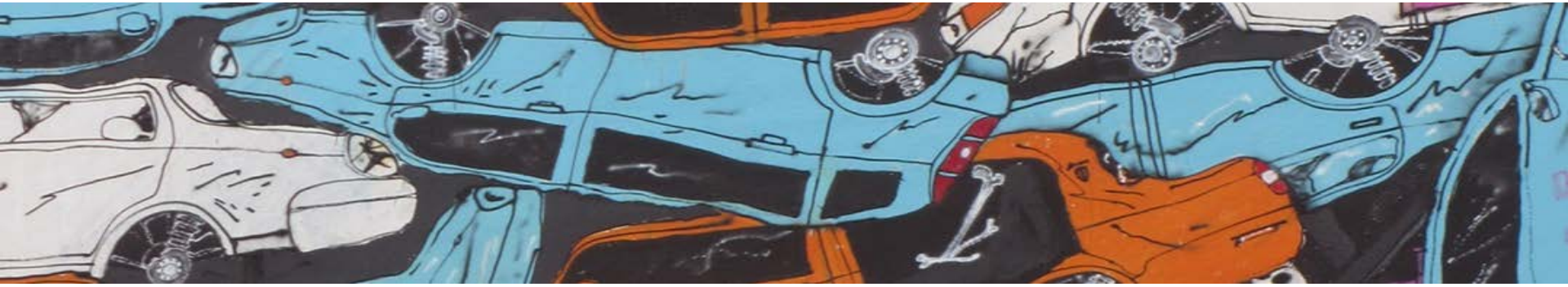
Medium Access Control for Delay-Sensitive Platooning Applications



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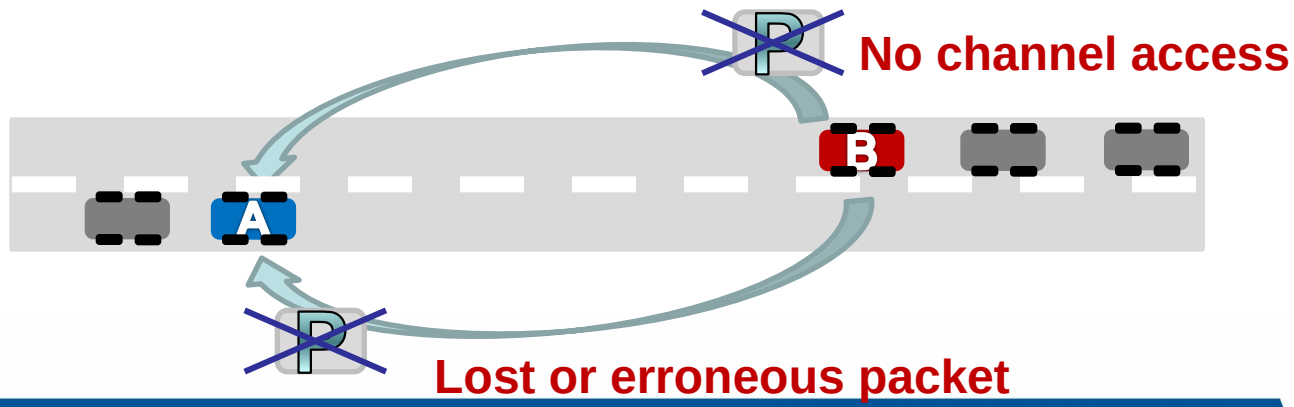
Outline

- Cooperative traffic safety & platooning
- Standardization and its limitations
- MAC method comparison
  - The control channel based IEEE 802.11p MAC
  - The proposed service channel based MAC
  - Simulation results
- Conclusion

Challenges of cooperative driving applications

- Ideally
  - Always up-to-date status information about every surrounding vehicle
  - Event warning dissemination with minimum delay
- Challenge
  - Packet loss over wireless medium
  - Packet drops due to limited, shared bandwidth

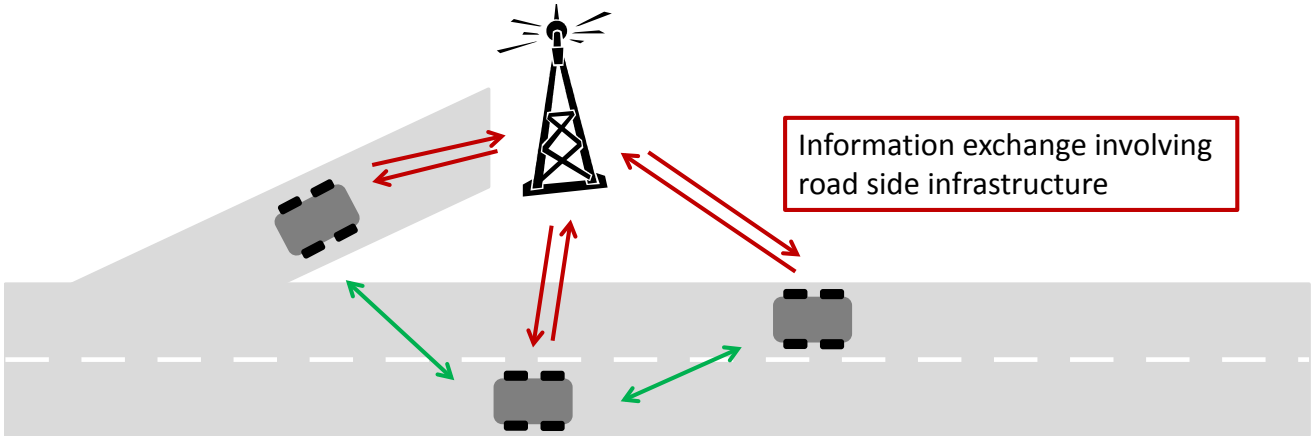


Wireless inter-vehicle data exchange

- Who is involved?
  - Directly vehicle to vehicle (V2V)
  - Involving roadside infrastructure (V2I)
- How is the communication organized?
  - Decentralized
  - Centralized → involving a central control unit

