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

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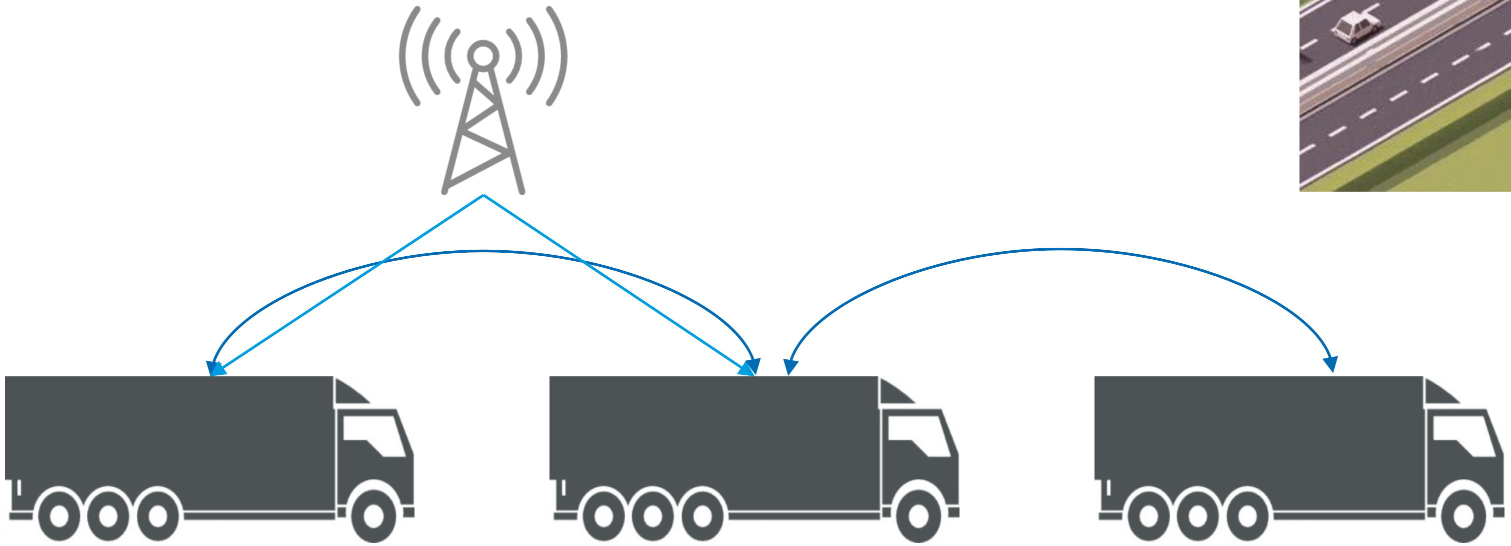
Outline

- 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
    - CO_2 emission reduction

[1]



[1] https://phys.org/news/2017-11-highway-youtruck-platooning.html

Motivation

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

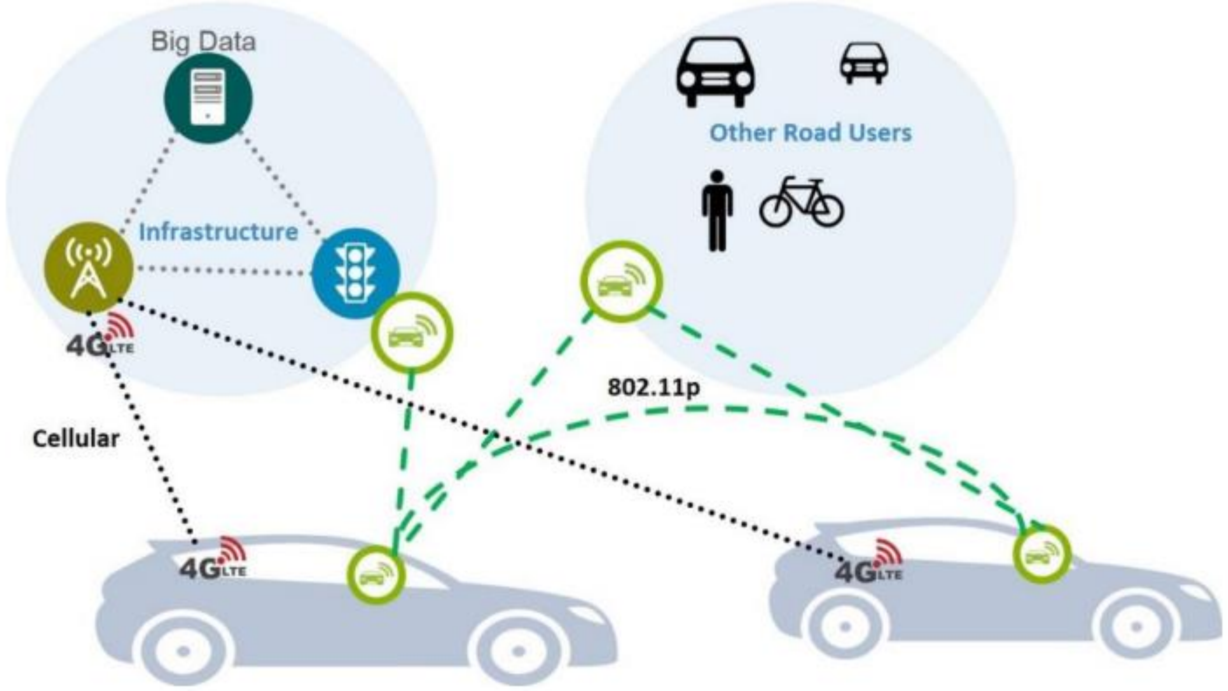
- Requirements achievable
  - To ensure resilience and low latency by
    - **Vehicle-to-Vehicle (V2V)** communication
    - **Vehicle-to-Infrastructure (V2I)** communication

[2] ETSI TS 102 637-2 V1.2.1
[3] Radio Resource Management for D2D-Based V2V Communication. Wanlu Sun, Erik G. Ström, Fredrik Brännström, Member, and Yutao Sui

