Greedy Algorithms for Information Dissemination within Groups of Autonomous Vehicles

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Introduction

- Most autonomous vehicles are based on a perception subsystem (on-board sensors, such as camera, radar, lidar and GPS) and a control subsystem
- This approach presents some drawbacks:
  - Limited perception range and accuracy of on-board sensors
  - Complex integration (high cost) of sensors into current vehicles
- V2X communications allow the **exchange of information** among nearby autonomous vehicles by means of ad-hoc networking
- Cooperative Autonomous Driving Systems (**C-ADS**) combine vehicular communication and autonomous driving to enable two key features:

Cooperative Sensing

- Increases sensing range of autonomous vehicles
- Allows cars to "see" behind obstacles and around corners

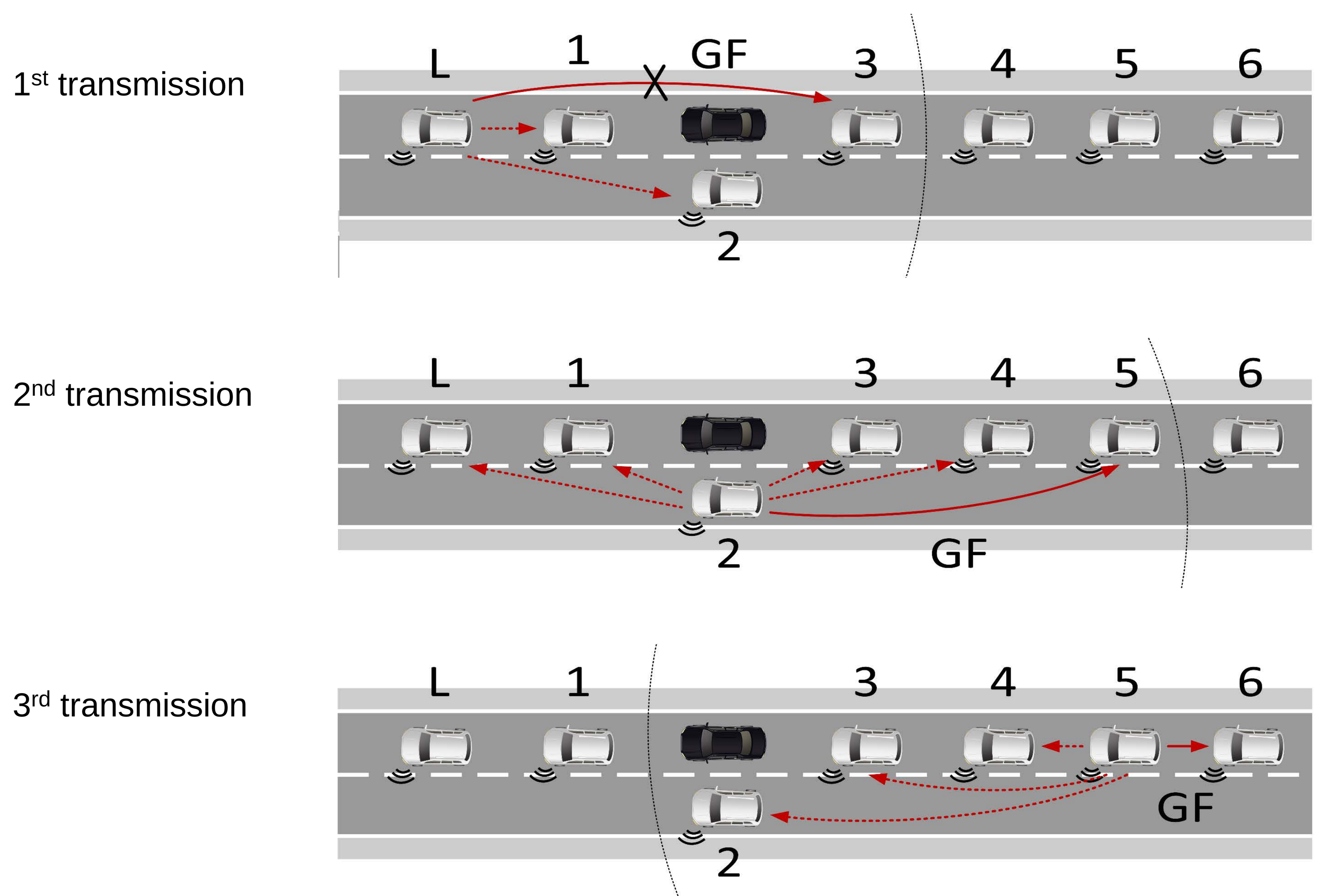
Cooperative Maneuvering

- Allows a group of autonomous vehicles to drive coordinately
- Enhances the safety and efficiency of maneuvers

- C-ADS are the object of several current European R&D projects:
  - AutoNet2030, i-GAME, AdaptIVe, COMPANION

Greedy Broadcast Forwarding (GBF)