application perspective

Medium Access Control (MAC) perspective



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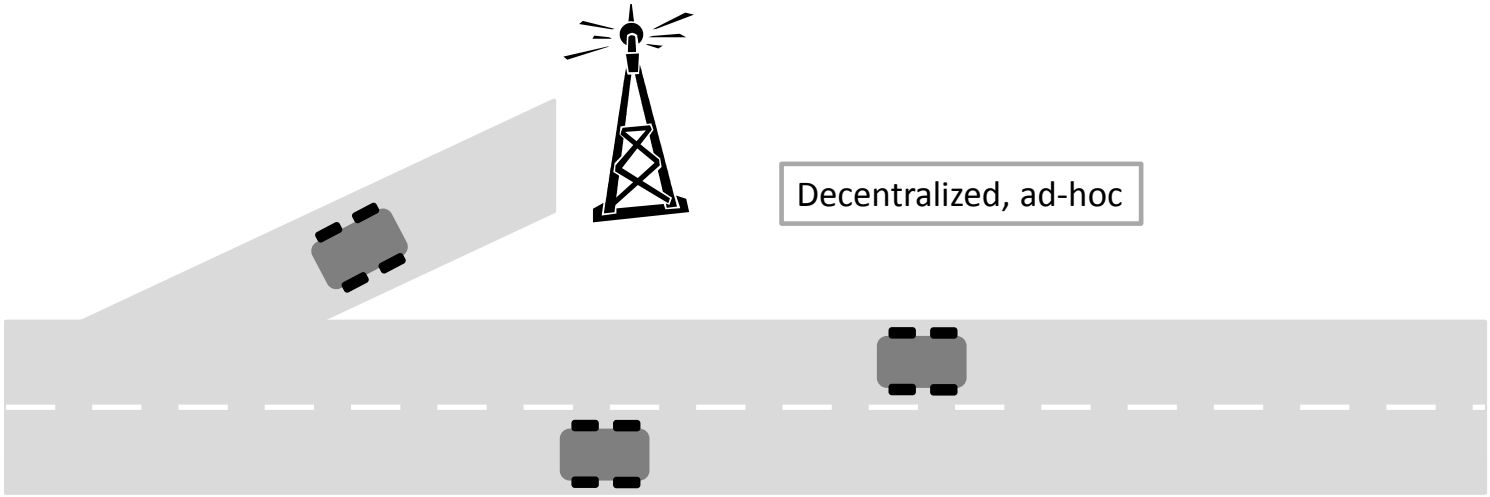

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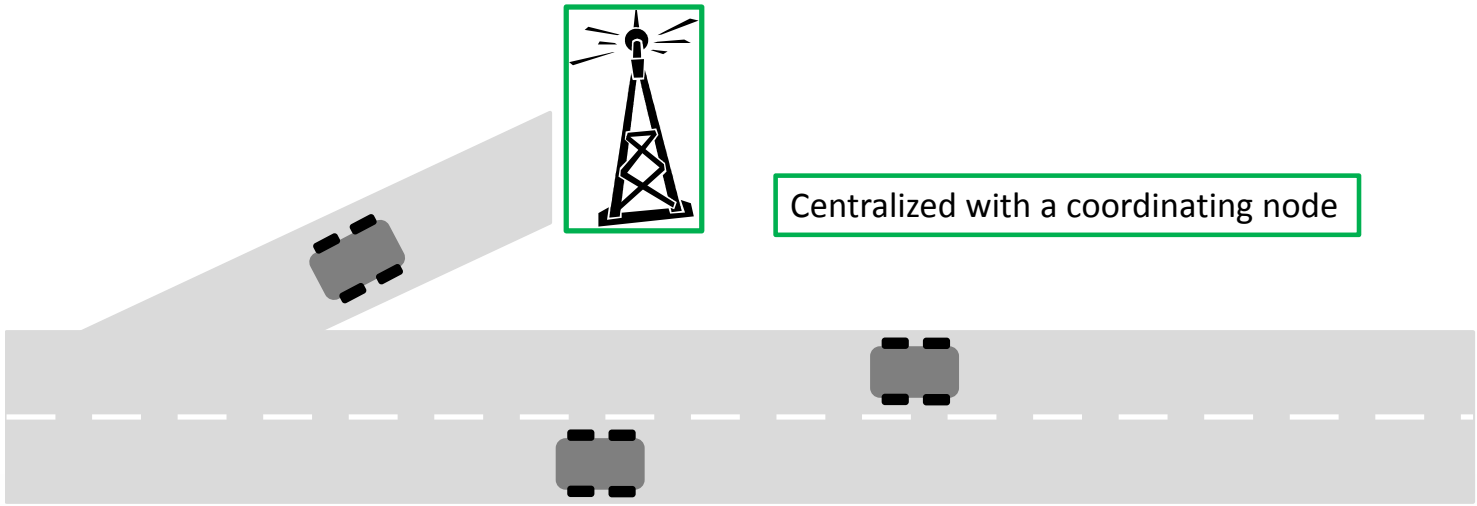

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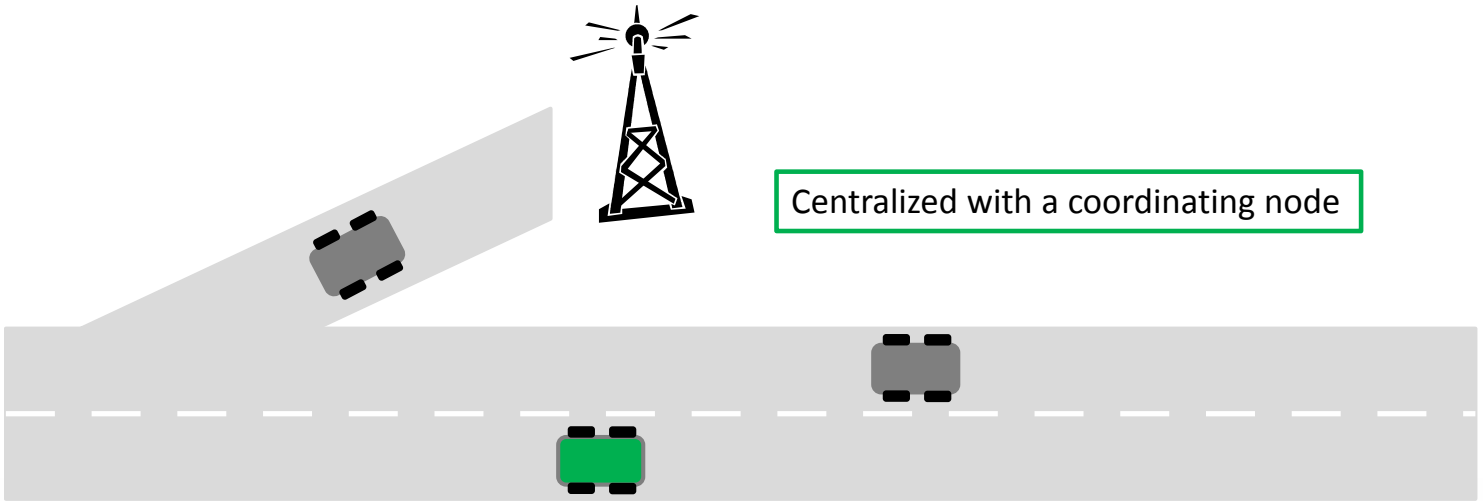