Motivation

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

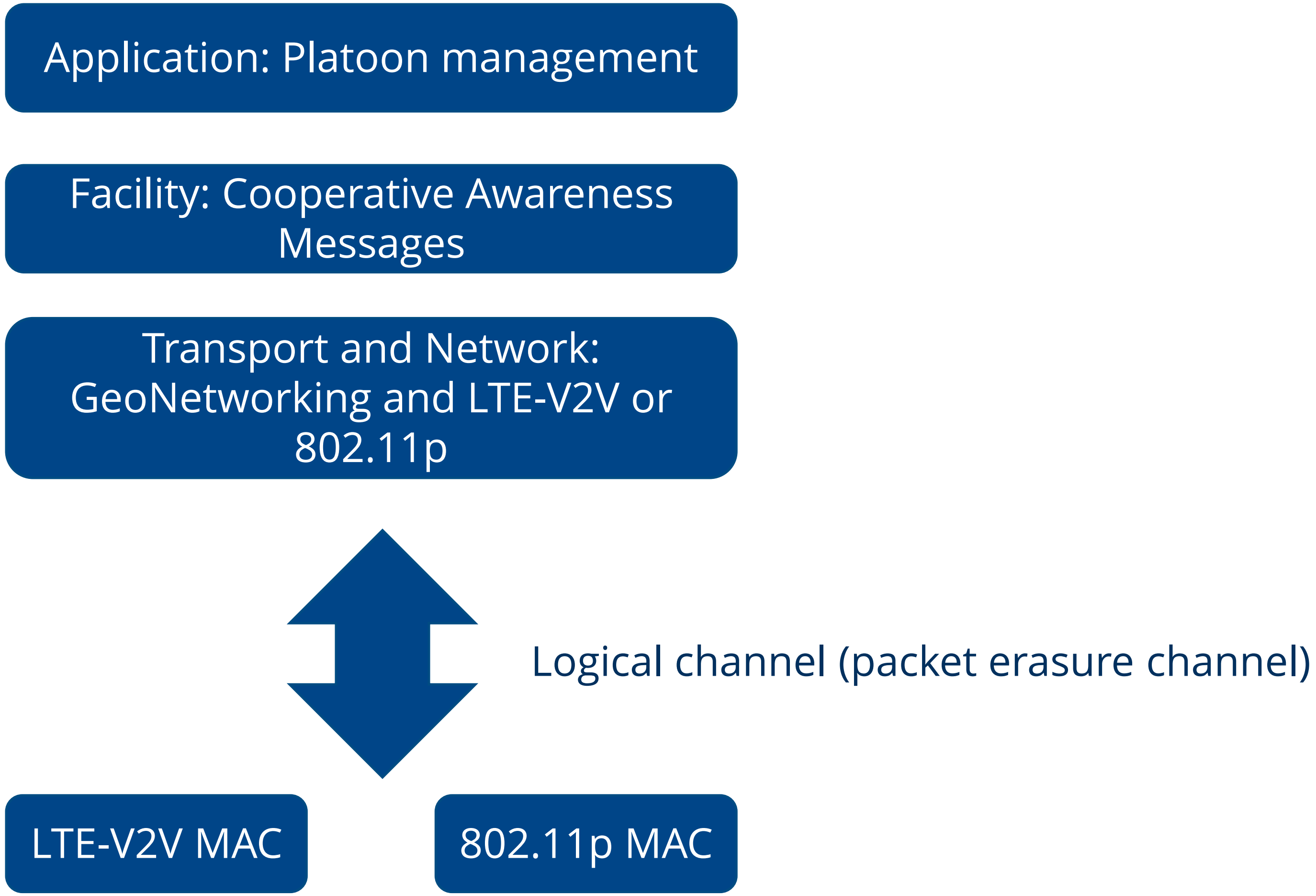
- Heterogeneous usage of both technologies
  - To improve reliability
  - To provide ubiquities connectivity



[4]

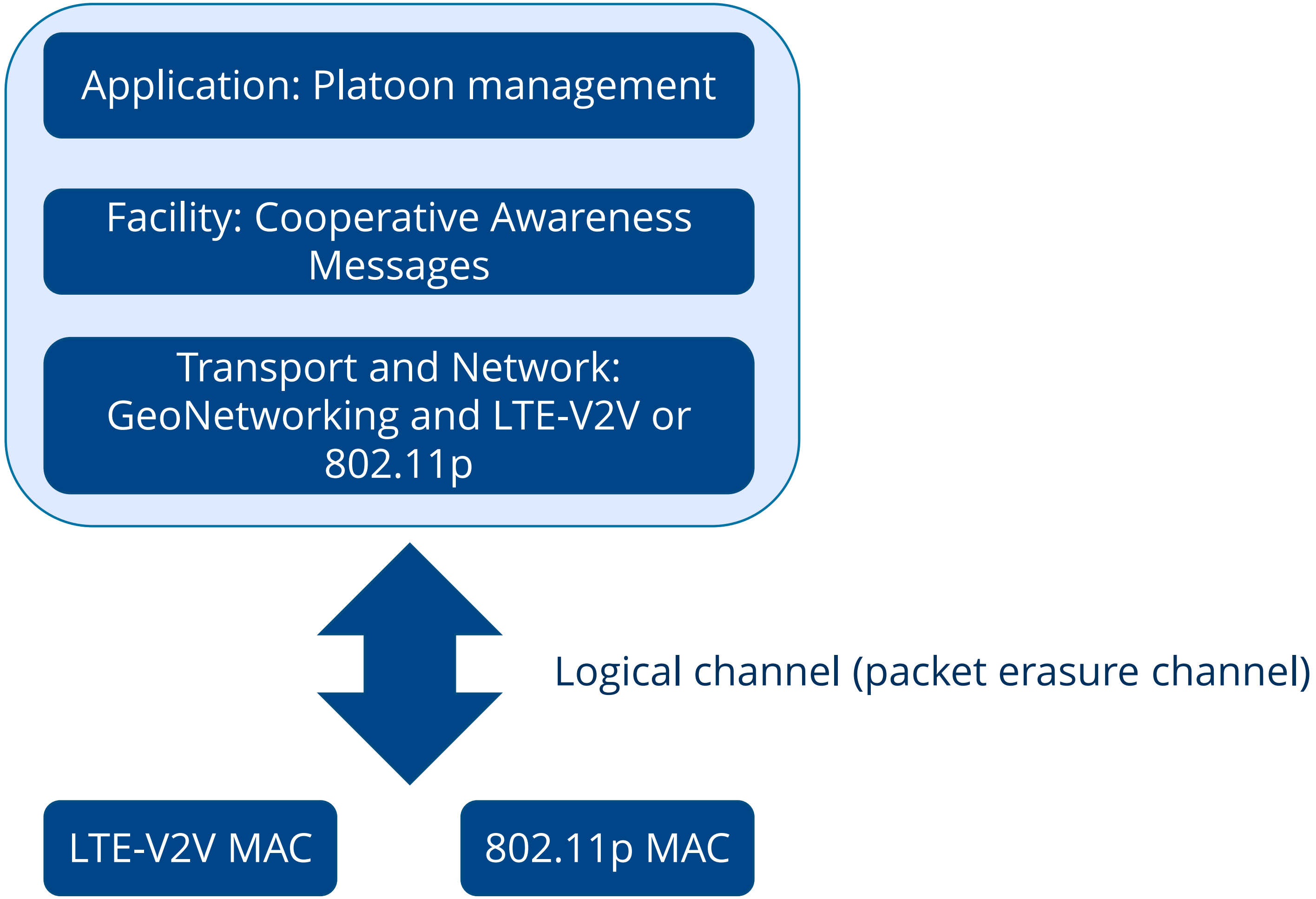
[4] Ready to roll: Why 802.11p beats LTE and 5G for V2X. Alessio Filippi, Kees Moerman, Gerardo Daalderop, Paul D. Alexander, Franz Schober, and Werner Pfliegl

