A Decentralized Network in Vehicle Platoons for Collision Avoidance

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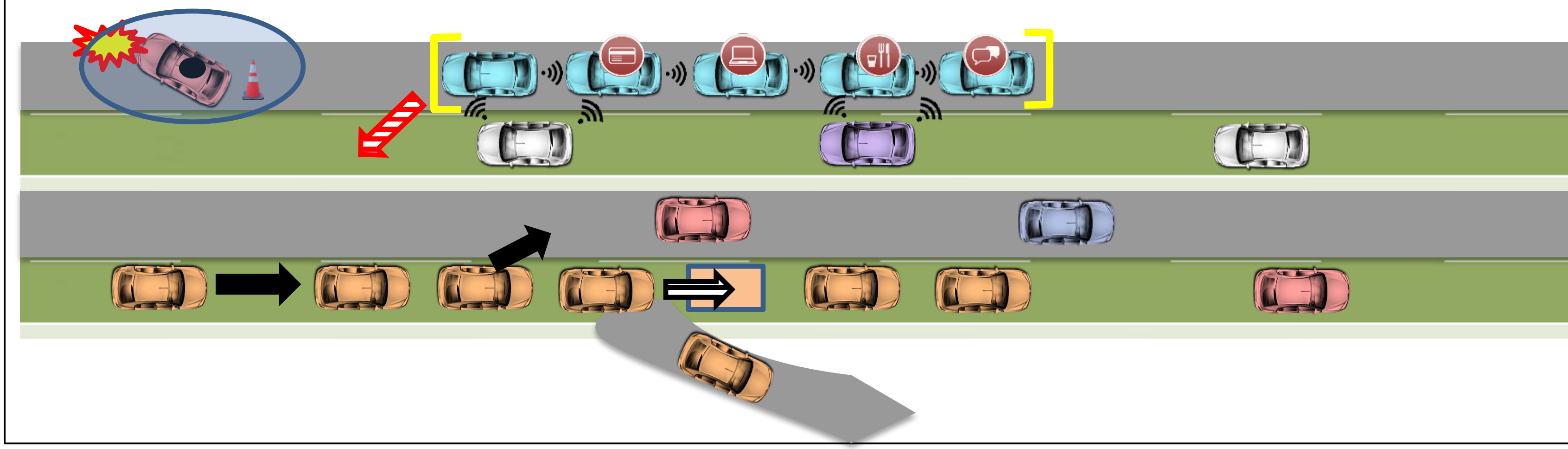
Outline

- Introduction
- System Design
  - Interference avoidance
  - The minimum number of channels
- Performance Evaluation
- Conclusions

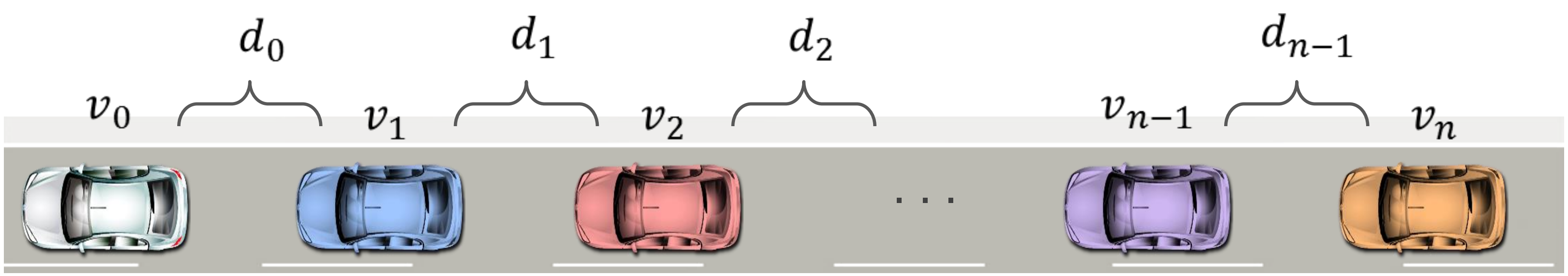
Introduction

As a future form of road transportation system, vehicle platoon has great potential.



Introduction

In a platoon, one leader vehicle and several follower vehicles drive in a single lane, maintain a safety inter-vehicle distance.



