Joint usage of 802.11p and LTE-V2V for reliable control of heterogeneous vehicle platoon

Oleksandr Zhdanenko
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Outline

• Introduction and Motivation
• Platoon management
• Communication solutions (LTE-V2V and 802.11p)
• Research plans and Testbed
• Conclusions
Introduction

• Platooning
  • Safety improvement
  • Traffic flow efficiency improvement
  • Cost saving
  • CO2 emission reduction

Motivation

- Platooning requirements:
  - Low latency communication
    - 10 - 100 ms depending on the message type [2] [3]
  - Network resilience (99.999%) [3]

- Requirements achievable
  - To ensure resilience and low latency by
    - Vehicle-to-Vehicle (V2V) communication
    - Vehicle-to-Infrastructure (V2I) communication

[2] ETSI TS 102 637-2 V1.2.1
Motivation

- Intelligent Transportation Systems (ITS) typically use:
  - LTE-V2V
  - 802.11p

- Heterogeneous usage of both technologies
  - To improve reliability
  - To provide ubiquitous connectivity

Protocol structure

Application: Platoon management

Facility: Cooperative Awareness Messages

Transport and Network: GeoNetworking and LTE-V2V or 802.11p

Logical channel (packet erasure channel)

LTE-V2V MAC

802.11p MAC
Platoon management, CAM and GeoNetworking
Platoon management

Application: Platoon management

Facility: Cooperative Awareness Messages

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LTE-V2V MAC

802.11p MAC
Distributed graph-based platoon control

- Supports multilane platoons of heterogeneous vehicles
- Uses Longitudinal and Lateral Controllers to manage the convoy [6]
- The data to be shared over Cooperative Awareness Messages (CAM)
  - GPS coordinates
  - Vehicle velocity
  - Length of the vehicle
  - ...

- Graphs calculated locally, based on received CAMs
- State is shared only with the neighbouring cars
- GeoNetworking could be used for messages dissemination

[6] Distributed Graph-Based Control of Convoys of Heterogeneous Vehicles using Curvilinear Road CoordinatesV2X. Iñaki Navarro, Florian Zimmermann, Milos Vasic, Alcherio Martinoli
Distributed graph-based platoon control

- Curvature zones cause bigger lateral errors [6]
- Lane change operation causes bigger longitudinal error
- Simulation speed ~ 10 m/s

[6] Distributed Graph-Based Control of Convoys of Heterogeneous Vehicles using Curvilinear Road CoordinatesV2X. Iñaki Navarro, Florian Zimmermann, Milos Vasic, Alcherio Martinoli
Intelligent Transportation System

- Standardized by ETSI EN 302 665
- Essential aspects [8]
  - Stations mobility and high dynamics of its topology
  - Potential support of multiple communication technologies
  - Multiple physical units in a single ITS-S
  - Prioritization of application classes
  - Unified format of awareness messages (CAM)

[8] ETSI EN 302 665 V1.1.1
Cooperative Awareness Message (CAM)

- Contains status and attribute information of the originating ITS-S [9]
  - Status information includes time, position, motion state, activated systems, etc.
  - Attribute information includes data about the dimensions, vehicle type and role in the road traffic, etc.
- Max messages frequency = 10 Hz (T = 100 ms)
- Min messages frequency = 1 Hz (T = 1000 ms)
- Message size = 800 bytes [2]
- High Frequency (HF) container
  - Contains all fast-changing (dynamic) status information
- Low Frequency (LF) container
  - Contains Static or slow-changing vehicle data

[2] ETSI TS 102 637-2 V1.2.1
[9] ETSI EN 302 637-2 V1.3.2
GeoNetworking

- Ad hoc networking based on geographical addressing and routing [7]
  - Every node has a partial view of the network topology in its vicinity
  - Every packet carries a geographical address
- Supports point-to-point and point-to-multipoint communication