Protocol structure



Platoon management, CAM and GeoNetworking

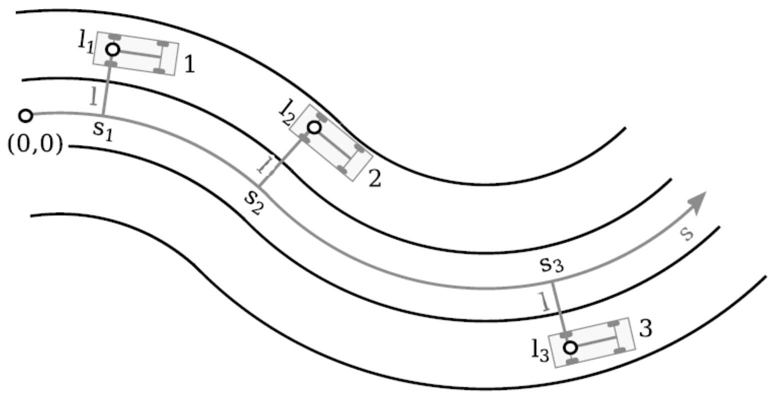
Platoon management

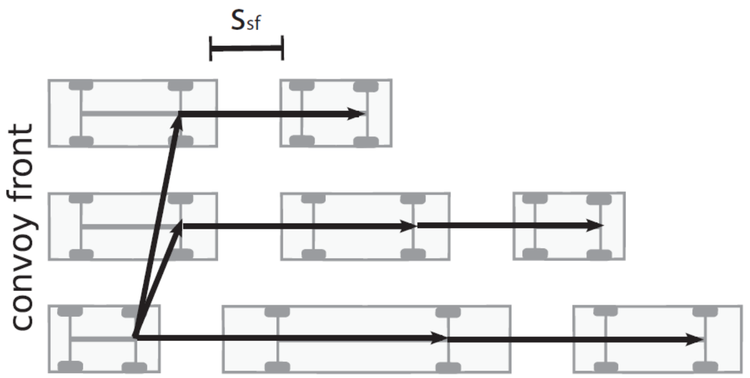


Distributed graph-based platoon control

- 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

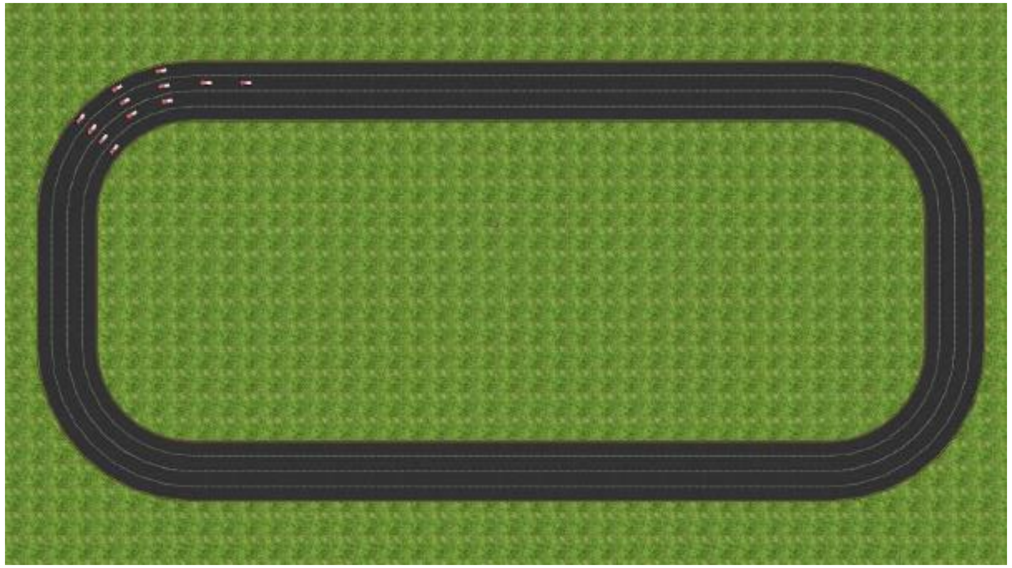


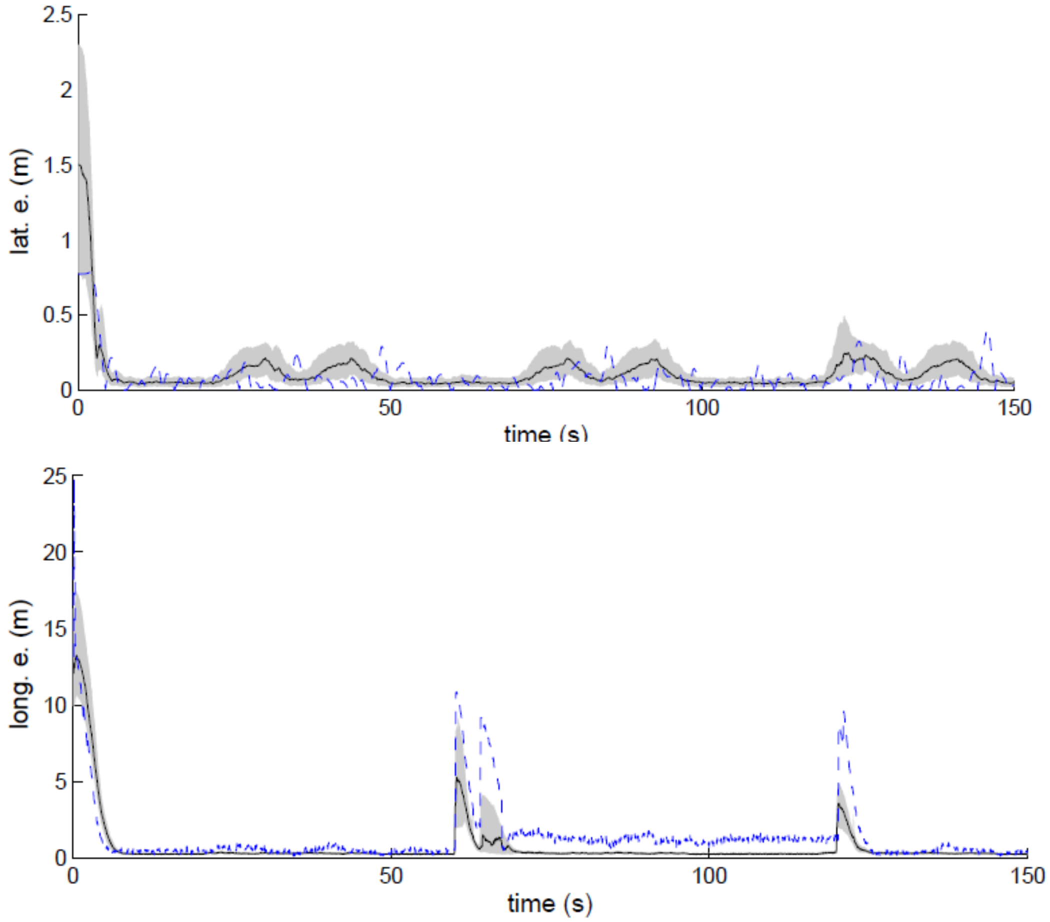


[6] Distributed Graph-Based Control of Convoys of Heterogeneous Vehicles using Curvilinear Road