Introduction

- Vehicle platoon provides-
  - Higher traffic throughput
  - Better traffic flow control
  - Increase energy efficiency
- Inter-vehicle communication is crucial
  - Avoid unwanted collisions between vehicles
  - Strictly maintain safety distance

Introduction

Existing centralized approaches -

- Platoon wrt sensor failures (ITS ‘14)
- Model predictive controller (CTS ‘11)
- Platoon dynamic beaconing (INFOCOM’13)

However-

- Do not consider dynamic joining/leaving of vehicles
- Introduce single point of failure
- Limited number of vehicles
- Safety cannot be guaranteed

Introduction

Proposed decentralized approach-

•Vehicles have short range communication device

•Guarantee vehicles’ safety

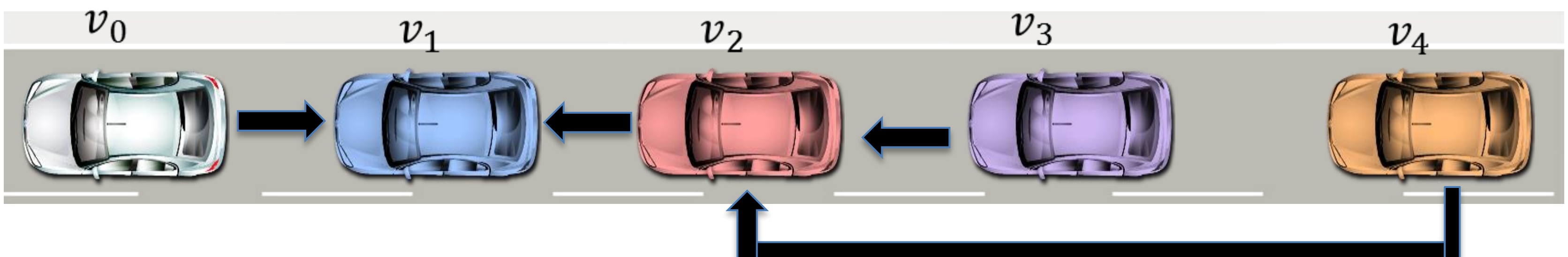
•Increase the number of vehicles

•Dynamic formation of platoon

Introduction

How to reduce signal interference?

Multiple active transmissions is crucial for safety



Introduction

How to reduce signal interference?

Multiple active transmissions is crucial for safety

Efficient channel allocation technique using platoon features.

Introduction

Our proposed method: Fast and Light weight

Autonomous channel allocation technique

- Utilize platoon architecture
- Distribute channels based on interference range
- Allow minimum number of channels

Advantages

- Decide communication channel automatically
- Reduce signal interference

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Vehicle channel allocation problem

Given:

•A finite set of senders S and their respective receivers R in a geometric plane, decoding threshold γ^{th}, and a constant Λ.

Problem:

•Using Λ channels, whether there exists a schedule, such that the SINR received by each vehicle receiver is higher than γth?

Overview of Proposed Approach

Number of Channels:

•Determine the minimum number of channels based on signal interference.

Autonomous channel selection:

•Each vehicle selects the communication channel based on its segment ID in platoon

Goal:

•Choose a channel allocation method so that communication overhead can be reduced

The minimum number of channels

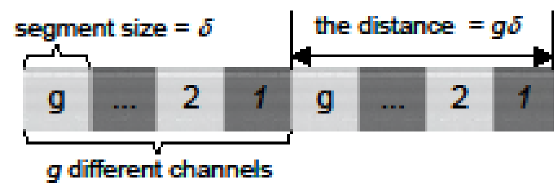
The required number of channels:

•Based on the transmission range of vehicles (R), path loss exponent (α), decoding threshold γ_{th}, and segment distance δ

•If the distance between two segments is $kg\delta$

•The safety distance between two segments is $kg\delta - \delta$

•The interference generated from nearby vehicles is at most $P(kg\delta - \delta)^{-\alpha}$



The minimum number of channels

The required number of channels:

- The sum interference received by each vehicle is at most $P(g - 1)^{-\alpha}\delta^{-\alpha}\zeta(\alpha)$
- Then, the minimum number of channel, g, is equal to $\lceil (R^{\alpha}\delta^{-\alpha}\zeta(\alpha)\gamma_{th})^{1/\alpha} + 1 \rceil$

[More details in the paper]

The autonomous channel selection

The channel selection:

