Optimized Cooperative Driving through Lightweight Vehicle Intention Sharing

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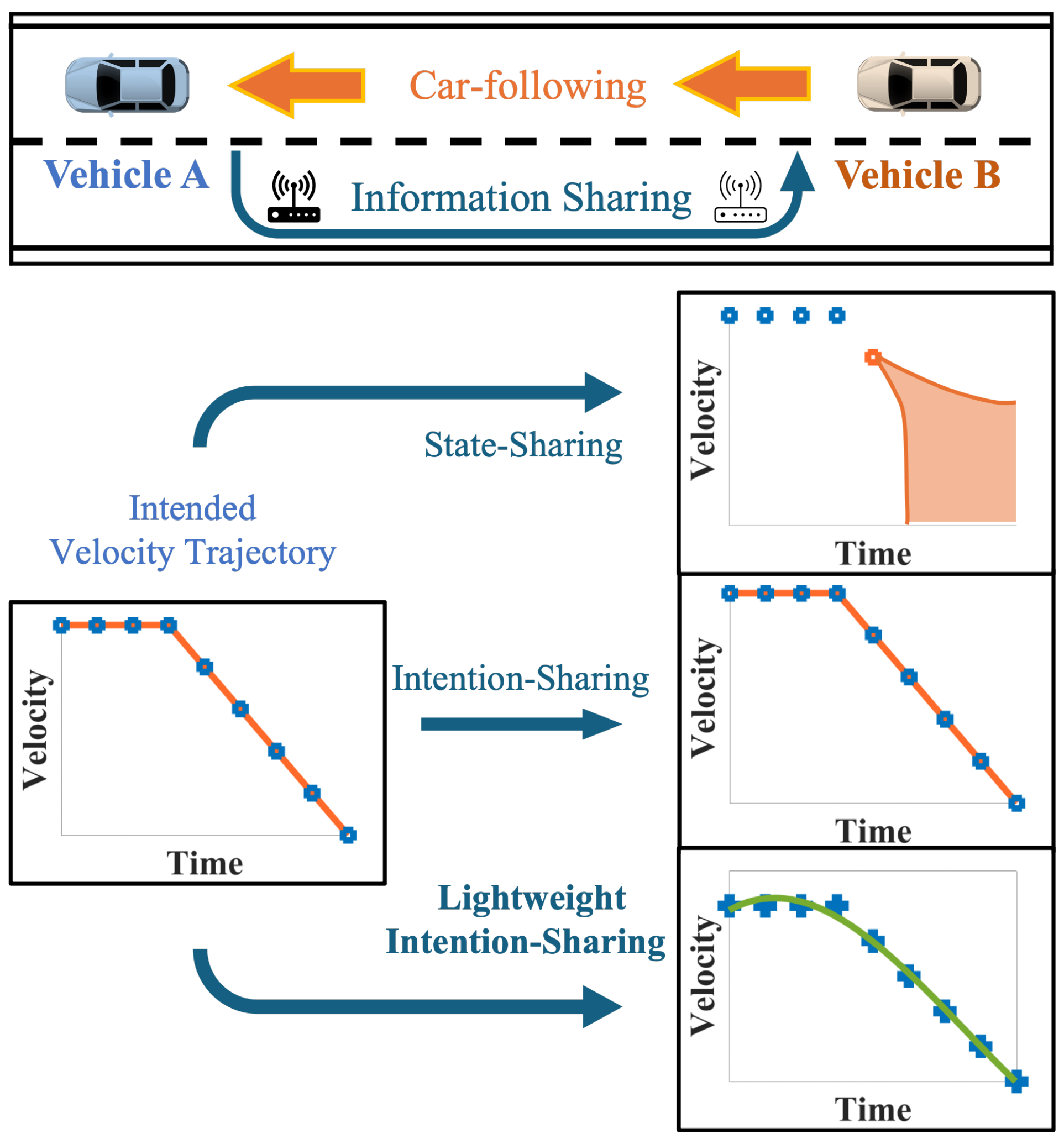
Abstract

Cooperative driving systems are expected to enhance autonomous vehicles' safety, mobility, and efficiency through vehicle connectivity technologies. Early-stage vehicle-to-vehicle communication transmits high-frequency **single-state information**. These approaches have limited prediction accuracy, require hardware with high-frequency capacity, and are easily affected by communication delays. Current studies have demonstrated that receiving planning and intention from surrounding vehicles, which transmit **multi-state information**, can improve prediction accuracy but require higher communication data volume. However, mainstream vehicle communication methods, such as dedicated short-range communication and cellular vehicle-to-everything, face difficulties in balancing cost and bandwidth to support intention sharing. To address this challenge, a **lightweight intention sharing** approach is proposed, offering potential **reductions in communication data volume** while **maintaining the prediction accuracy** of surrounding vehicles. The feasibility of this approach and its robustness to communication delays have been verified through Linear–Quadratic Regulators for car-following behavior by both simulation and real vehicle experiments. The results have shown that both the planned and actual trajectories of the following vehicle maintain high consistency with those adopting ideal intention sharing approaches while achieving significant reductions in data transmission.

