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"A Reliable Token-Based MAC Protocol for Delay Sensitive Platooning Applications"

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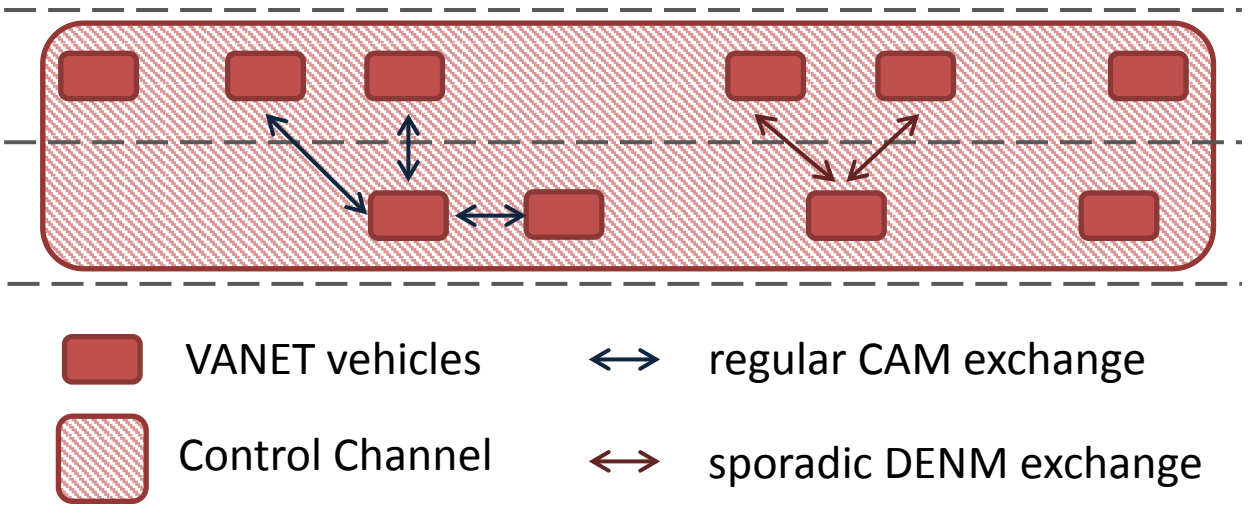
Background on VANETs and platooning

Vehicular Ad-Hoc Network (VANET)

- Ad-hoc network of vehicles
- Short to medium-range communication (radius < 1 km)
- Dedicated frequency channel of safety-related data exchange
  - Regular exchange of status data (CAM)
  - Event-triggered messages (DENM)
- Physical & MAC layer standardized as IEEE 802.11p



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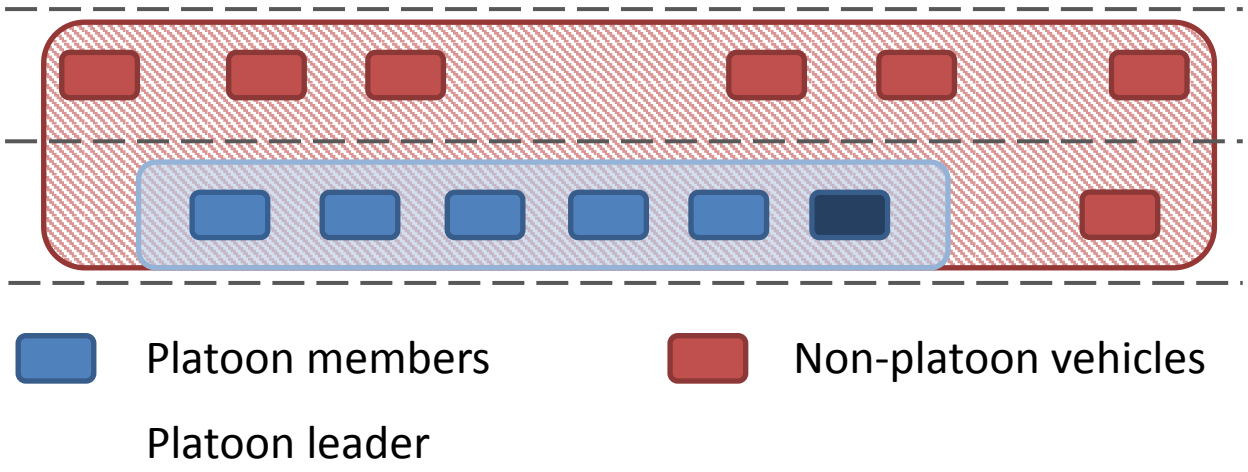
Background on VANETs and platooning