- The distance offset of a follower vehicle receiver r_i, denoted by Δ_i, is defined as the remainder of its distance from the leader vehicle (r_1) divided by $g\delta$
- Each vehicle's distance offset determines its segment ID, and then determines its channel
- Given the distance offset of a receiver r_i, Δ_i, the segment ID of this vehicle is $\lceil \frac{\Delta_i}{g\delta} \rceil$

[More details in the paper]

The autonomous channel selection

The channel selection:

•It associates each distance offset with each channel in g channels

•A vehicle receives this table from its preceding vehicle after it joins the platoon. This table is kept in each vehicle's storage

•Since the partition is static over time, once the table is built, each vehicle does not need to change the FLA table anymore

The autonomous channel selection

The channel selection:

- Using the FLA table, each vehicle only needs to know its distance from the leader vehicle
- The leader vehicle's current location is periodically propagated to all the follower vehicles
- By piggybacking, leader's location information is periodically sent from a preceding vehicle to its succeeding vehicle

The autonomous channel selection

The channel selection:

•Based on the location, each follower vehicle can calculate its distance from the leader vehicle

•Then, it checks the FLA table by the calculated distance offset and finds the corresponding channel

The autonomous channel selection

The channel selection:

•For example, if the safety distance is 30m, the number of channels, g, is 5. If, a vehicle i estimates that the distance between the leader vehicle and itself is 195m

•Then, vehicle i's distance offset equals 195 mod (30 × 5) = 45m

•Since 45 ∈ [30,60), it chooses channel 2 based on the FLA table

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Performance Evaluation: Settings

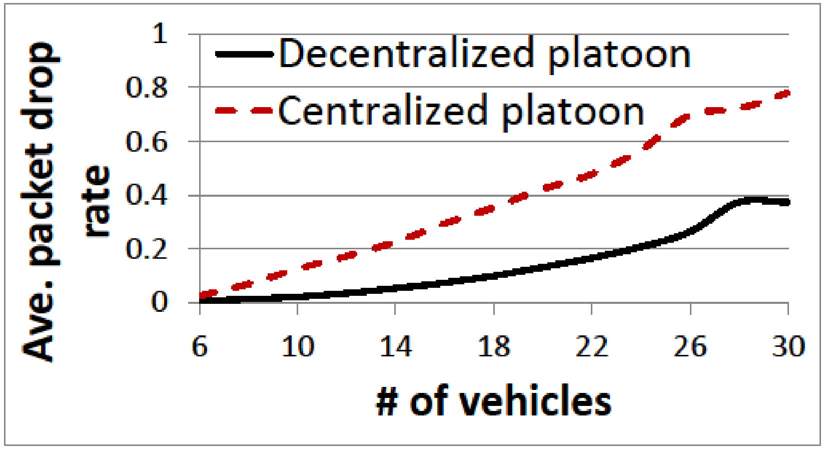
- Simulation
  - Platoon Network
    - Network Simulator 3
  - Channel allocation
    - Matlab
  - 6-30 vehicles
- Comparison methods
  - Centralized platoon network
  - Graphed-based channel allocation
  - SINR-based channel allocation

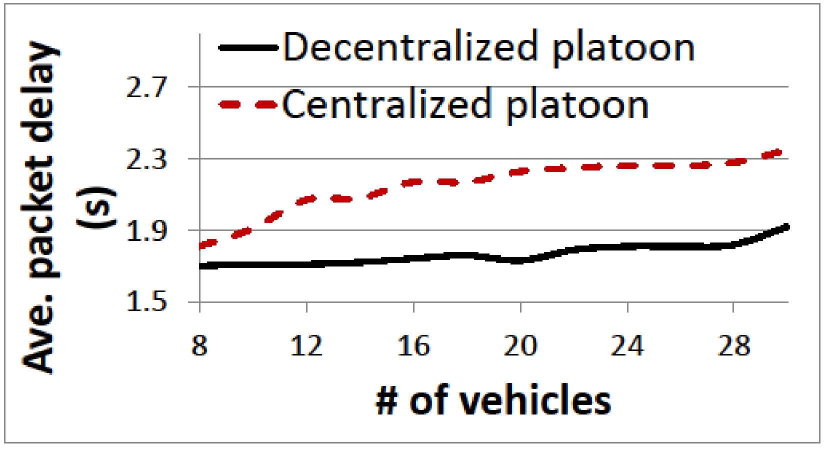
[3] https://www.palmetto.clemson.edu/palmetto/.