GeoUnicast

GeoAnycast

GeoBroadcast

[7] ETSI EN 302 636-1 V1.2.1
LTE-V2V and 802.11p
LTE-V2V and 802.11p

Application: Platoon management

Facility: Cooperative Awareness Messages

Transport and Network: GeoNetworking and LTE-V2V or 802.11p

Logical channel (packet erasure channel)

LTE-V2V MAC  802.11p MAC
802.11p CSMA / CA

- Current standard for V2V communications
- Support of variable packet sizes
- Requires no strict synchronization between nodes
- Unbounded delays before channel access
- Collisions on the channel
- Multiple consecutive packet drops
- Problems with predictability for periodic positioning messages

T_{CCH} – Sending period [10]

802.11p Self-organizing TDMA (STDMA)

- Is already in commercial use in automatic identification system (AIS) [11]
- Predictable channel access delay
- Good scalability

- **Initialization**: Listen to the channel activity during 1 frame
- **Network entry**: Select the free time slot or the slot used by the station located furthest away
- **First Frame**: Reserve the slot
- **Continuous operation**: Periodically transmit messages [12]

[12] In-depth Analysis and Evaluation of Self-Organizing TDMA. Tristan Gaugel, Jens Mittag, Hannes Hartenstein, Stylianos Papanastasiou, Erik G. Stroem
802.11p Self-organizing TDMA (STDMA)

- Requires slot synchronization and position information
- STDMA outperforms CSMA / CA with growing number of the vehicles

- Evaluation performed for [13]
  - Frequency = 2 Hz
  - Packet size = 800 byte
  - Communication range = 1000m

**802.11p Self-organizing TFDMA (STFDMA)**

- Resource block are split by time slots and frequency sub-carriers [14]
- Can handle more simultaneous transmissions

- Outperforms STDMA, but no deep evaluation has been done yet

Data rate 40 kbit/s/user

Number of resource blocks = 1000

**LTE-V2V**

  - Underlay
  - Overlay
- Managed Mode
- Unmanaged mode

- V2V services have stringent latency and reliability requirements
- Cellular traffic on the other hand aims at maximizing the sum throughput under certain fairness considerations [3]

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LT-EV2V

- Drawbacks
  - Interference with Cellular-UEs
  - Computational overhead for Radio Resource Management
  - Required channel state information is not always available, especially for vehicle ITS with high mobility
  - Current infrastructure doesn't cover all roads
  - Malfunction of the Base station will cause problems in vehicular safety systems in its range

[16] Performance Analysis of V2V Beaconing Using LTE in Direct Mode with Full Duplex Radios. Alessandro Bazzi, Barbara M. Masini, Alberto Zanella
Joint usage of 802.11p and LTE-V2V

- Balance between LTE-V2V Managed mode and 802.11p when sender and receiver are in the LTE coverage area
- Use LTE-V2V Unmanaged mode and 802.11p for out of cell communication
- Switch between CSMA/CA and STDMA/SFTDMA depending on the number of vehicles in range for 802.11p
Adaptive platoon management framework

- Based on Channel State Information of LTE-V2V and 802.11p
  - Select appropriate way to transfer messages
  - Use both ways if higher reliability should be achieved
    - Collision warning
    - Public safety messages
  - Adapt platoon parameters based on the channel quality
    - Speed
    - Distance between vehicles
    - CAM sending period
- Predict Quality of Service
Testbed
Testbed

- Simulation of realistic highway traffic system
- Test emergency scenarios with different network parameters
  - 802.11p CSMA / CA
  - 802.11p STDMA
  - 802.11p STFDMA
  - LTE-V2V mode 3
  - LTE V2V mode 4
  - Joint usage of 802.11p and LTE-V2V

- Heterogeneous platoon members
- Static and adaptive platoon parameters mode
Conclusions

• To guarantee delay constraints 802.11p should implement alternative MAC protocol for high network loads
• Managed LTE-V2V alone could not be sufficient for platoon management in dense traffic scenarios
• Channel bonding of 802.11p and LTE-V2V should be considered
• Use Testbed for joint modelling of communication solutions and platoon management
Thank you!