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

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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 $\gamma^\text{th}$, and a constant $\Lambda$.

Problem:
• Using $\Lambda$ channels, whether there exists a schedule, such that the SINR received by each vehicle receiver is higher than $\gamma^\text{th}$?
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 $\gamma_{th}$, and segment distance $\delta$
• 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 $\Delta_i$, 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 $r_i$, $\Delta_i$, the segment ID of this vehicle is $\left\lfloor \frac{\Delta_i}{g\delta} \right\rfloor$

[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 $195 \mod (30 \times 5) = 45$m
• Since $45 \in [30,60)$, 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

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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