Platooning

- Group of vehicles following a dedicated leader at highly reduced inter-vehicle distances
- Considerable fuel reduction
- Semi-automated driving → high requirements on underlying communication



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VANET vs Platooning

VANET

- Unpredictable topology and high relative mobility
- Vehicles have no given role or hierarchy
- Broadcast only
- Relatively high requirements on timing and reliability
- Coexistence and integration of various C-ITS applications
- Demand driven status updates

VANET vs Platooning

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⇨ Decentralized, random access MAC protocol (8021.p)

⇨ No retransmissions

⇨ Control Channel

⇨ CAM triggering rules

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Do those assumptions fit a typical platooning application?

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VANET vs Platooning

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PLATOON

- Relatively static topology
- Vehicles can be assigned certain roles within the platoon
- Very high requirements on timing and reliability
- Coexistence and integration of various C-ITS applications
- Platoon-specific updates
- Requirement on strict periodicity of status updates

VANET vs Platooning

		PLATOON
"Cluster-based, slot-based, centralized, deterministic, TDMA"	⇦	• Relatively static topology • Vehicles can be assigned certain roles within the platoon
Retransmission capabilities	⇦	• Very high requirements on timing and reliability
Control Channel + Service Channel	⇦	• Coexistence and integration of various C-ITS applications • Platoon-specific updates
Periodic status updates	⇦	• Requirement on strict periodicity of status updates

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Data age-based token passing MAC

We would like to

- Address the short-comings of IEEE 802.11p
- Make use of the special properties and opportunities of platooning
- Support the strict requirements on timing and reliability

while

- Still using standardized hardware
- Ensuring compatibility with other C-ITS applications

We propose

- A data age-based token passing MAC protocol to improve timely and reliable intra-platoon communication

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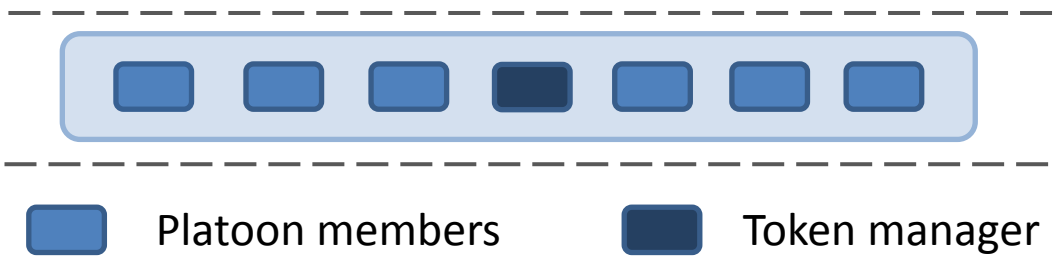
Data age-based token passing MAC

We need

- Two separate frequency channels
  - SCH for intra-platoon data exchange only
  - CCH for integration into non-platoon C-ITS applications
- Two message types
  - Periodic status updates (beacons)
  - Event-triggered maintenance/warning messages
- Two roles amongst platoon vehicles
  - Token manager with special responsibilities
  - Regular platoon members



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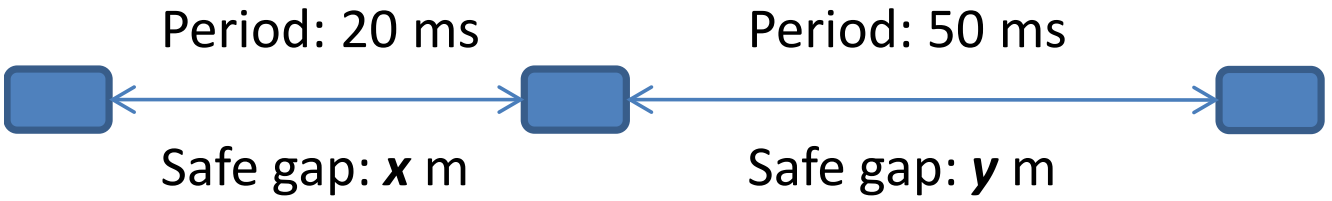
Data age

- A platoon can only be operated safely at a certain inter-vehicle distance if at least one beacon is broadcasted successfully within a beacon period
- If the data age exceeds a threshold, safety measures must be taken (e.g. increased inter-vehicle gaps)