Comparison



State Sharing

- *Lowest data volume*
- *High frequency*
- *Limited prediction accuracy*

Intention Sharing

- *High data volume*
- *Highest prediction accuracy*

Lightweight Intention Sharing

- *Reduced bandwidth*
- *Maintained accuracy*

Approaches	Frequency	Data Volume	Delay Sensitivity	Prediction Deviation
Single-state sharing	High	**Low**	High	High
Intention sharing	**Low**	High	**Low**	**Low**
(ours) Lightweight intention sharing	**Low**	**Low**	**Low**	**Low**

Method

Car-following State

- State vector (position and velocity) $s_i(t) := [p_i(t), v_i(t)]^T$
- Distance and velocity difference $[d_i(t), \Delta v_i(t)]^T = s_i(t) - s_{i-1}(t)$

Vehicle Dynamics

- Control law $a_i(t) = g(d_i(t-\eta), \Delta v_i(t-\eta), v_i(t-\eta))$
- Linear control $a_i(t) = g_i^d\,(d_i(t-\eta) - d_s) + g_i^{\Delta v}\Delta v_i(t-\eta) + g_i^v v_i(t-\eta)$
- Discrete time $s_i(t+\tau) = C_i s_i(t) + D_i u_i(t)$

$$C_i = \begin{bmatrix} 1 & \tau \\ 0 & 1 \end{bmatrix}, \quad D_i = \begin{bmatrix} 0 \\ \tau \end{bmatrix}.$$

CACC & LQR

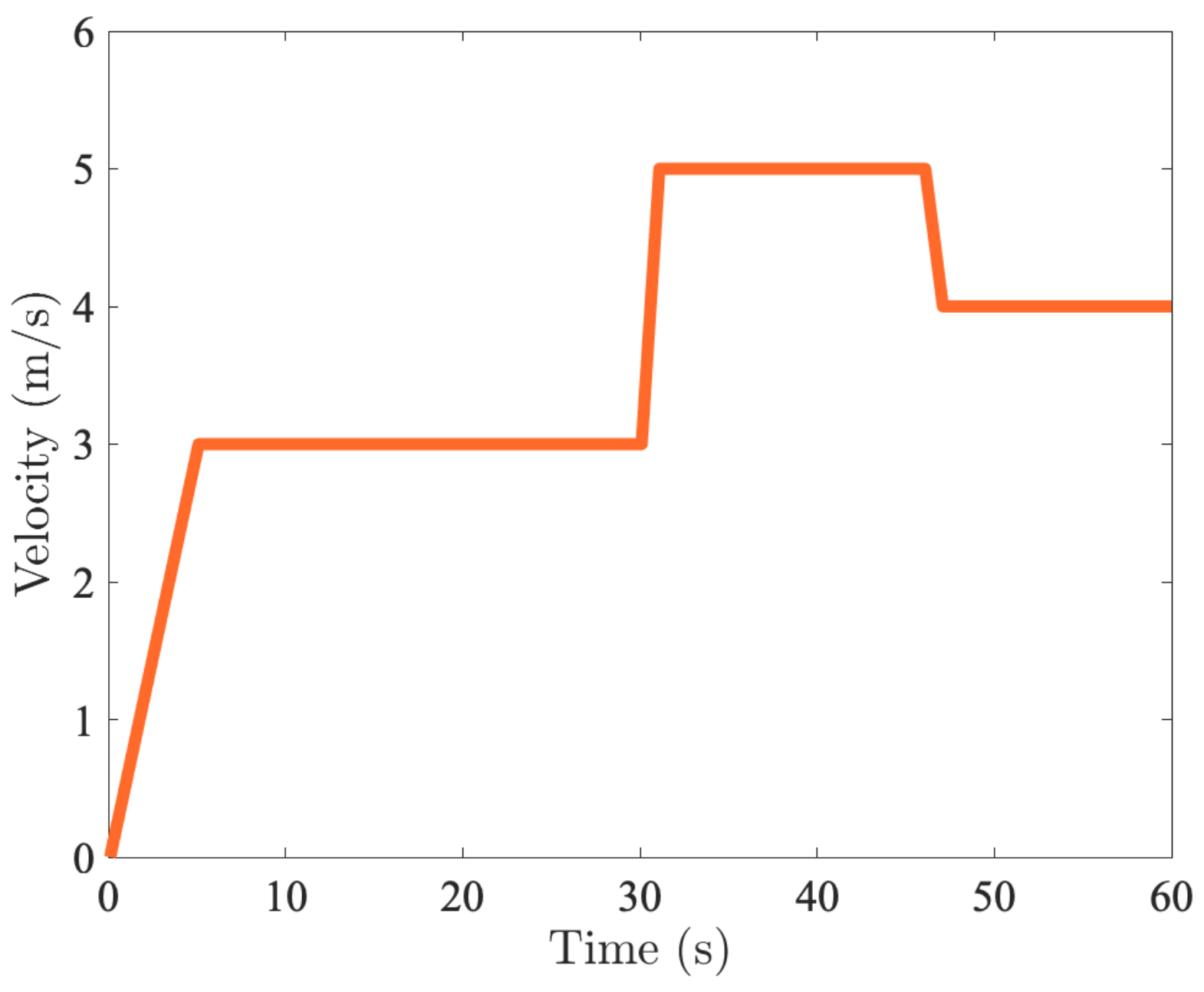
- Time horizon $\mathscr{T}_\psi := \{t_\psi, t_\psi + \tau, \ldots, T_\psi\}$
- Distance gap $d(t) = d_\psi + \sum_{\mathscr{T}_\psi} \left(v_\psi(t) - v(t)\right)\tau, \forall t \in \mathscr{T}_\psi$
- State error $e(t) = s(t) - s_\psi(t),$