Platooning

- First step towards autonomous driving
- Platoon of vehicles (e.g. trucks) on a highway
  - Vehicles follow a leading vehicle with minimum distance
    - + reduced fuel consumption
    - + increased safety and efficiency
    - - tight control needed
  - Exchange of status data and hazard warnings between platoon vehicles

    → Fast and reliable inter-vehicle communication

Recent standardization

- Global interoperability and standards needed
- Standardization in Europe
  - Dedicated frequency band for ITS safety communication
    - Three 10 MHz channels in the 5.9 GHz range
    - 1 Control Channel, 2 Service Channels
  - IEEE 802.11p
    - Communication protocols for short to medium range inter-vehicle communication
    - Profile of the IEEE 802.11 protocol suit
    - e.g. Medium Access Control (MAC) protocol

Message types

- Cooperative Awareness Messages (CAM)
  - Periodically exchanged status updates (2-10 Hz send rate)
  - Basic information like position, speed, direction etc.
  - Always present
- Decentralized Environmental Notification Messages (DENM)
  - Event-triggered hazard warning messages
  - Only sent out for the duration of the event

Limitations of IEEE 802.11p MAC

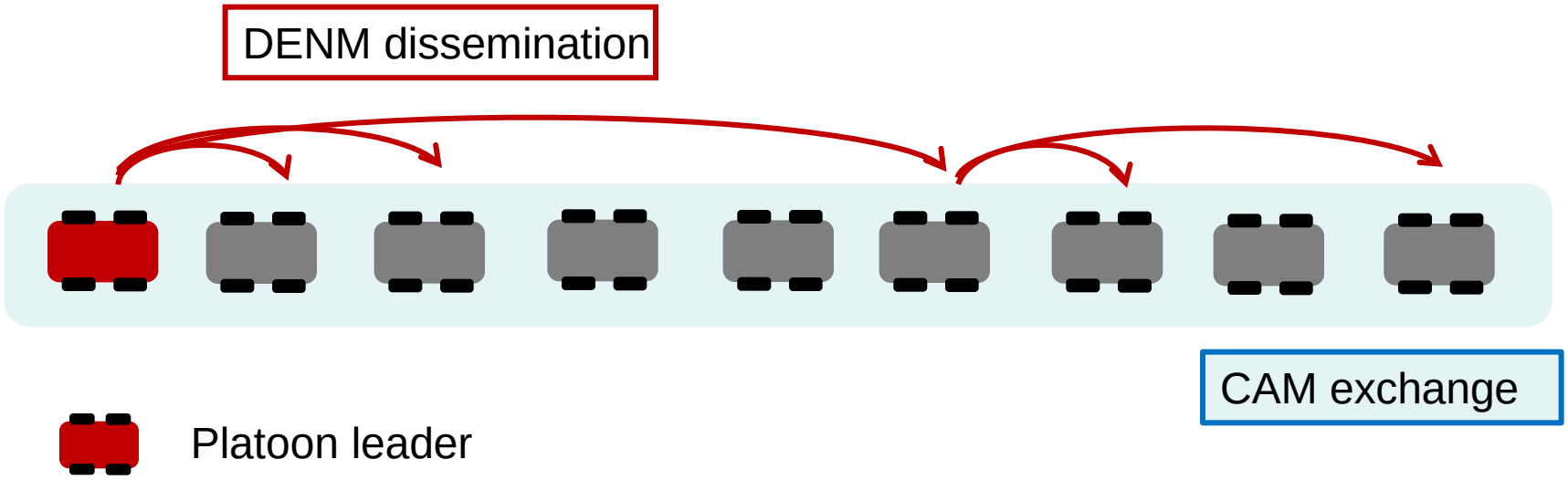
- No guaranteed channel access before a given deadline
  - IEEE 802.11p MAC uses a random access protocol
    - CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance)
    - ”Listen before talk” protocol
    - Channel access before a given deadline not guaranteed
- Only messages of the CAM and DENM type allowed on the Control Channel

→ Propose alternative MAC method

→ Make use of the Service Channel instead

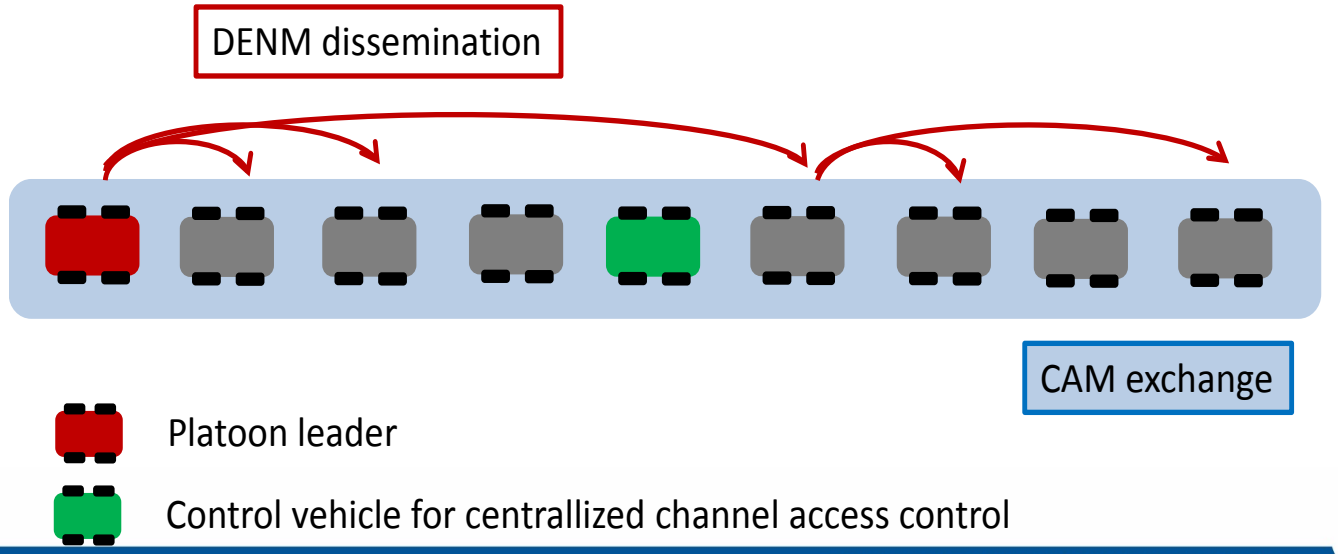
Platooning

- Periodic CAM exchange between all platoon members
- Event-triggered DENM dissemination in case of unexpected hazardous event