CoordinatesV2X. I˜naki Navarro, Florian Zimmermann, Milos Vasic, Alcherio Martinoli

Distributed graph-based platoon control

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

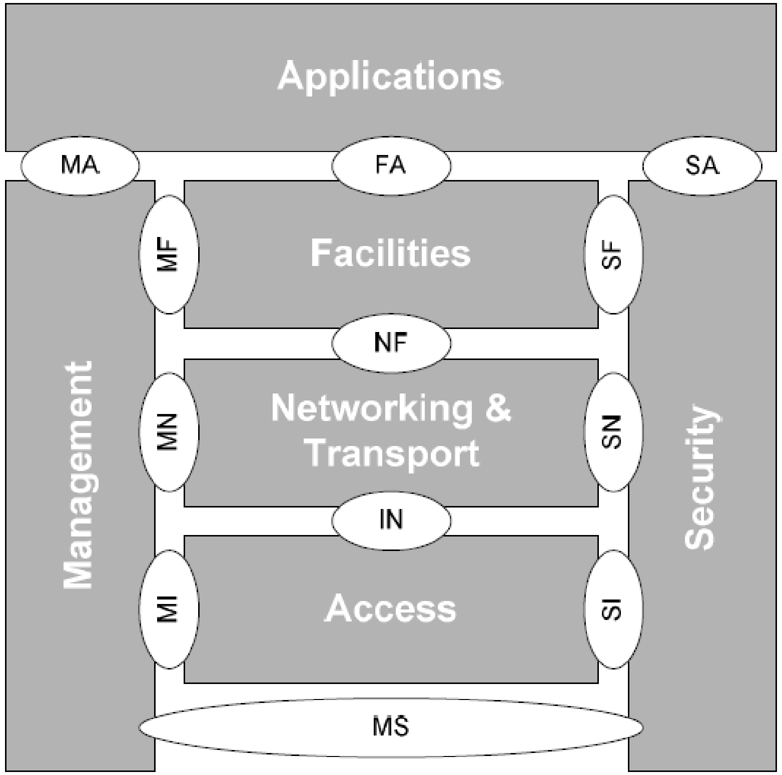




[6] Distributed Graph-Based Control of Convoys of Heterogeneous Vehicles using Curvilinear Road CoordinatesV2X. I˜naki Navarro, Florian Zimmermann, Milos Vasic, Alcherio Martinoli

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)