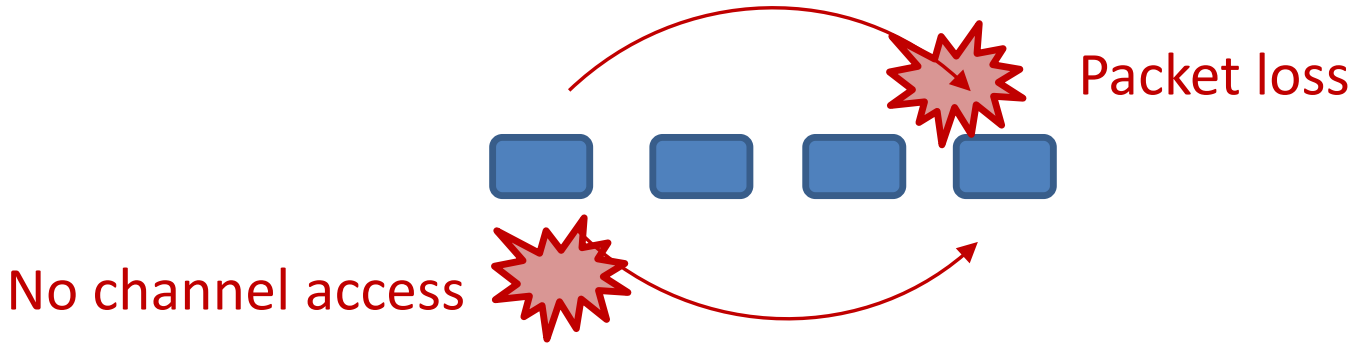


- The **data age** of a beacon (as it is perceived by individual platoon members) says a lot about the status of the platoon

Data age-based token passing

What threatens successful periodic receptions

- No channel access
- Packet loss, packet errors



Data age-based token passing

What threatens successful periodic receptions

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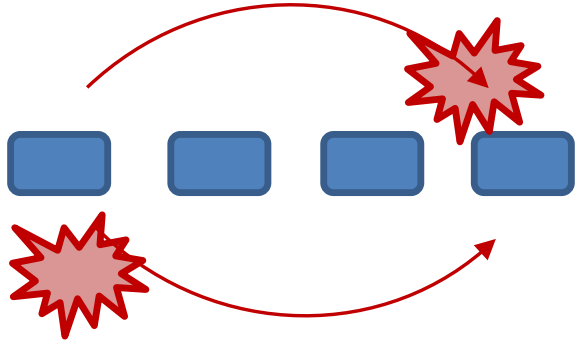
Retransmission opportunities for unsuccessfull transmissions



Individual channel access without competition

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Protocol details

Token passing

- Token is circulated with beacon packets → *no extra packets needed*
- Whoever holds the token has unique right to access the channel → *channel access without competition*

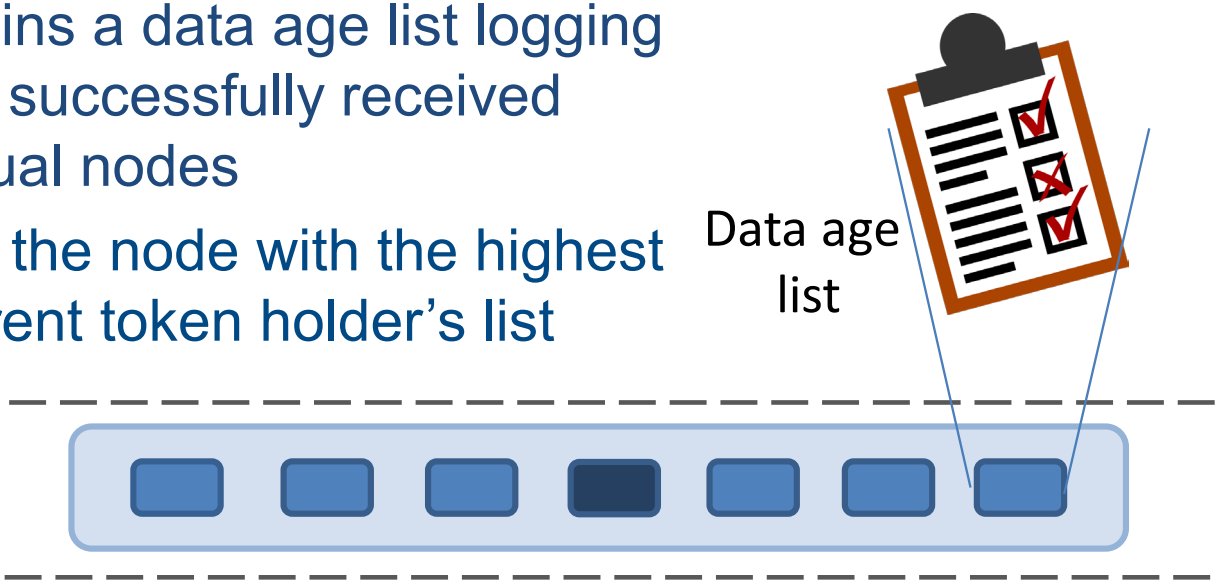
Node responisbility

- Each token holder is responsible for the choice of the next token holder → *no central control needed*
- The token manager is responsible for initial token introduction, recovery of lost tokens and Integration of new vehicles

