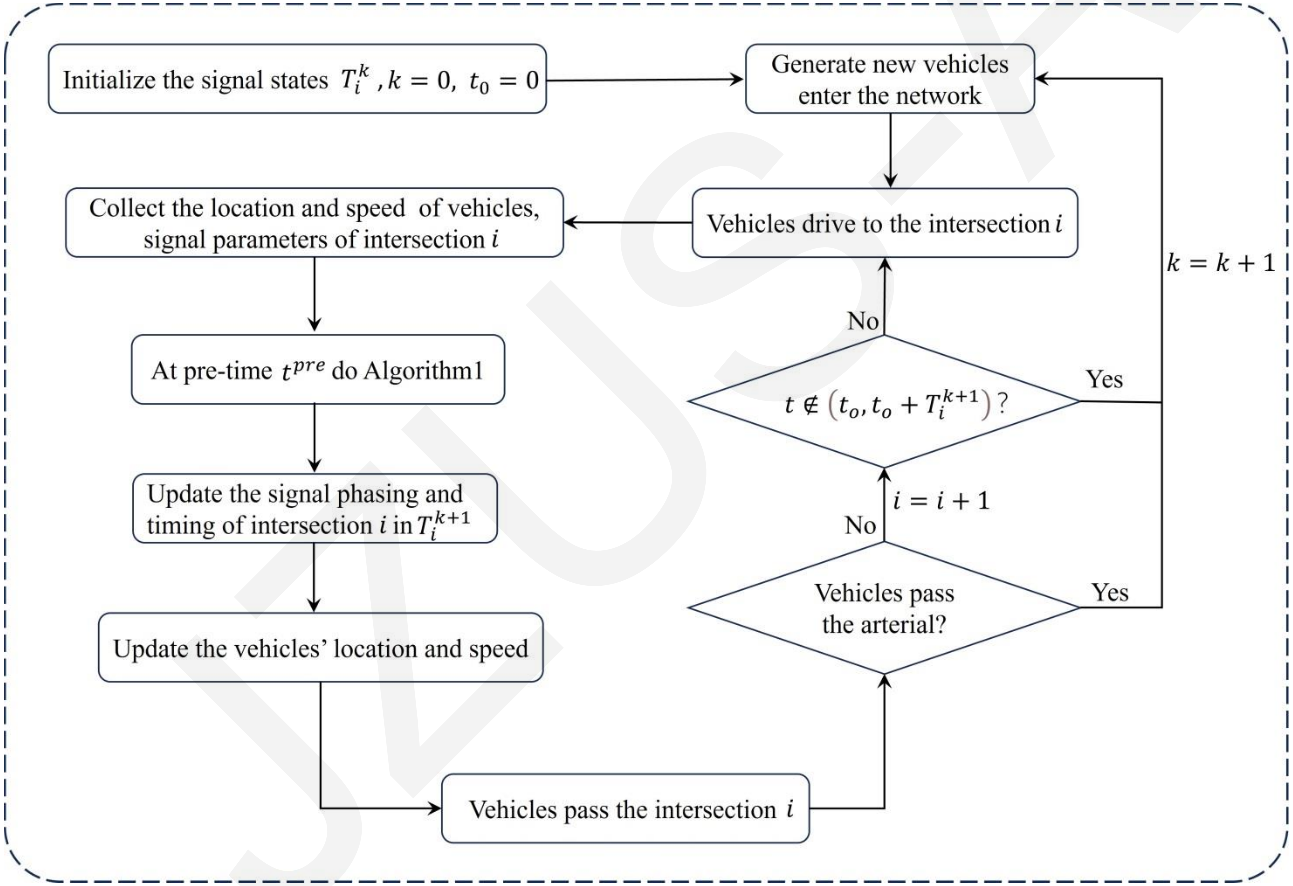

Fig. 4 Framework of the proposed adaptive signal control method.

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Simulation

The simulation scenario contains three intersections. The parameters of the links and the initial signal phasing are provided below.