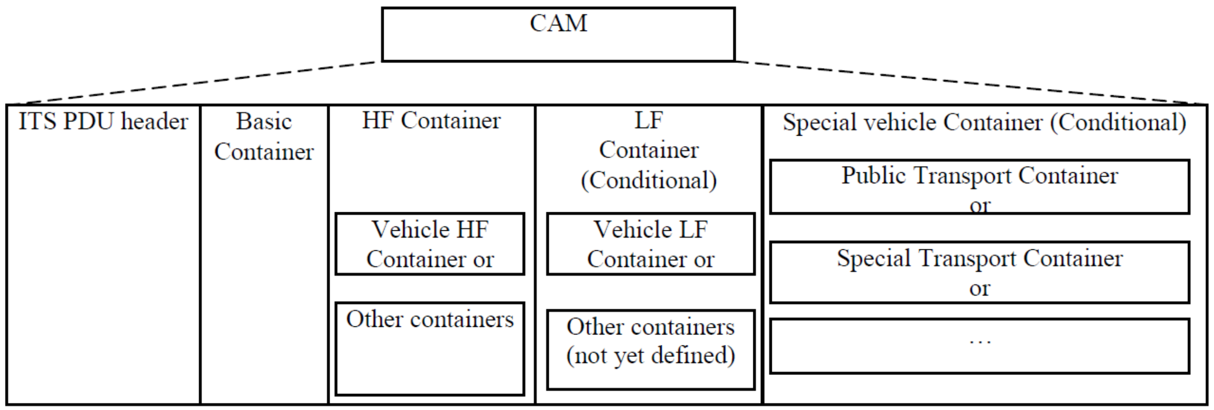
ITS Stations (ITS-S) architecture

[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

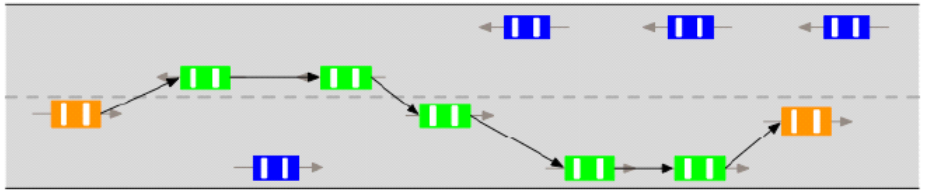


[2] ETSI TS 102 637-2 V1.2.1
[9] ETSI EN 302 637-2 V1.3.2

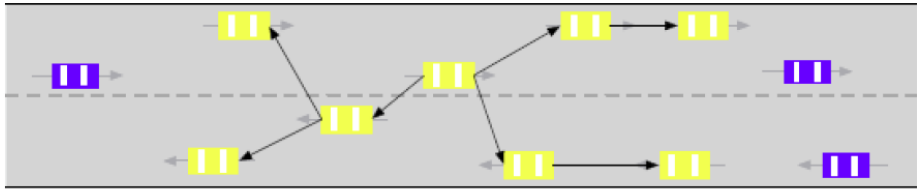
GeoNetworking

- 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

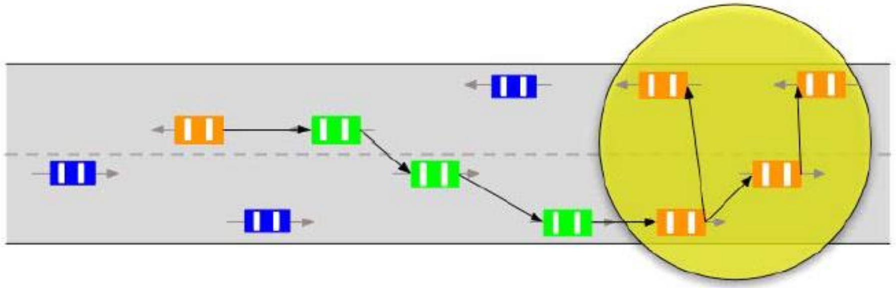
GeoUnicast



GeoAnycast



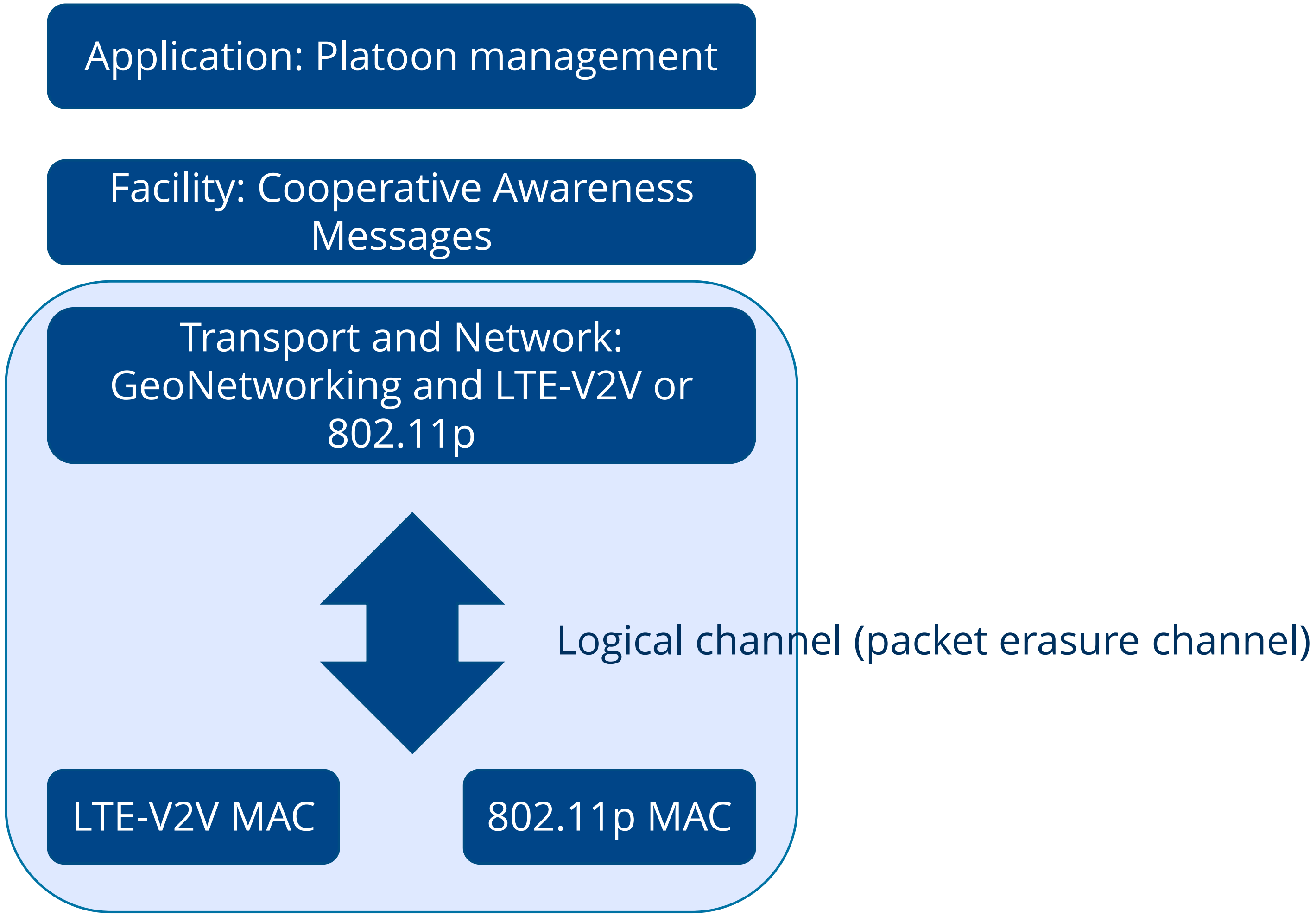
GeoBroadcast



[7] ETSI EN 302 636-1 V1.2.1