- We propose **Greedy Broadcast Forwarding** as a novel forwarding protocol designed for information dissemination within groups of autonomous vehicles
- Algorithm description:
  - The source vehicle selects a next hop by Greedy Forwarding (GF), as the vehicle with the highest forward progress towards the destination
  - Vehicles within transmission range overhear the packet and start a retransmission timer whose value is proportional to the distance to the GF next hop
  - If a vehicle overhears the packet for the second time, the packet is discarded
  - When the retransmission timer expires, the vehicle forwards the packet by GF
- Example with a 7-vehicle platoon



Greedy Multicast Forwarding (GMF)

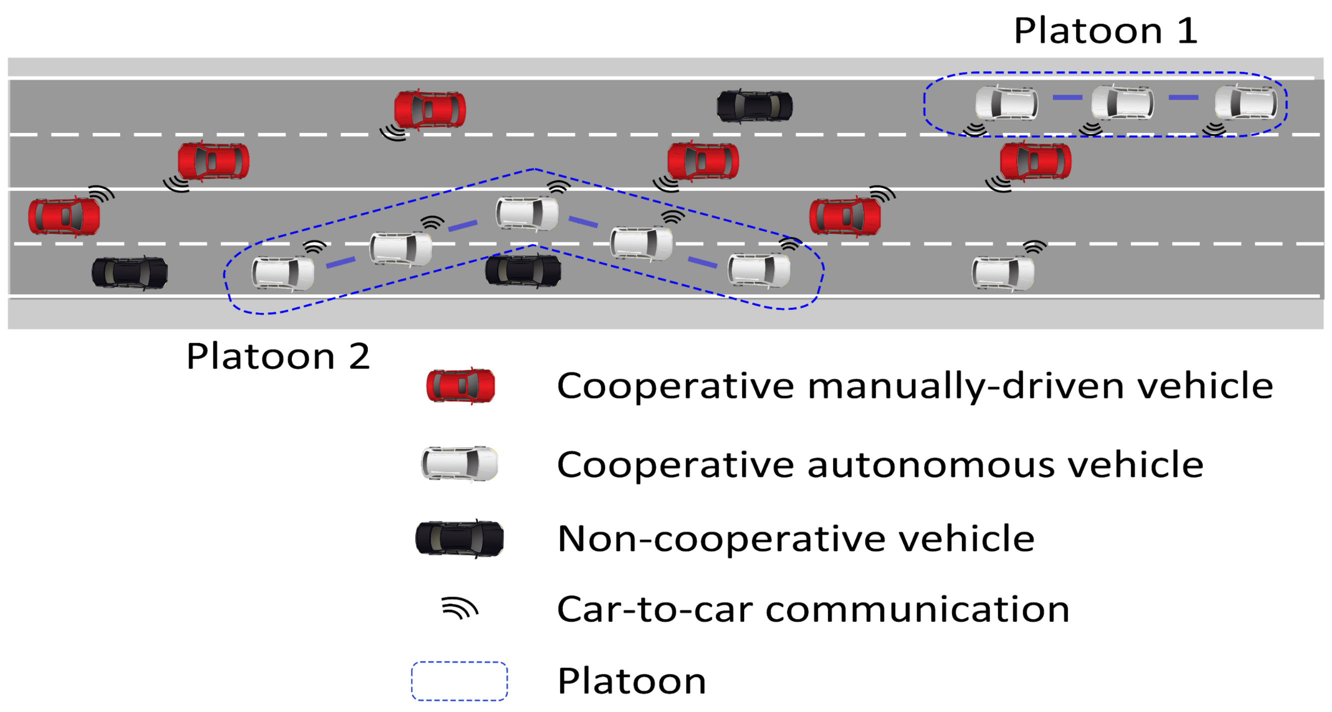
- **Greedy Multicast Forwarding** allows the distribution of packets only among a predefined set of vehicles (group members)
- Main differences with respect to Greedy Broadcast Forwarding:
  - Only members of the vehicle group are considered as potential GF next hops
  - Vehicles not belonging to the group which overhear a packet do not forward it
- As a result, this protocol presents some advantages:
  - The algorithm only needs to be implemented in the vehicles belonging to the group
  - Reducing the number of forwarders results in a lower traffic overhead