Protocol details

The data age list

- Each vehicle maintains a data age list logging the age of the latest successfully received beacon from individual nodes
- Next token holder is the node with the highest data age on the current token holder's list



→ ***Prioritizing*** *vehicle that is in most need to communicate to keep its deadline*

→ *Built-in* ***retransmission*** *opportunities (if bandwidth available)*

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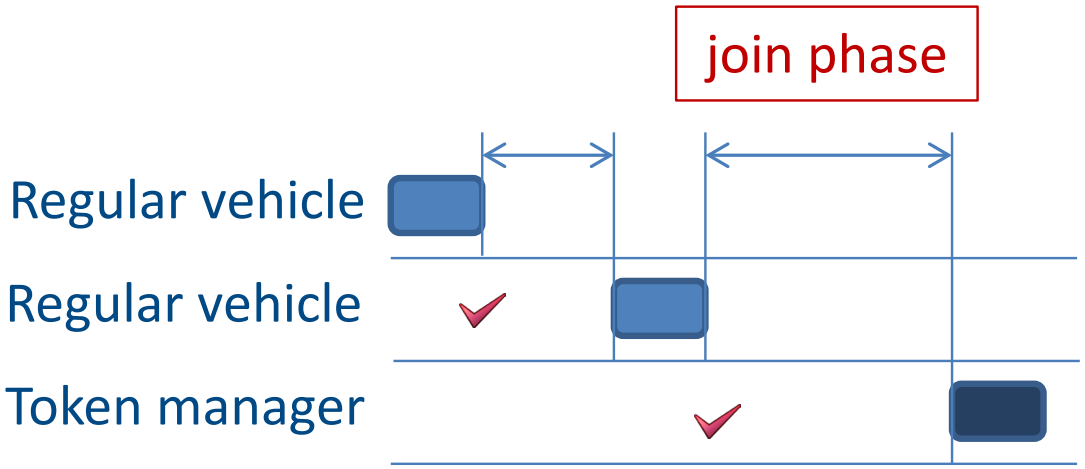
What about…

- Temporary token loss
  - Token manager listens to the channel and reintroduces a token (acc. to data age list) in case no transmission was detected for a certain time
- Disconnected vehicles
  - Vehicle A has not been heard by Vehicle B during one beacon period, A is removed from B's data age list
  - Removal from some lists → automatic reintroduction
  - Removal from all lists → join request to token manager



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Performance evaluation

- Simulation in Veins (OMNET++ & SUMO vehicular mobility models)
- Comparing our token passing method to standard IEEE 802.11p for different platoon lengths and beacon periods
- Performance parameter: IRT (Inter Reception Time)

Platoon size	5 or 10 vehicles
Transmission range	500 m
Propagation model	Simple path loss + Log-normal shadowing
Beacon frequency	10, 50 and 100 Hz
Packet length	400 bytes
Frequency	5.9 GHz
Data Rate	6 Mbps
Antenna-antenna spacing	30 m