LTE-V2V and 802.11p

LTE-V2V and 802.11p

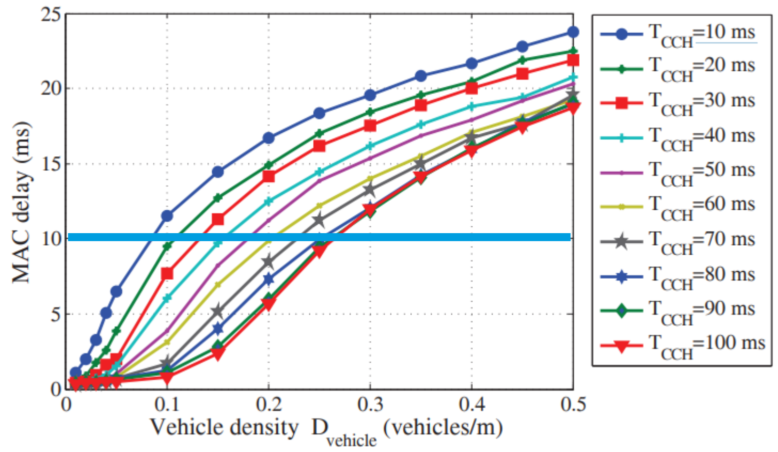


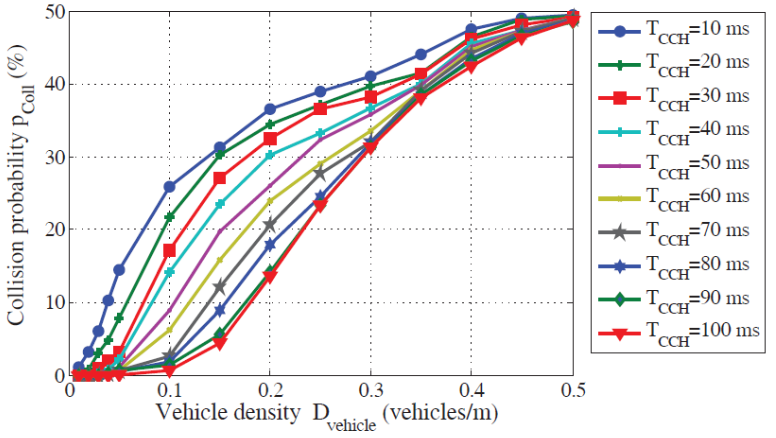
802.11p CSMA / CA

- 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]

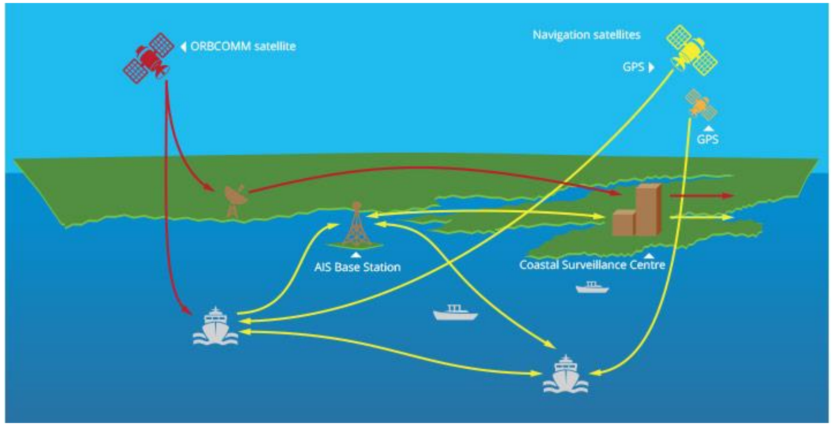




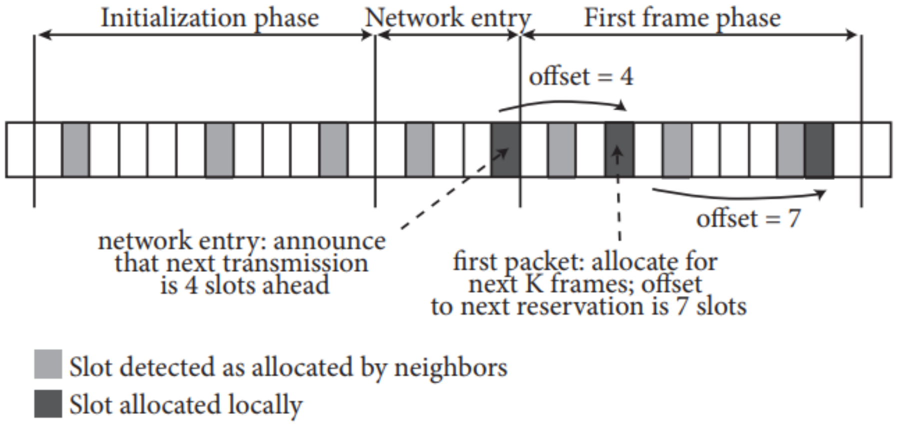
[10] Performance Evaluation of IEEE 802.11p MAC Protocol in VANETs Safety Applications. Lusheng Miao, Karim Djouani, Barend Jacobus Van Wyk, Yskandar Hamam

802.11p Self-organizing TDMA (STDMA)

