UNIVERSITY OF TRENTO
Department of Information Engineering and Computer Science

Wireless Mesh and Vehicular Networks

Introduction to Vehicular Networks

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with special thanks to
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Motivation

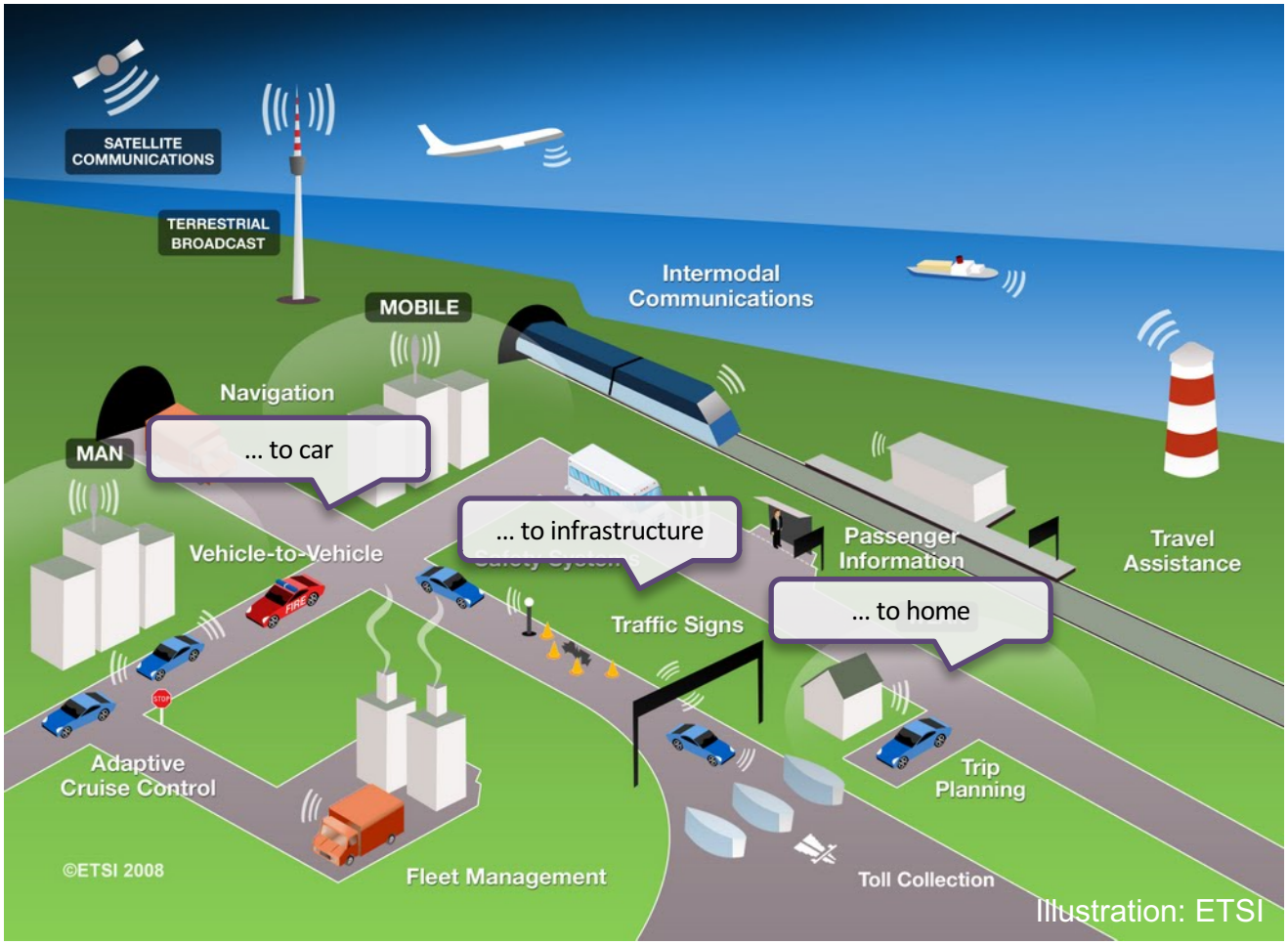
- Car-to-X (C2X) communication patterns

Vehicle-to-X (V2X),

Inter-Vehicle Communication (IVC),