Idealistic goal

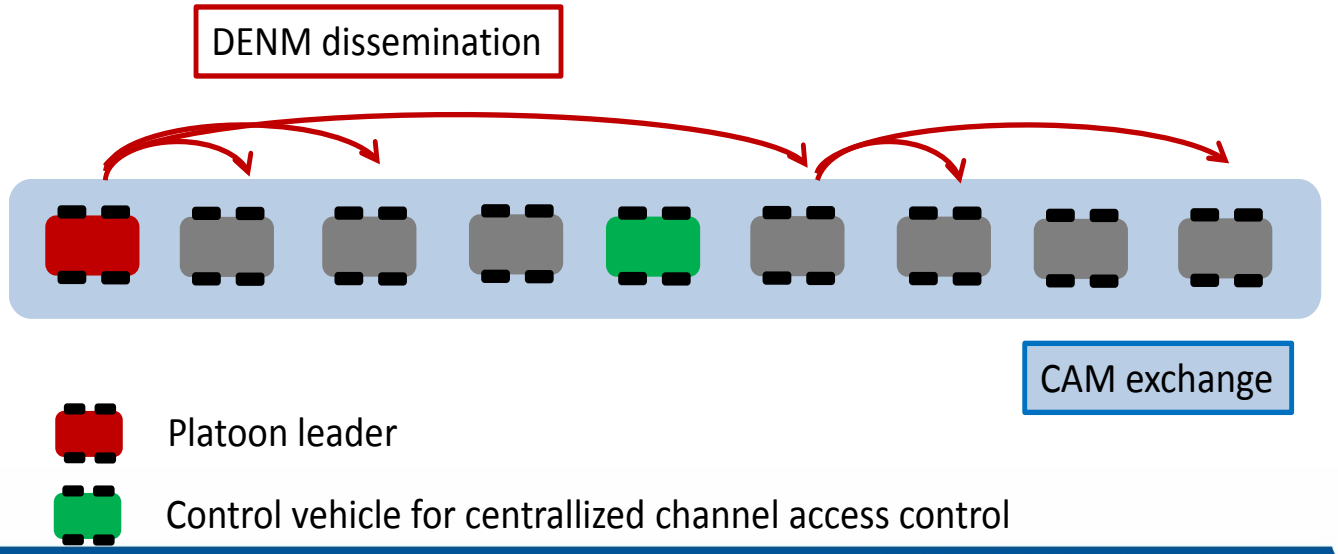
- **CAM**
  - Every vehicle is informed about the up-to-date status of its surrounding platoon members at any given time
- **DENM**
  - Every vehicle is warned of unexpected situations with minimal delay



Performance measures

– CAM Up-To-Dateness (UTD) (inter-arrival time)
  - What is the worst-case inter-arrival time of CAMs from a specific neighbor?

– DENM Dissemination Delay (DD)
  - How fast can a hazard warning be spread throughout the entire platoon?



Intra-platoon communication

- Very strict timing and reliability requirements

+ Make use of the relatively static nature of a platoon topology

  - Number of vehicles (and their positions within the platoon) rarely changes
  - Communication requirements are known

+ Dedicated Service Channel for platoon feasible

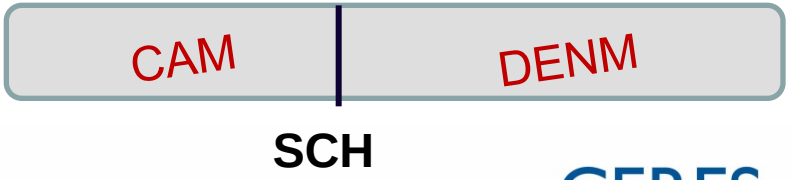
  - Not restricted to specific message types
  - Not shared with non-platoon members

→ Use available bandwidth for CAM and DENM requirements at hand

MAC comparison

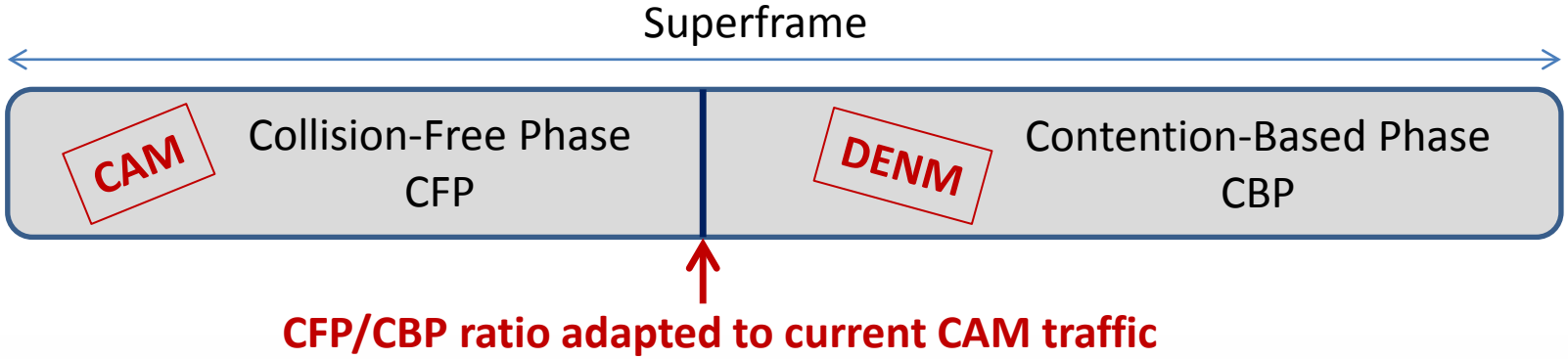
- Decentralized
  - Standard-compliant using 802.11p MAC and send rates
  - CAM and DENM coexist
  - Dedicated ITS Control Channel