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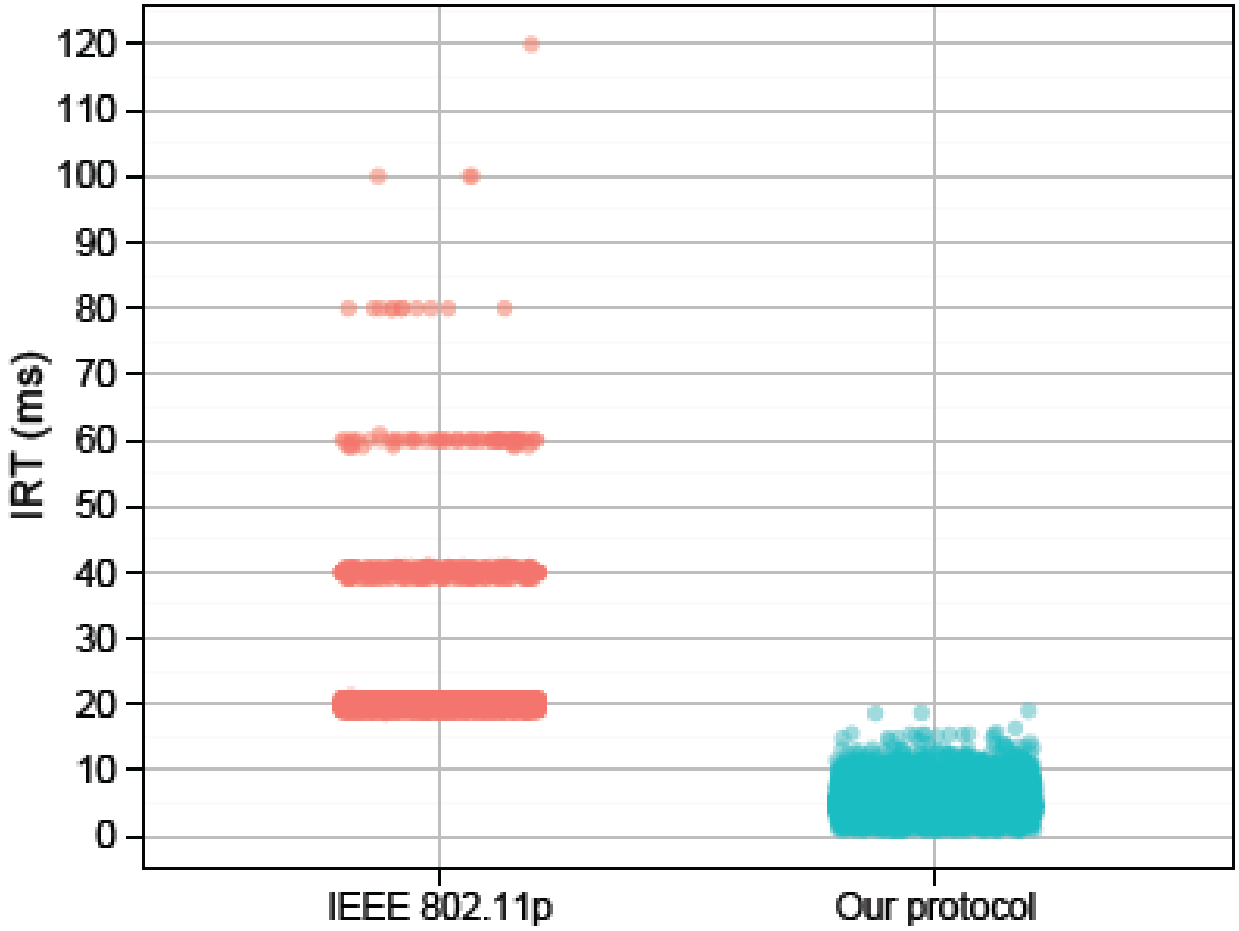
Performance evaluation



IRT for a platoon with 5 vehicles and beacon frequency of 50 Hz.