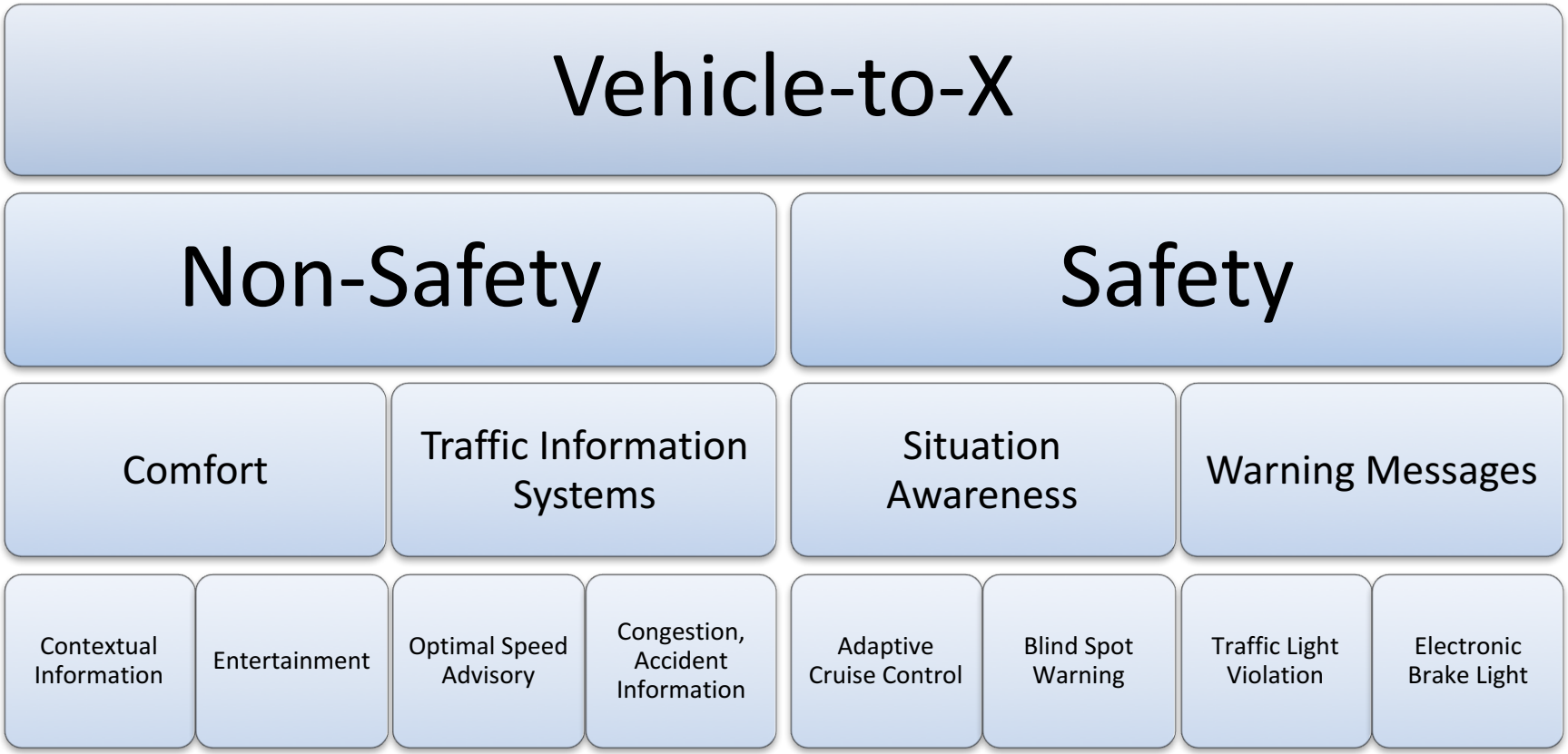
Vehicular ad-hoc network (VANET),

…



Audi Travolution

- Taxonomy of Use Cases



- Taxonomy of Use Cases

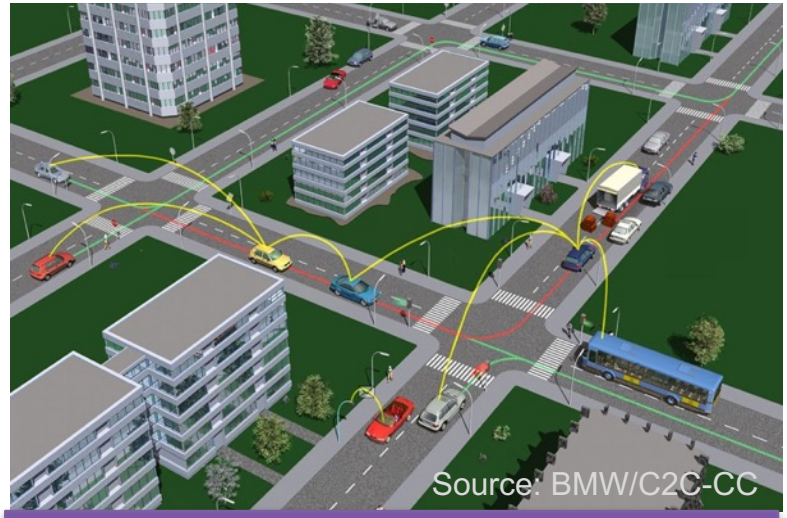
Vehicle-to-X

Non-Safety	Safety
▪ Many messages ▪ High data rate ▪ Low latency demands ▪ Low reliability demands ▪ Long range	▪ Few messages ▪ Small packet size ▪ High latency demands ▪ High reliability demands ▪ Short range

Motivation

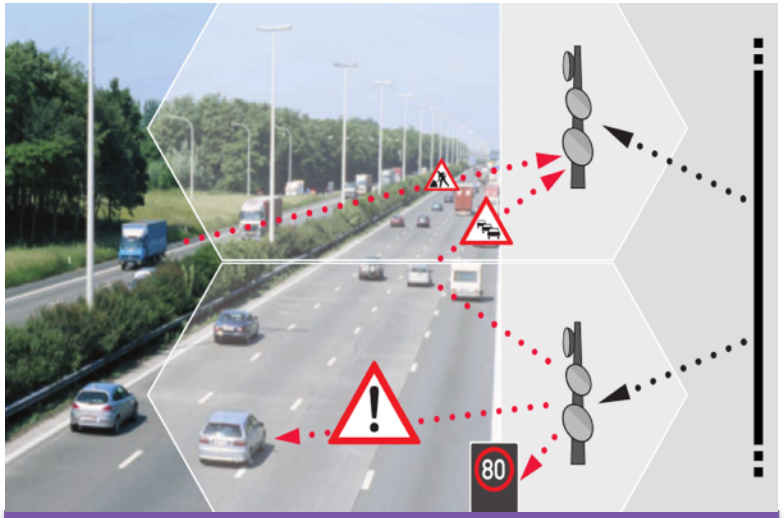