- Centralized
  - MAC method, message types and send rates not acc. to standard
  - CAM and DENM separated
  - Dedicated Service Channel



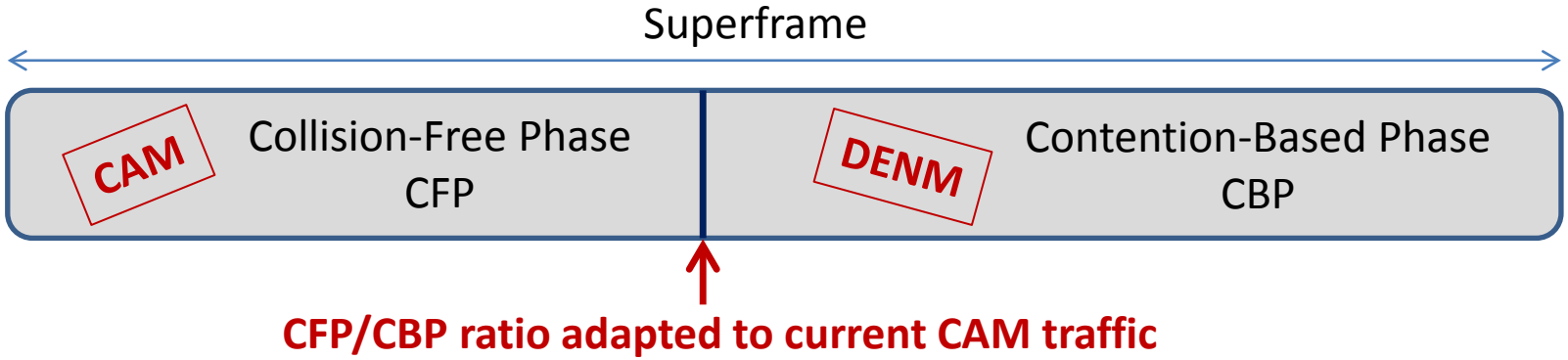
The proposed centralized MAC

- Divide bandwidth into
  - Centrally controlled, deterministic, collision-free MAC phase with real-time support (CFP)
    → used for periodic CAMs
  - Contention-based, non-deterministic MAC phase (CBP)
    →used for event-triggered DENMs
    →CSMA/CA-based



The proposed centralized MAC

What is the suitable SF size and CBP/CFP ratio do support guaranteed channel access for CAMs and reasonable dissemination delays for DENMs?