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



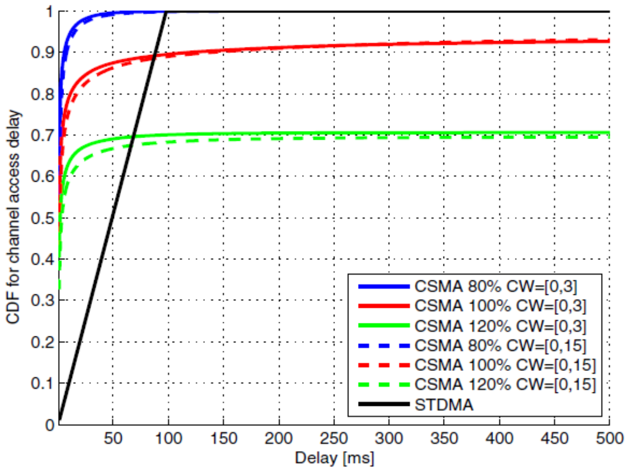
- **Initialization:** Listen to the channel activity during 1 frame
- **Network entry:** Select the free time slot or the slot used by the station located furthest away
- **First Frame:** Reserve the slot
- **Continuous operation:** Periodically transmit messages [12]



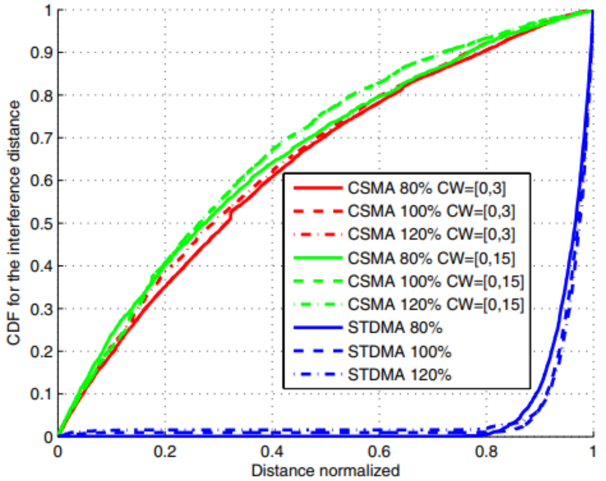
[11] On the Ability of the 802.11p MAC Method and STDMA to Support Real-Time Vehicle-to-Vehicle Communication. Katrin Bilstrup, Elisabeth Uhlemann, ErikG Ström, Urban Bilstrup
[12] In-depth Analysis and Evaluation of Self-Organizing TDMA. Tristan Gaugel, Jens Mittag, Hannes Hartenstein, Stylianos Papanastasiou†, 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



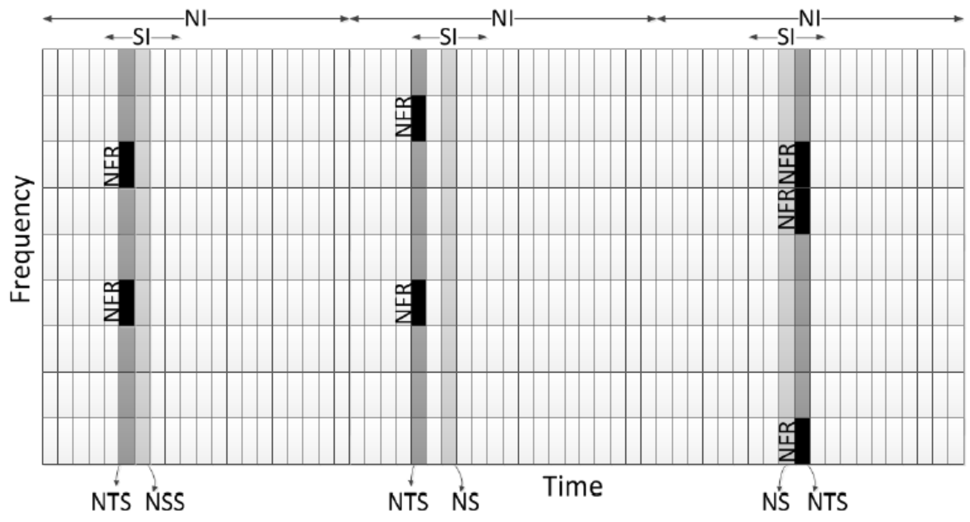
- Evaluation performed for [13]
  - Frequency = 2 Hz
  - Packet size = 800 byte
  - Communication range = 1000m



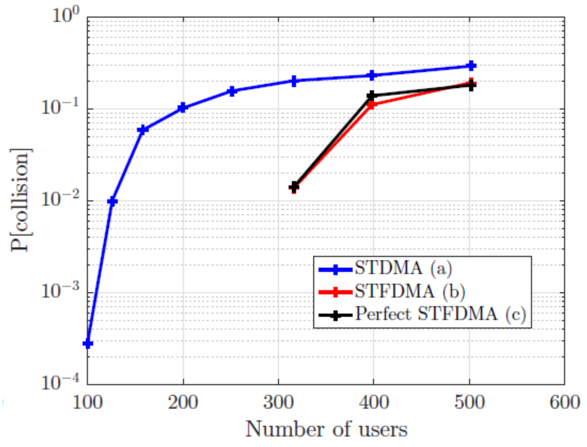
[13] Scalability Issues of the MAC Methods STDMA and CSMA of IEEE 802.11p When Used in VANETs. Katrin Sjöberg-Bilstrup, Elisabeth Uhlemann†, Erik G. Ström