V2X communication standards

- IEEE 802.11p and ITS-G5 define the PHY and MAC layers of V2X communications
- The ETSI GeoNetworking protocol defines several V2X forwarding algorithms for the broadcast distribution of messages within a geographical area:
  - Simple GeoBroadcast (S): packet flooding scheme
  - Contention-based Forwarding (CBF): vehicles which overhear a packet set a retransmission timer based on their distance to the sender
  - Advanced Forwarding (AF): combines CBF with Greedy Forwarding, which selects the next hop as the neighbor closest to the destination
- The application of these standards to C-ADS presents some challenges:
  - Designed for safety and driver information messages in manual vehicles (not C-ADS)
  - Lack of multicast support

Main requirements in C-ADS

- We focus in the communication aspects of C-ADS, in particular on the design of protocols for the management and information sharing within vehicle groups
- V2X communications in groups of autonomous vehicles (such as platoons) present three main requirements:
  - **Reliability**: guarantee the correct delivery of messages to all destination vehicles
  - **Latency**: minimize the communication delay in order to reduce the vehicle reaction time
  - **Traffic overhead**: keep the number of transmitted packets low to avoid channel congestion
- Standardized forwarding protocols may not be able to satisfy these requirements



Performance evaluation

- We compare the performance of the forwarding protocols in a C-ADS:
  - Standardized ETSI GeoBroadcast protocols (S, CBF, AF)
  - Greedy Broadcast Forwarding (GBF) and Greedy Multicast Forwarding (GMF)
- Simulation scenario:
  - Vehicle group with 5-80 vehicles/km/lane driving on the a 3-lane freeway
  - Simulation frameworks: SUMO (vehicle traces) and ns-3 (networking protocols)
  - The group leader sends periodic DENMs and all vehicles broadcast CAMs.
  - Propagation model: multi-slope log-distance with Nakagami fading
- Main results:
  - **Node coverage ratio**: GBF and AF show the highest values thanks to the GF algorithm
  - **End-to-end delay**: S has the lowest latency (few ms), followed by GBF and GMF (~10 ms)
  - **Traffic overhead**: GBF and GMF require the lowest number of packet transmissions, while S yields a huge overhead (broadcast storm)
- Conclusions:
  - GBF is the best protocol for **broadcast multi-hop information dissemination** among autonomous vehicles
  - GMF shows the highest performance in **congested traffic scenarios**
  - Both are promising candidates for release 2 standardization in ETSI TC ITS