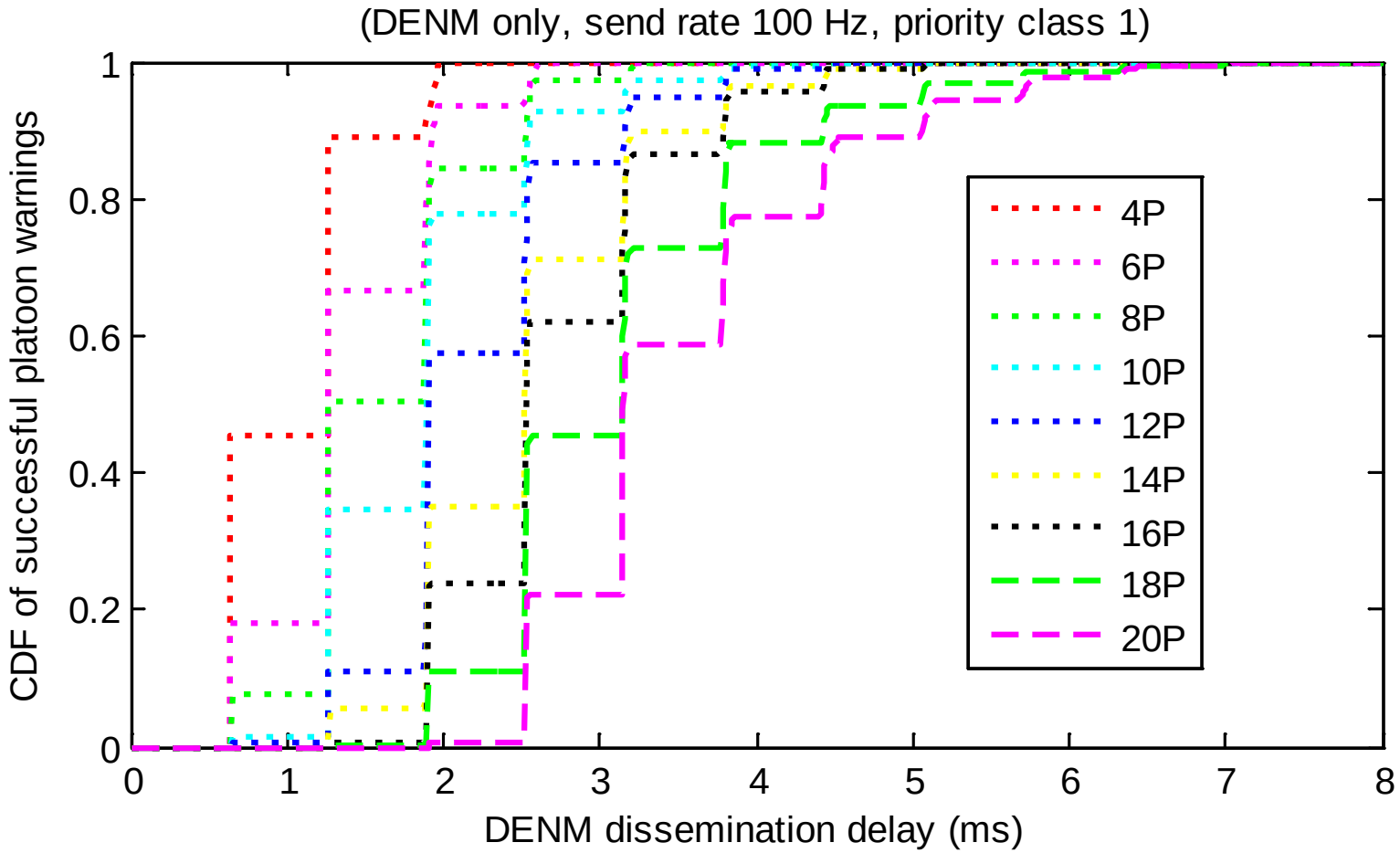


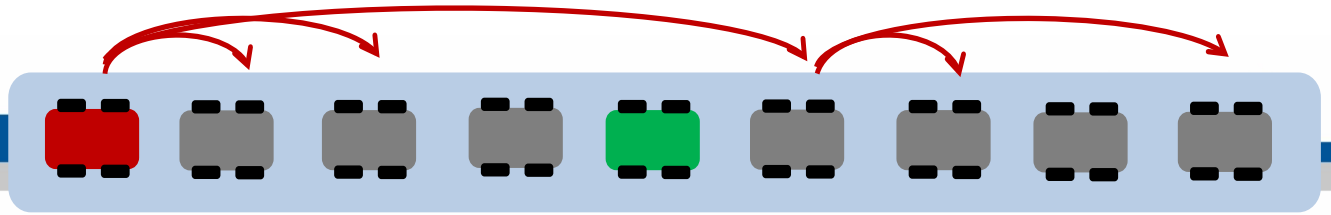
- 2 steps
  1. **Determine CBP size** based on knowledge of typical DENM Dissemination Delay for the platoon length at hand (e.g. from simulation)
  2. **Determine CFP size** by applying **real-time schedulability analysis**

Real-time scheduability analysis

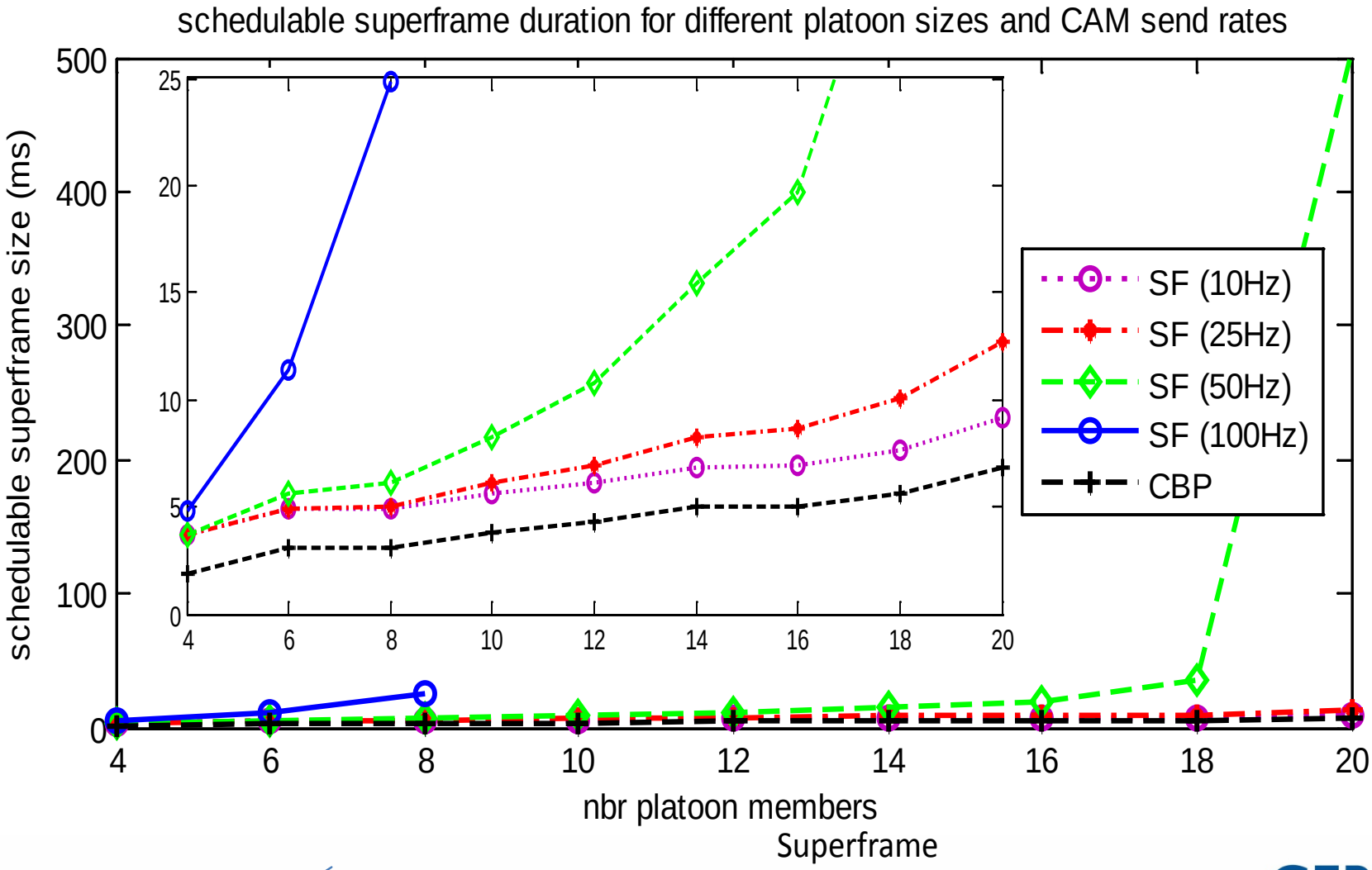
- Derived from uni-processor task scheduling
- Given:
  - k vehicles → k logical real-time channels that need to be scheduled, each with a period and deadline
  - A certain bandwidth that the real-time channels need to share
- Question:
  - Are the real-time channels schedulable given the resources specified
- Two checks must be fullfilled
  - **Utilization check**: available bandwidth must not be utilized more than 100%
  - **Workload check**: sum of the transmission times of all packets of all RTCs with an absolute deadline less than or equal to t at any given time t