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

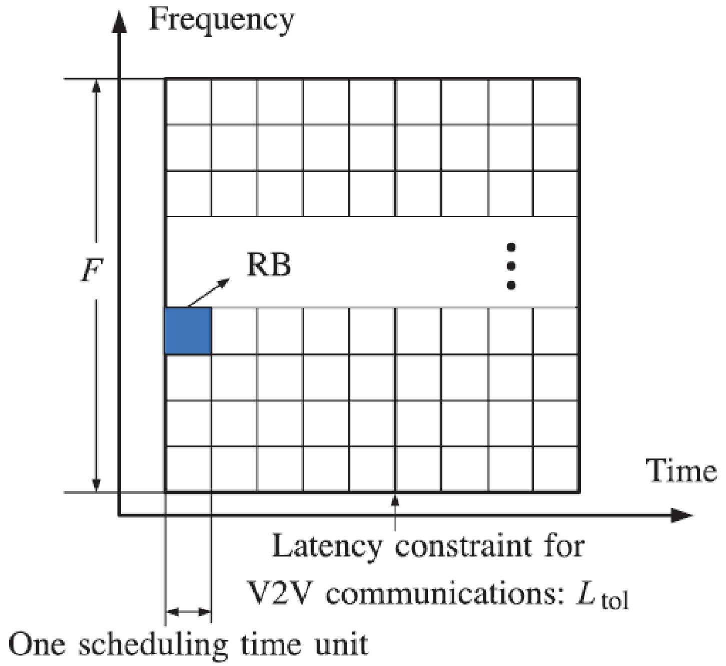
[14] STFDMA: A Novel Technique for Ad-Hoc V2V Networks Exploiting Radio Channels Frequency Diversity. M. A. Gutierrez-Estevez, D. Gozalvez-Serranoy, M. Botsovy, S. Sta´nczak

LTE-V2V

- Performs centralized Radio Resource Management for D2D communications [15]
  - Underlay
  - Overlay

  - Managed Mode
  - Unmanaged mode

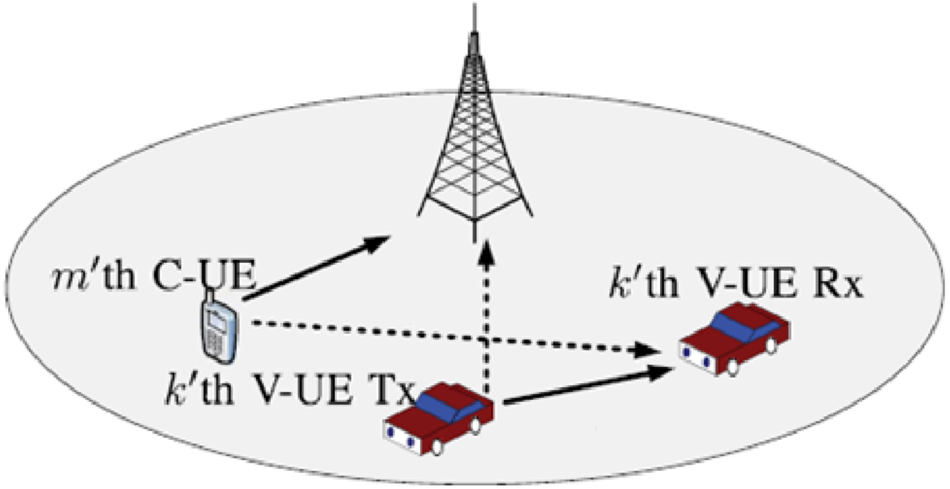
- V2V services have stringent latency and reliability requirements
- Cellular traffic on the other hand aims at maximizing the sum throughput under certain fairness considerations [3]



[3] Radio Resource Management for D2D-Based V2V Communication. Wanlu Sun, Erik G. Ström, Fredrik Brännström, Member, and Yutao Sui
[15] 5G D2D Networks: Techniques, Challenges, and Future Prospects. Rafay Iqbal Ansari, Chrysostomos Chrysostomou, Syed Ali Hassan, Mohsen Guizani, Shahid Mumtaz, Jonathan Rodriguez, Joel J. P. C. Rodrigues

LTE-V2V

- 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

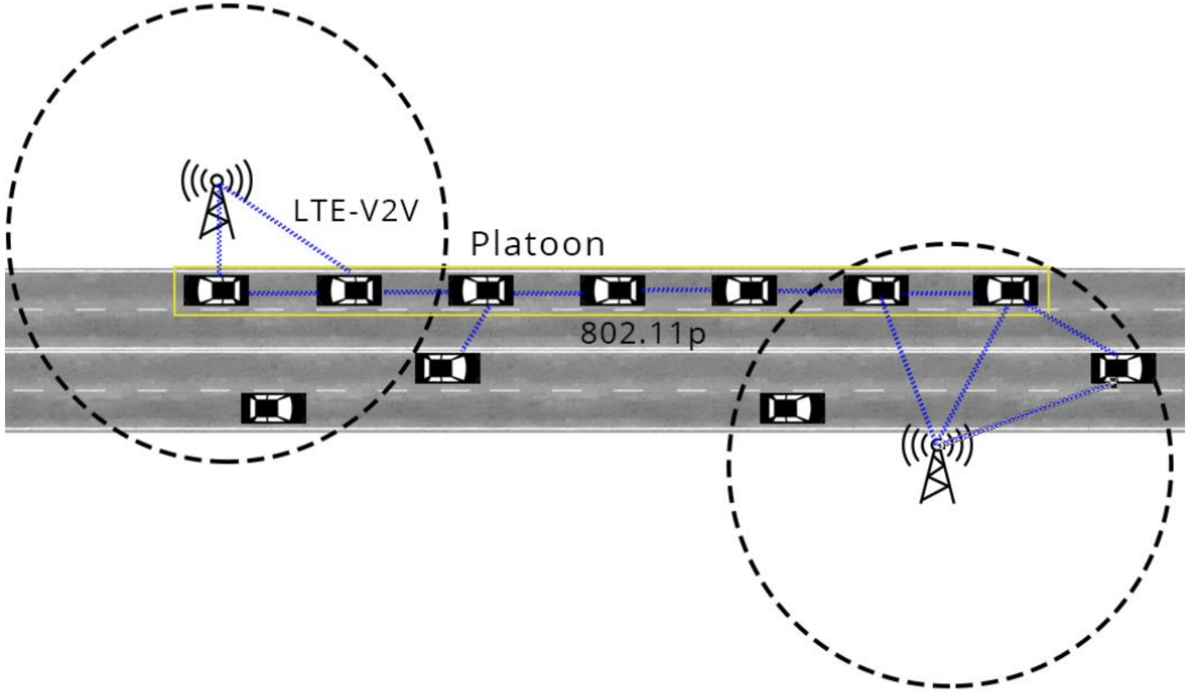


[3]

[3] Radio Resource Management for D2D-Based V2V Communication. Wanlu Sun, Erik G. Ström, Fredrik Brännström, Member, and Yutao Sui
[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!