$$= [d(t) - v(t)T - d_s, v(t) - v_\psi(t)]^T$$

- LQR optimization

$$J = \sum_{t=t_\psi}^{T_\psi} \left(\frac{1}{2}e(t)^T Q e(t) + \frac{1}{2}u(t)^T R u(t)\right)$$

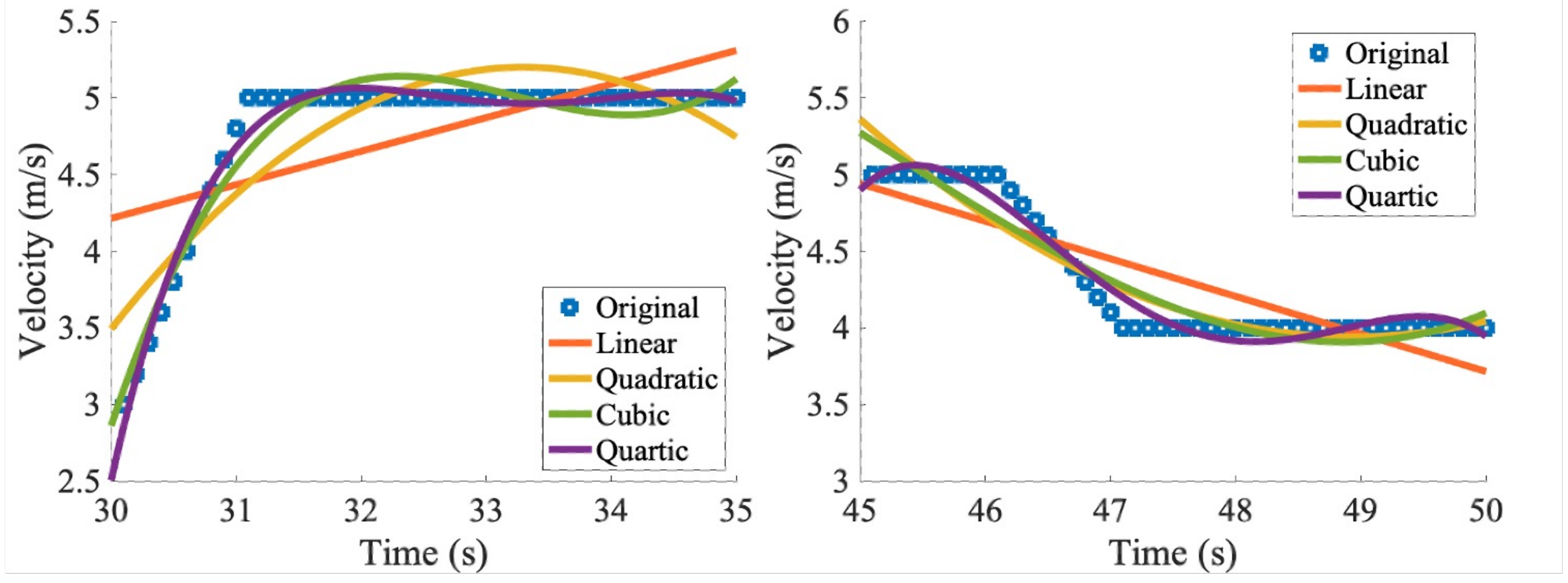
Lightweight Intention Sharing



Velocity cycle: A designed velocity cycle includes two