Performance Evaluation: Results

- Average packet drop and delay wrt network

Setting: different number of vehicles



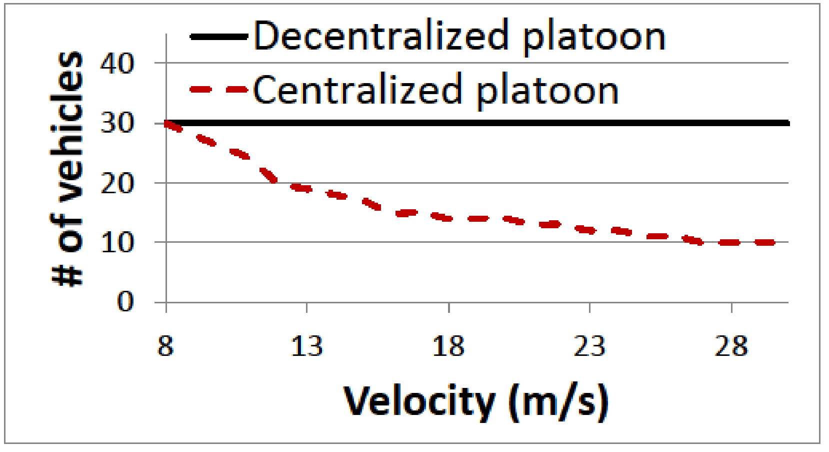


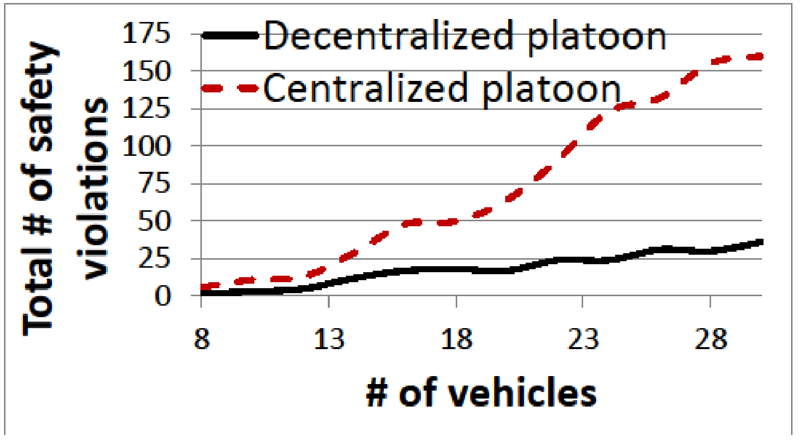
- Observation: Decentralized platoon network < Centralized platoon network
- Reason: In Decentralized platoon network, vehicles only communicate with neighbors.