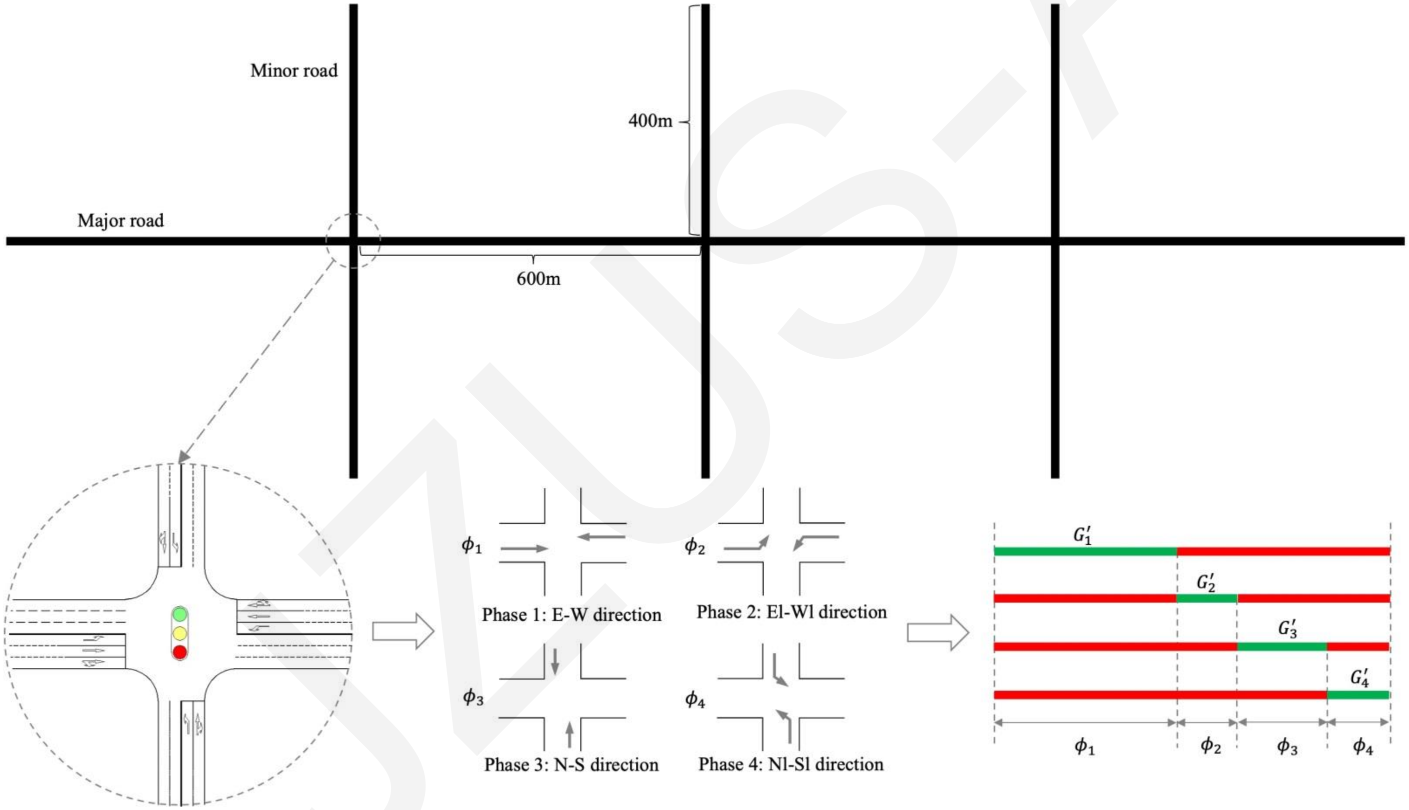

Fig. 5 Arterial scenario and signal settings in the simulation.

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Results

The performance in reducing the average travel delay on both the major and minor roads is shown in Table 2 and Table 3, respectively.