acceleration processes, a deceleration process, and three constant speed processes.

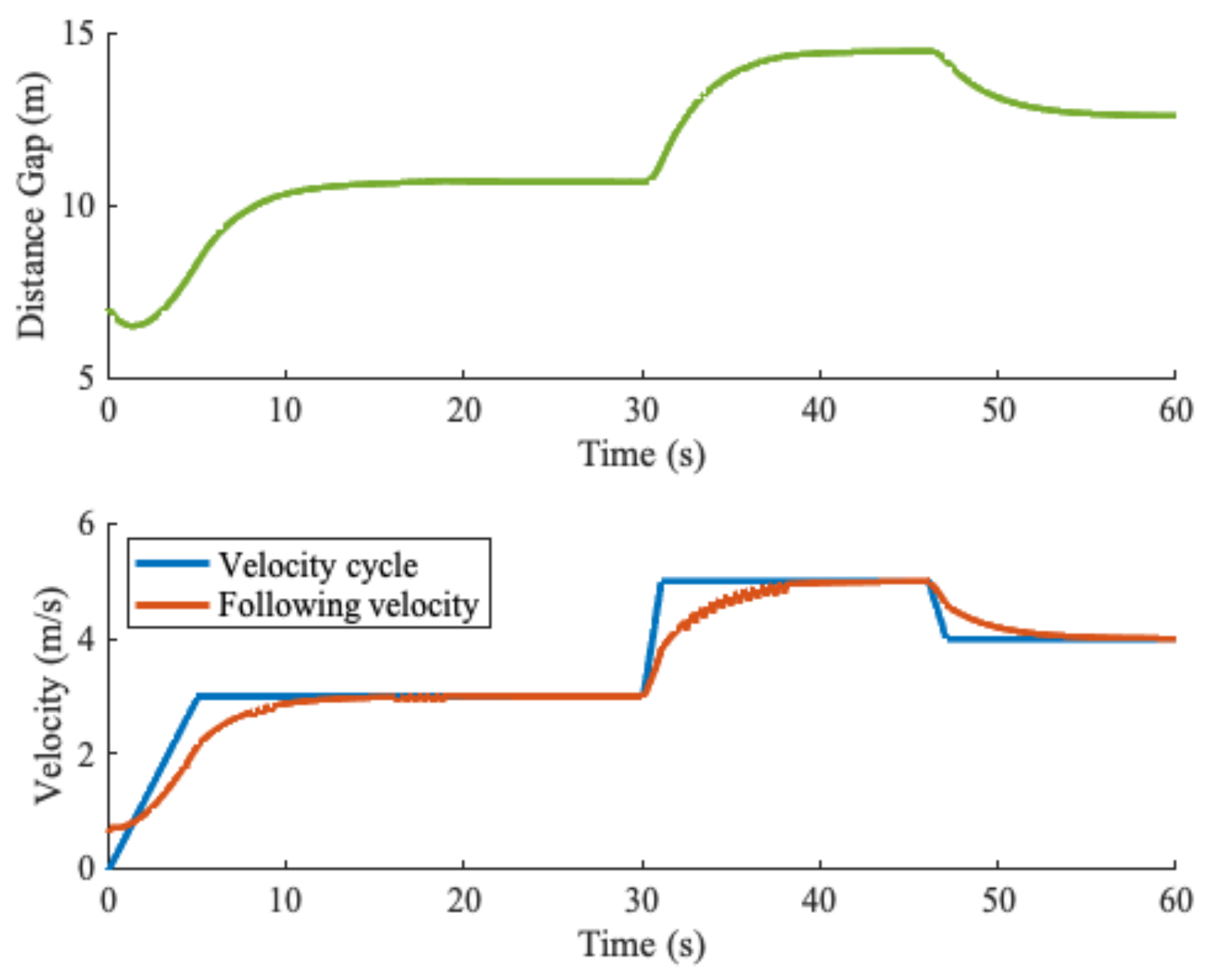
Data piece: The whole cycle is split into 12 segments, with time intervals of five seconds (motion prediction duration). Each piece is utilized for sharing as intentions.