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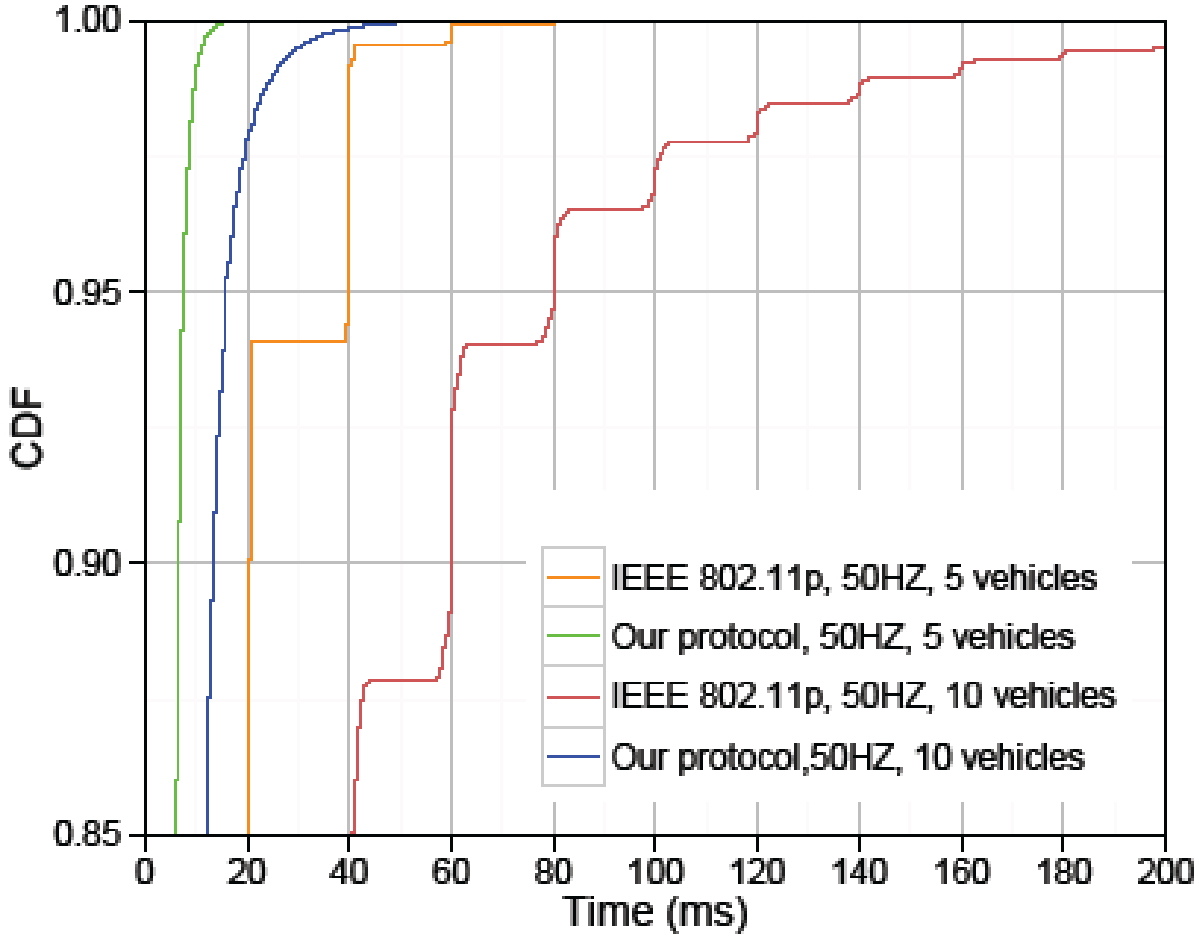
Performance evaluation



CDF of IRT for beacon frequency of 50 Hz.

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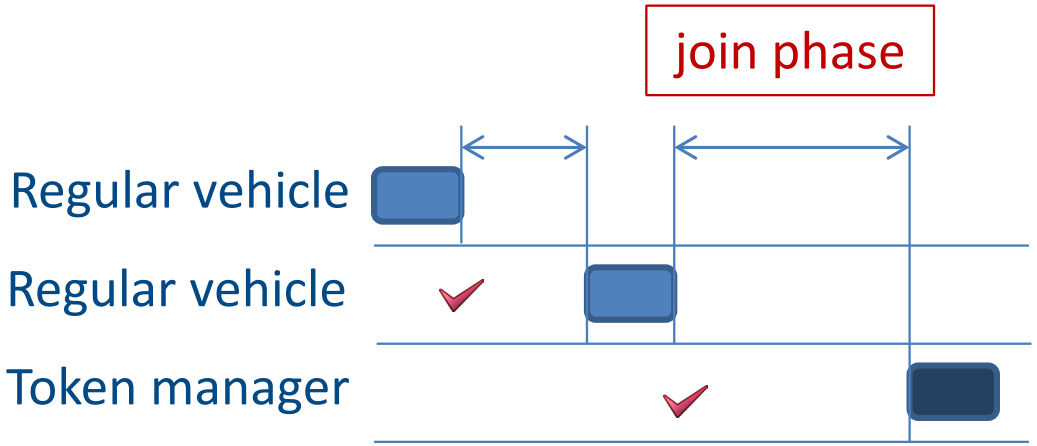
Event-based messages

- Two types of messages
  - Periodic beacons
  - Event-based messages
    - Highly time-critical warning messages
    - Sporadic broadcast of maintenance messages
- How to integrate those into the token passing protocol
  1. During joining phase only
  2. Whenever a vehicles holds the token (before beacon transmission)
  3. Any time an event occurs (interrupting the token passing routine)

Event-based messages

1. **During joining phase only**
   - Event-based messages compete with join requests during an extended join phase
     - No impact on token passing scheme
     - Very little impact on beacon transmissions
     - Potentially long waiting time until event messages can be transmitted
     - Potential packet collisions



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Event-based messages

2. Whenever a vehicles holds the token

- Token holder sends all event-based messages before sending on the token with its beacon
  - Delaying token passing scheme
  - Potentially long waiting time until event messages can be transmitted
  - No packet collisions