Performance Evaluation: Results

- Number of vehicles and safety violation wrt network

Setting: different number of vehicles



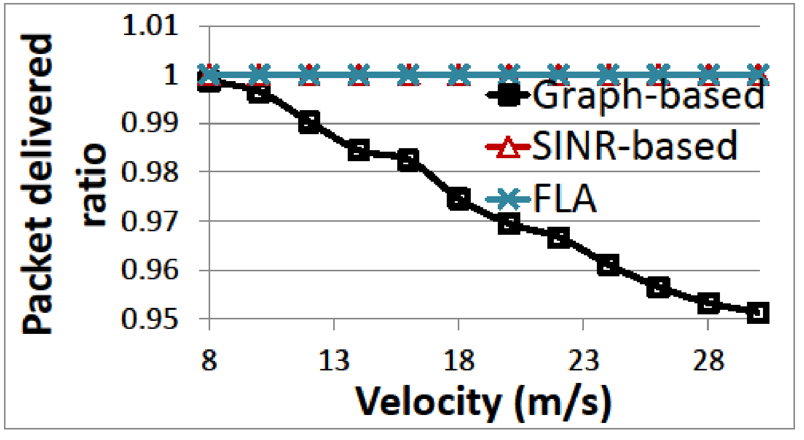


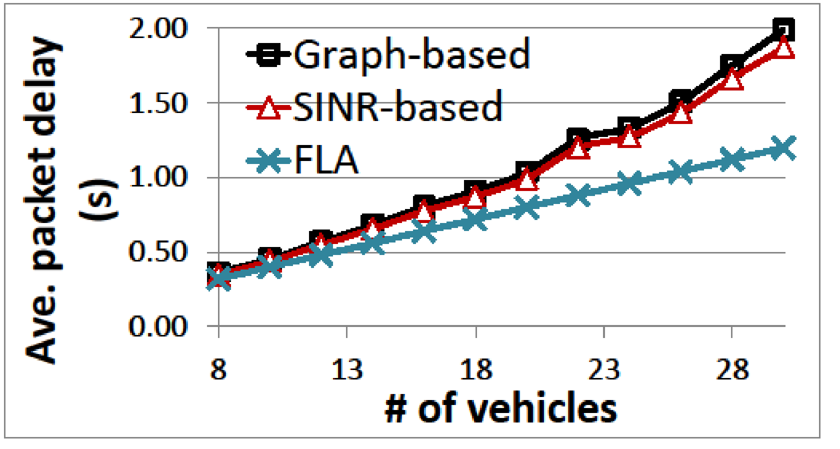
- Observation: Decentralized platoon network < Centralized platoon network
- Reason: In Centralized platoon network, the length of platoon limits the number of vehicles inside platoon. Also, Higher packet delay causes more safety violations.

Performance Evaluation: Results

- Packet delivered ratio and delay wrt channel allocation methods

Setting: different number of vehicles



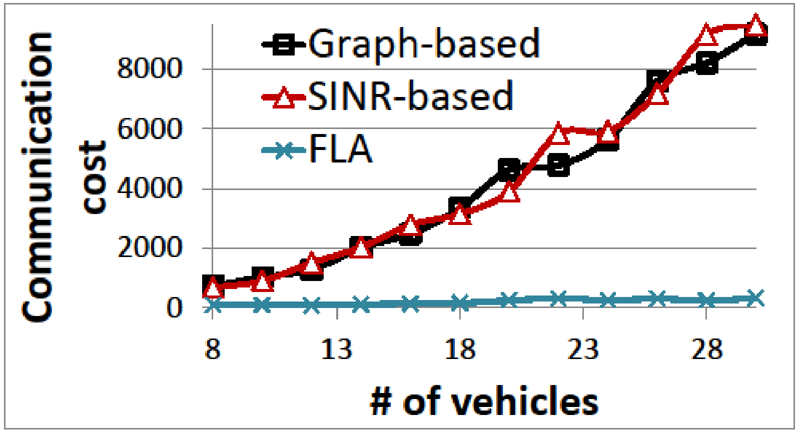


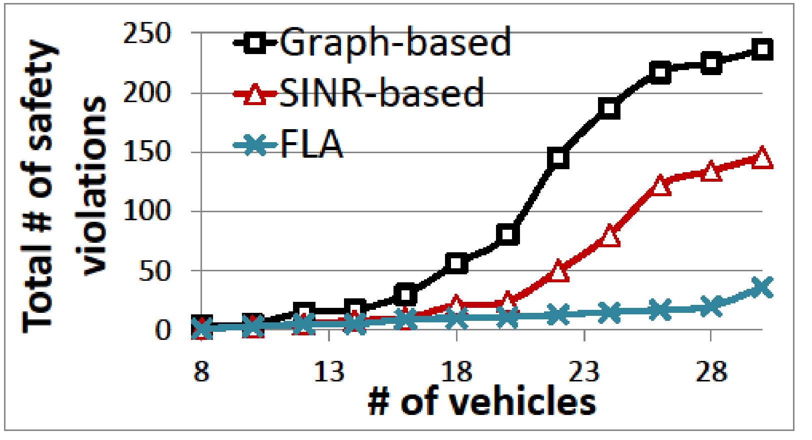
- Observation: FLA is better than Graph-based and SINR-based methods
- Reason: In FLA, each packet does not need to wait longer time for other packets.

Performance Evaluation: Results

- Communication cost and safety violation wrt channel allocation methods

Setting: different number of vehicles





- Observation: FLA ≤ SINR-based ≤ Graph-based
- Reason: In FLA, vehicle can change its own channel based on its scored FLA table. Also, vehicle can adjust its position quickly in FLA to avoid collisions.

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Conclusion

- Fast and Light weight Autonomous channel allocation: allocates channel based on interference range
- Simulation in different scenarios evaluate:
  - Reduce packet drop rate, packet delay, and communication cost
  - Support more vehicles in platoon
  - Reduce safety violation and provide more safety

- Future work: Study different channel allocation models for high-speed decentralized platoon network

Thank you!

Questions & Comments?

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