Step 1: Find suitable CBP size from earlier simulations





Step 2: Find CFP size through RT schedulability analysis



Superframe

CAM | Collision-free Phase CBP | DENM | Contention-Based Phase CBP

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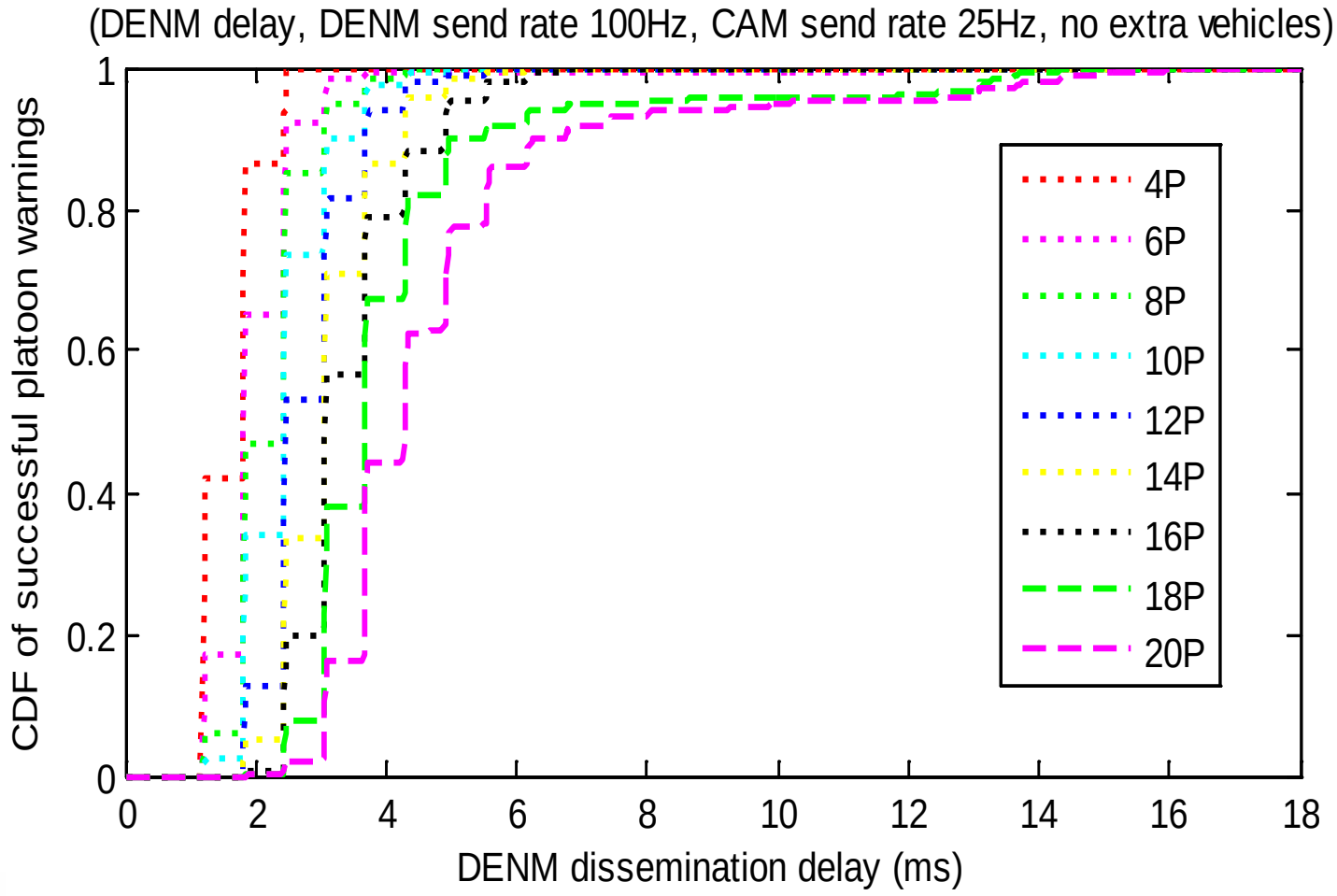
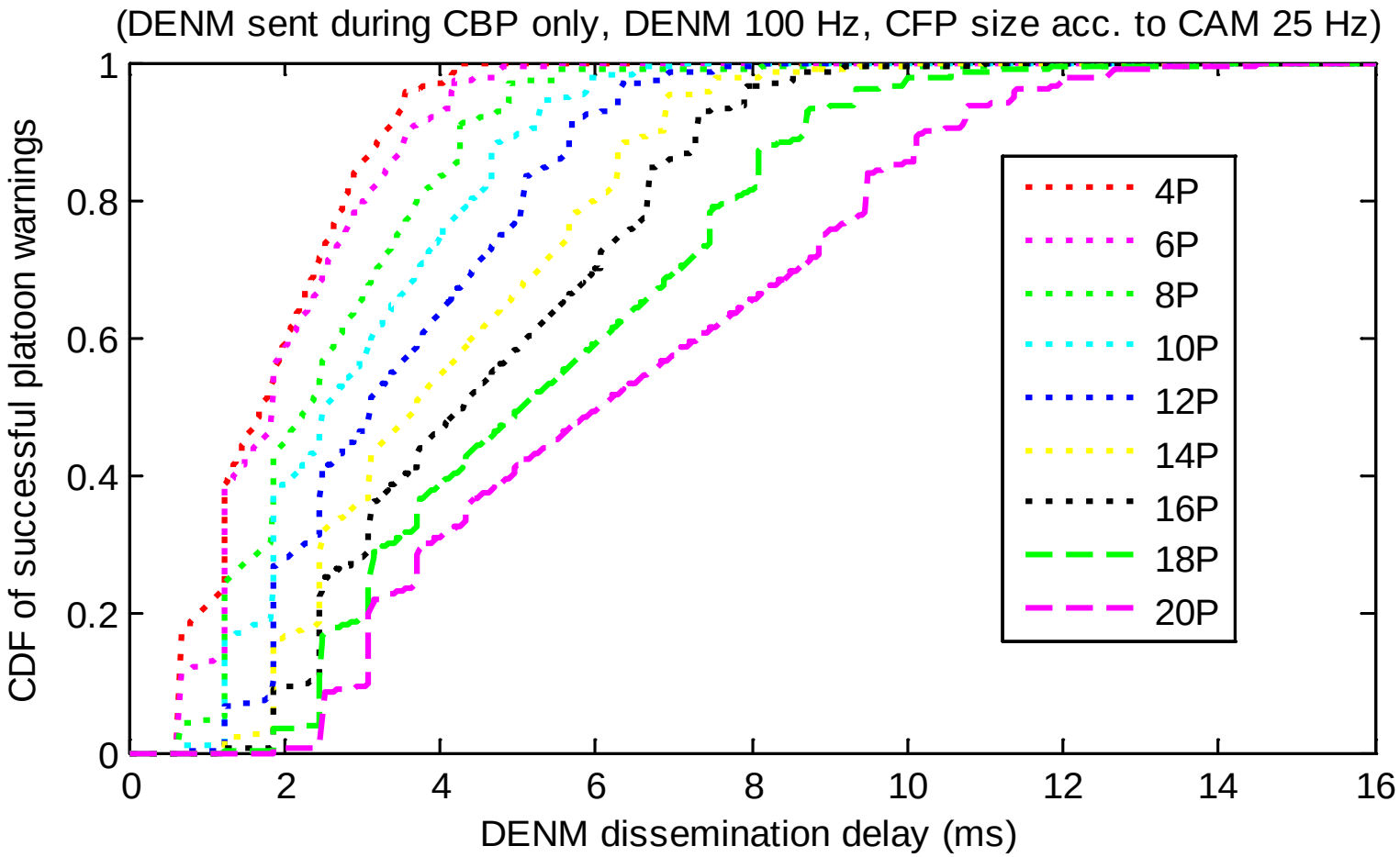
DENM dissemination delay: CAM & DENM sharing Control Channel, standard compliant, 802.11p MAC