3. Any time an event occurs

- Vehicle having an event message to send opportunistically seizes the channel before new token holder accesses it
  - High impact on token passing scheme and beacon transmissions
  - Immediate event transmission possible
  - Packet collisions might occur

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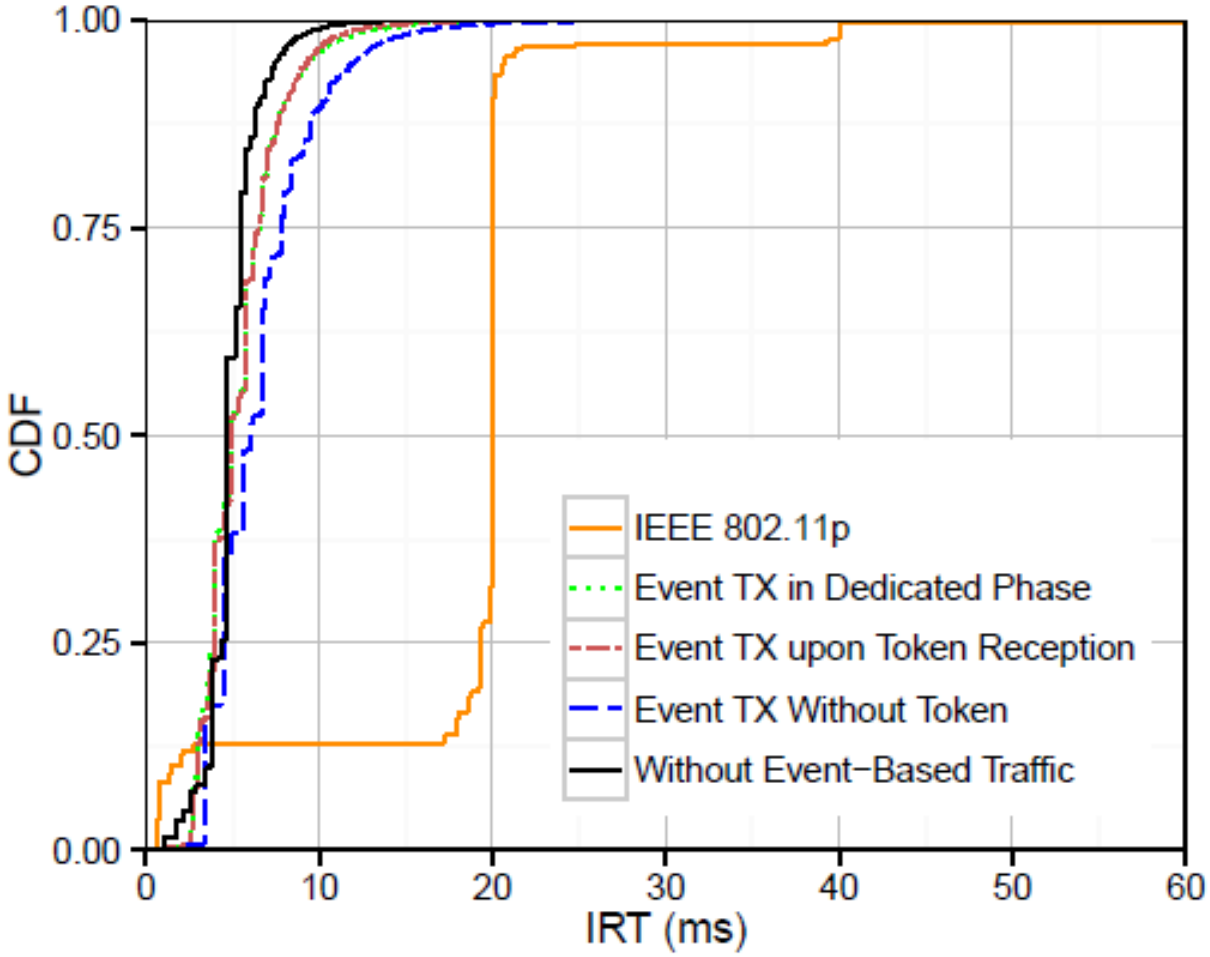
Impact on event-based data on beacon performance



CDF of IRT for beacon with and without the presence of event-based data (50Hz)