Polynomial regression: We illustrate the cases of linear regression, quadratic regression, cubic regression, and quartic polynomial regression.

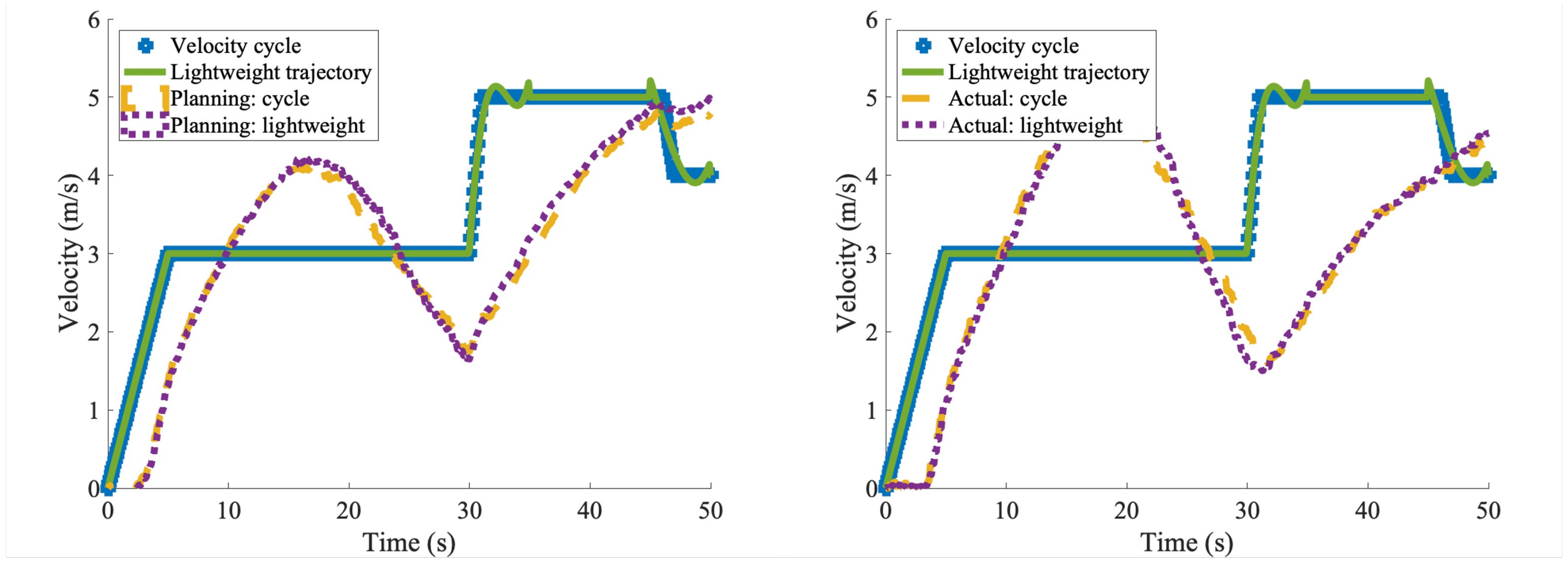


Experiments

Simulation: We transmitted the velocity cycle to the following CAV and deployed LQR control. (upper) temporal variation of the distance gap; (lower) reference velocity cycle and velocity of the following CAV.



Real vehicle experiments: Intention sharing and our lightweight intention sharing are compared. (left) planning of following CAV; (right) actual velocity of following CAV.



Conclusion

We propose a lightweight intention sharing approach between vehicles. Specifically, we adopt a **polynomial regression to represent a five-second period velocity profile and transmit the coefficients** from the preceding vehicle to the following vehicle. We verified this lightweight intention sharing through simulation and real vehicle experiments. The results demonstrate that the planning and actual vehicle trajectories supported by the original velocity cycle and our lightweight intention sharing are precisely consistent, which proves that our approach is **effective in decreasing communication bandwidth requirements, while maintaining the expected improvement of intention sharing** in cooperative driving. It also sparks consideration for using low-cost but low-bandwidth approaches like LED-generated barcodes to quickly improve the traffic utility of connected vehicles *(refer to other papers of our group)*.

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