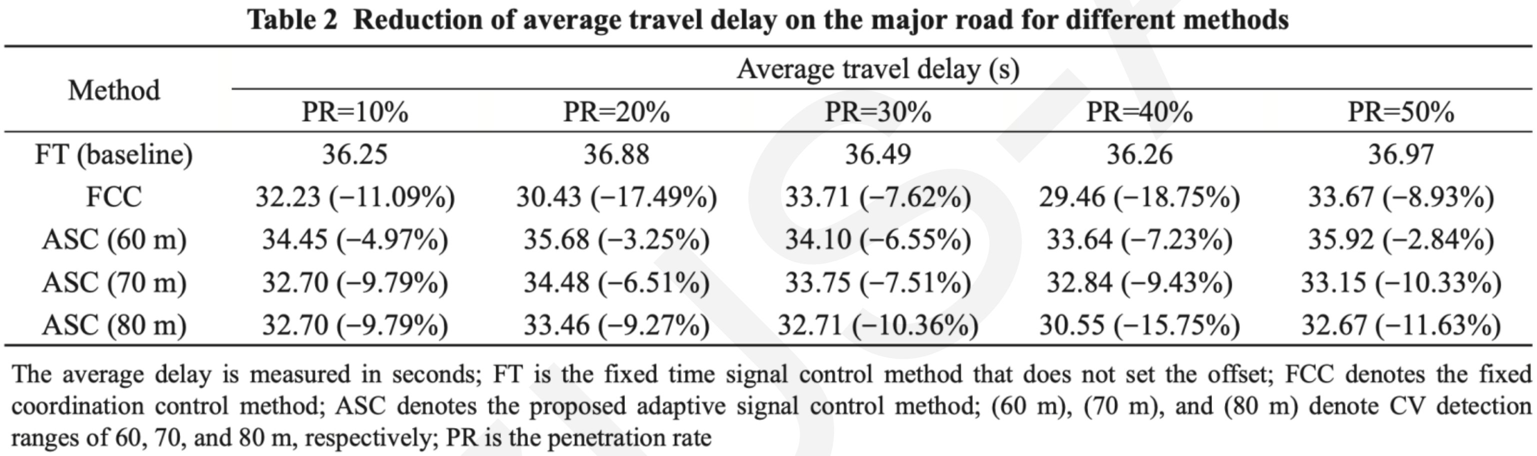


Table 2 Reduction of average travel delay on the major road for different methods

Method	Average travel delay (s)				
	PR=10%	PR=20%	PR=30%	PR=40%	PR=50%
FT (baseline)	36.25	36.88	36.49	36.26	36.97
FCC	32.23 (−11.09%)	30.43 (−17.49%)	33.71 (−7.62%)	29.46 (−18.75%)	33.67 (−8.93%)
ASC (60 m)	34.45 (−4.97%)	35.68 (−3.25%)	34.10 (−6.55%)	33.64 (−7.23%)	35.92 (−2.84%)
ASC (70 m)	32.70 (−9.79%)	34.48 (−6.51%)	33.75 (−7.51%)	32.84 (−9.43%)	33.15 (−10.33%)
ASC (80 m)	32.70 (−9.79%)	33.46 (−9.27%)	32.71 (−10.36%)	30.55 (−15.75%)	32.67 (−11.63%)

The average delay is measured in seconds; FT is the fixed time signal control method that does not set the offset; FCC denotes the fixed coordination control method; ASC denotes the proposed adaptive signal control method; (60 m), (70 m), and (80 m) denote CV detection ranges of 60, 70, and 80 m, respectively; PR is the penetration rate