DENM dissemination delay: Service Channel, DENM transmission in CBP only, CAM in CFP only



Superframe

CAM Collision-Free Phase CFP

DENM Contention-Based Phase CBP

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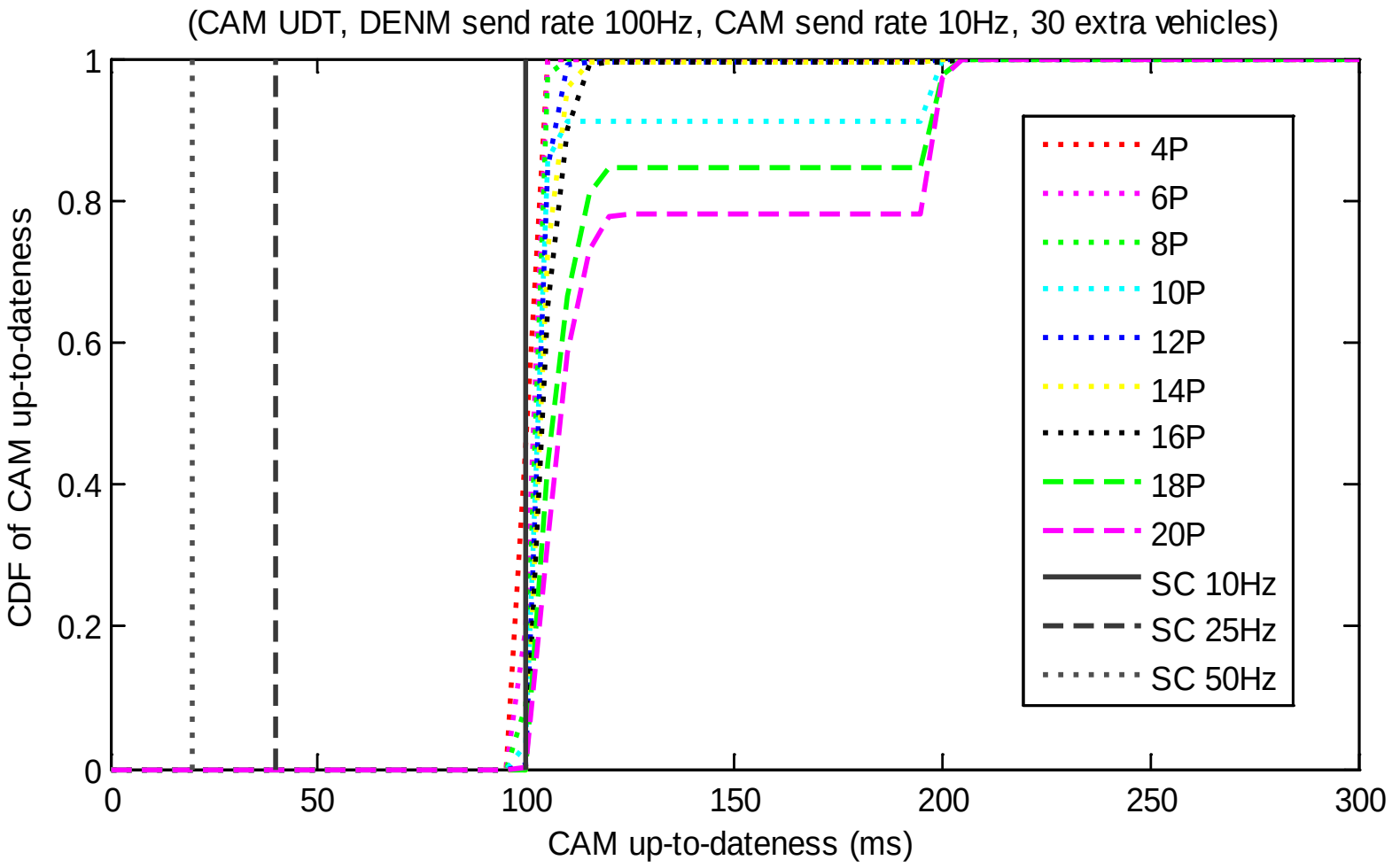
CAM up-to-dateness: Control Channel based vs. Service Channel based



Worst case DENM dissemination delay and CAM up-to-dateness

Model	CAM rate	Worst case DENM DD (10 veh)	Worst case DENM DD (20 veh)
CC	10 Hz	6 ms	16 ms
	25 Hz	11 ms	27 ms
	50 Hz	42 ms	25 ms
SC	10 Hz	9 ms	20 ms
	25 Hz	10 ms	27 ms
	50 Hz	14 ms	1000 ms

Model	CAM rate	Worst case CAM UTD (10 veh)	Worst case CAM UTD (20 veh)
CC	10 Hz	300 ms	300 ms
	25 Hz	120 ms	280 ms
	50 Hz	80 ms	880 ms
SC	10 Hz	100 ms	100 ms
	25 Hz	40 ms	40 ms
	50 Hz	20 ms	20 ms

Conclusion

- Cooperative driving puts high demands on timing and reliability, especially in platooning where desired vehicle spacing is < 5m
- Support for delay-sensitive data traffic through deterministic channel access is needed
  - In the current standard this support is compromized due to the properties of IEEE 802.11p MAC
- Applications with semi-static topologies (e.g. platooning) offer possibilities of centralized, deterministic MAC solutions
- A centralized, Service Channel based MAC method supports fast DENM dissemination and reliable CAM broadcast in a platooning scenario
  - CAMs are guaranteed to be delivered before their deadline
  - The dissemination delay of DENMs is not affected considerably (for platoons up to 16 vehicles)

Open issues

- How to integrate several platoons on one common Service Channel?
- How to handle new or leaving vehicles?
- How to cope with dynamic CAM rates (Decentralized Congestion Control)?
- How to make use of power control?

Thank you for your attention!