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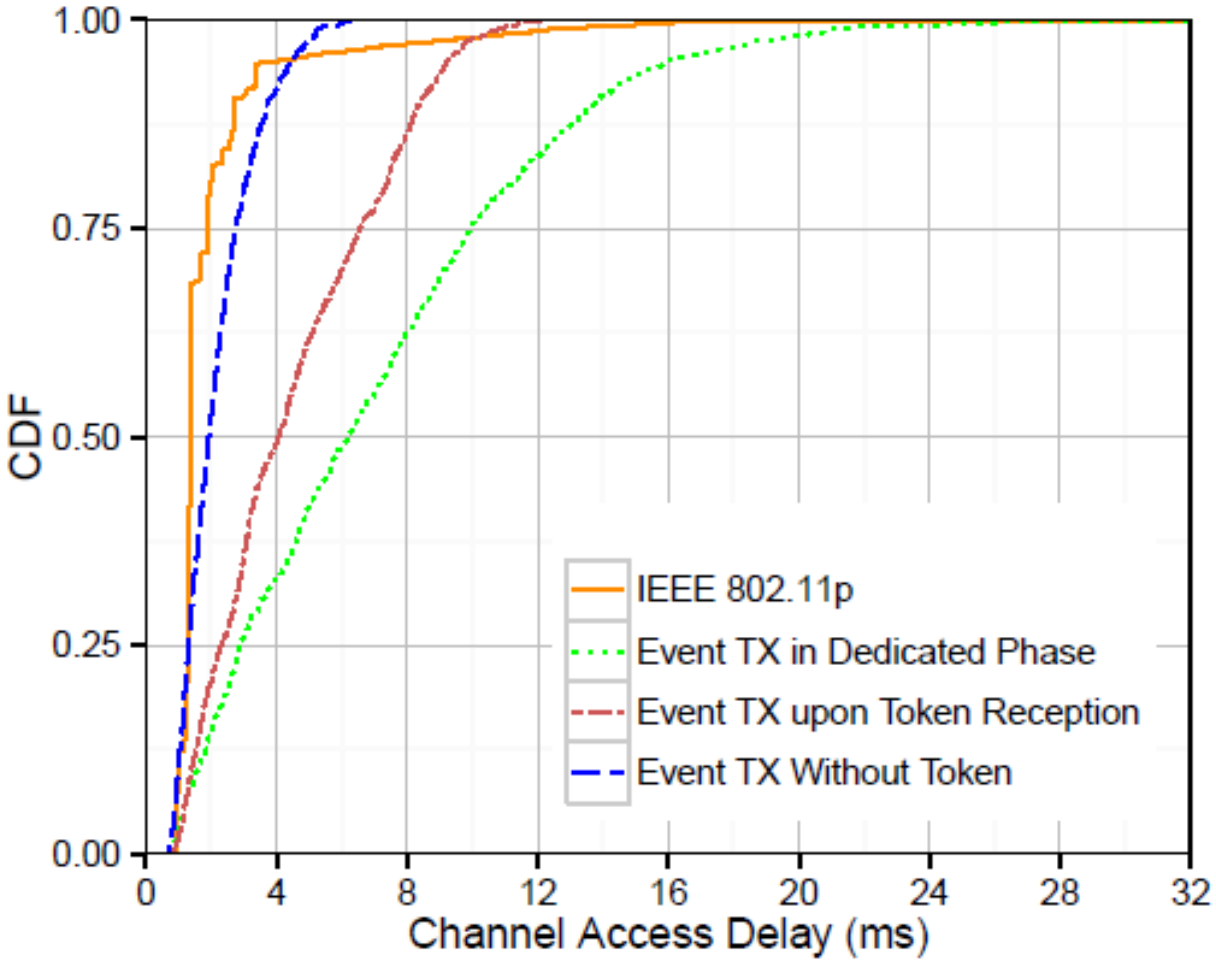
Channel access delay of event packets



CDF of the channel access delay of event data

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Average message delivery ratio for event-based data

Average Event-Driven Message Delivery Ratio (%)				
Vehicle ID	*IEEE802.11p*	*Event TX in Dedicated Phase*	*Event TX upon Token Reception*	*Event TX Without Token*
1	77	87	95.25	88.25
2	84	87	96.25	87.25
3	85	87	97	87
4	83	87	96.50	88.25
5	77	87	96	89.87
Average	**81.20**	**87**	**96.20**	**88.14**

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Conclusion

Given the freedom of a *platoon-specific service channel*, the specific properties of a platoon can be successfully exploited by a *decentralized, data age-based token passing scheme* with built-in *retransmission capabilities*.

Basing scheduling decisions on the *data age* of previously received packets smoothens the variations in data age experienced by the platoon's control loop and thereby helps meeting its *high requirements on timing and reliability*.

Different ways of integrating event-based data traffic were explored with small impact on periodic beacon delivery.