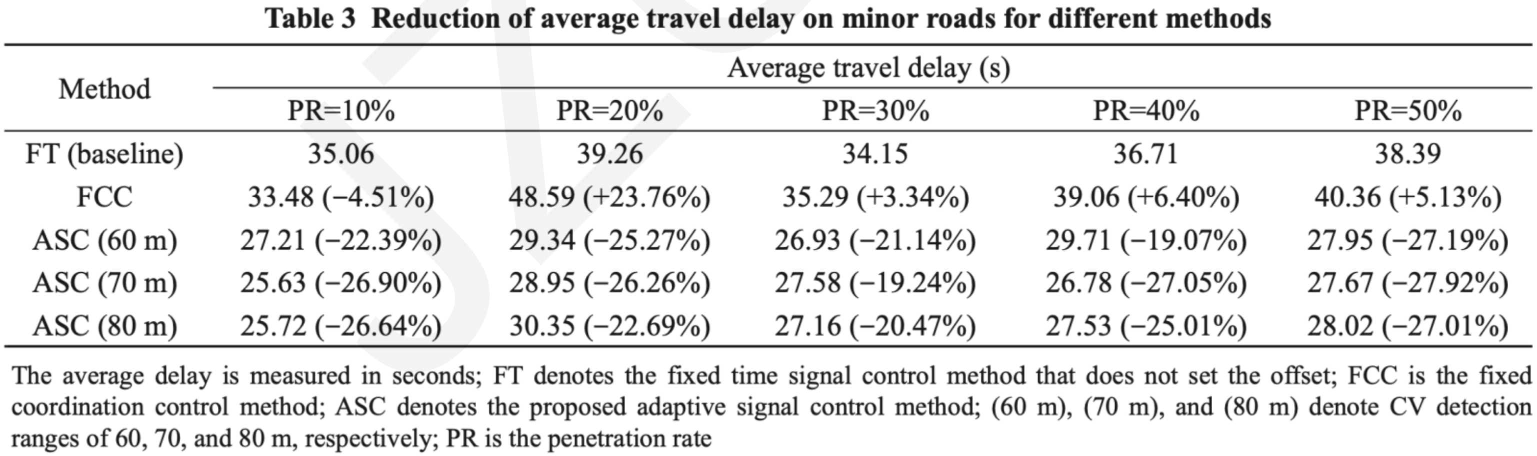
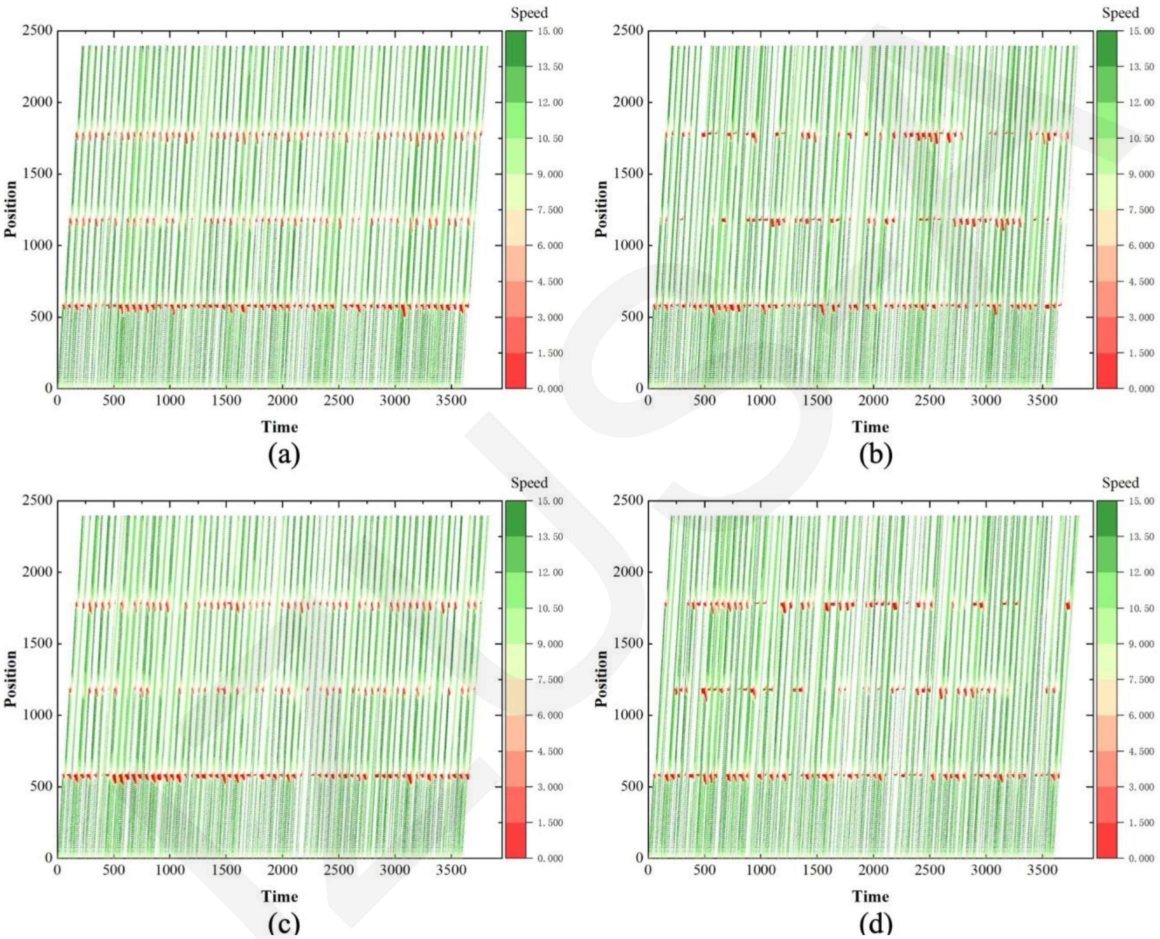


Table 3 Reduction of average travel delay on minor roads for different methods

Method	Average travel delay (s)				
	PR=10%	PR=20%	PR=30%	PR=40%	PR=50%
FT (baseline)	35.06	39.26	34.15	36.71	38.39
FCC	33.48 (−4.51%)	48.59 (+23.76%)	35.29 (+3.34%)	39.06 (+6.40%)	40.36 (+5.13%)
ASC (60 m)	27.21 (−22.39%)	29.34 (−25.27%)	26.93 (−21.14%)	29.71 (−19.07%)	27.95 (−27.19%)
ASC (70 m)	25.63 (−26.90%)	28.95 (−26.26%)	27.58 (−19.24%)	26.78 (−27.05%)	27.67 (−27.92%)
ASC (80 m)	25.72 (−26.64%)	30.35 (−22.69%)	27.16 (−20.47%)	27.53 (−25.01%)	28.02 (−27.01%)

The average delay is measured in seconds; FT denotes the fixed time signal control method that does not set the offset; FCC is the fixed coordination control method; ASC denotes the proposed adaptive signal control method; (60 m), (70 m), and (80 m) denote CV detection ranges of 60, 70, and 80 m, respectively; PR is the penetration rate

Results



(a)

(b)

(c)

(d)

Fig. 6 Spatiotemporal trajectories of the mixed traffic flow at various penetration rates: (a) PR of 10% with the fixed time control method; (b) PR of 10% with the proposed adaptive signal control method; (c) PR of 30% with the fixed time control method; (d) PR of 30% with the proposed adaptive signal control method

Conclusions

This paper designed a real-time adaptive signal control method that uses data collected by CVs to dynamically optimize the SPaT at intersections along an arterial road. The proposed method only uses the data collected by CVs; it does not require road-side units to record the speeds and locations of human-driven vehicles. Additionally, the proposed method considers the traffic efficiency of both major and minor roads. Through testing of the proposed adaptive signal control method in SUMO, we demonstrated that our approach outperforms a fixed coordination control method in reducing the total travel delay of the arterial network. This novel strategy may provide insights into formulating signal control plans that enhance traffic efficiency. Future work might include designing adaptive signal control methods for regional traffic networks using CV data.

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