- Freeway ⇔ Urban

- 1D mobility
- Bimodal connectivity
  - Stable connection (➔➔)
  - ∧ Unstable connection (➔➔)
- High speed
- …

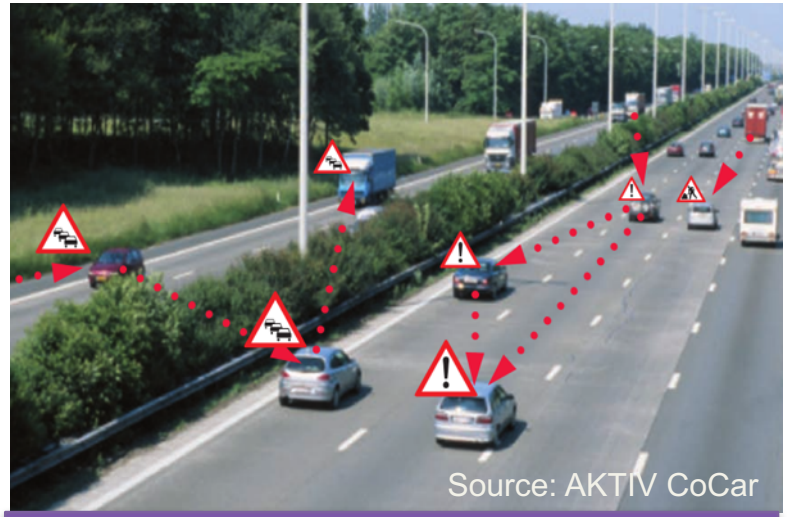


- 2D mobility
- Bipolar connectivity
  - Many neighbors (standing)
  - ∨ Few neighbors (driving)
- Obstacles
- …

- Infrastructure ⇔ No Infrastructure



- Central coordination
  - Resource management
  - Security
- High latency
- High load on core network
- …



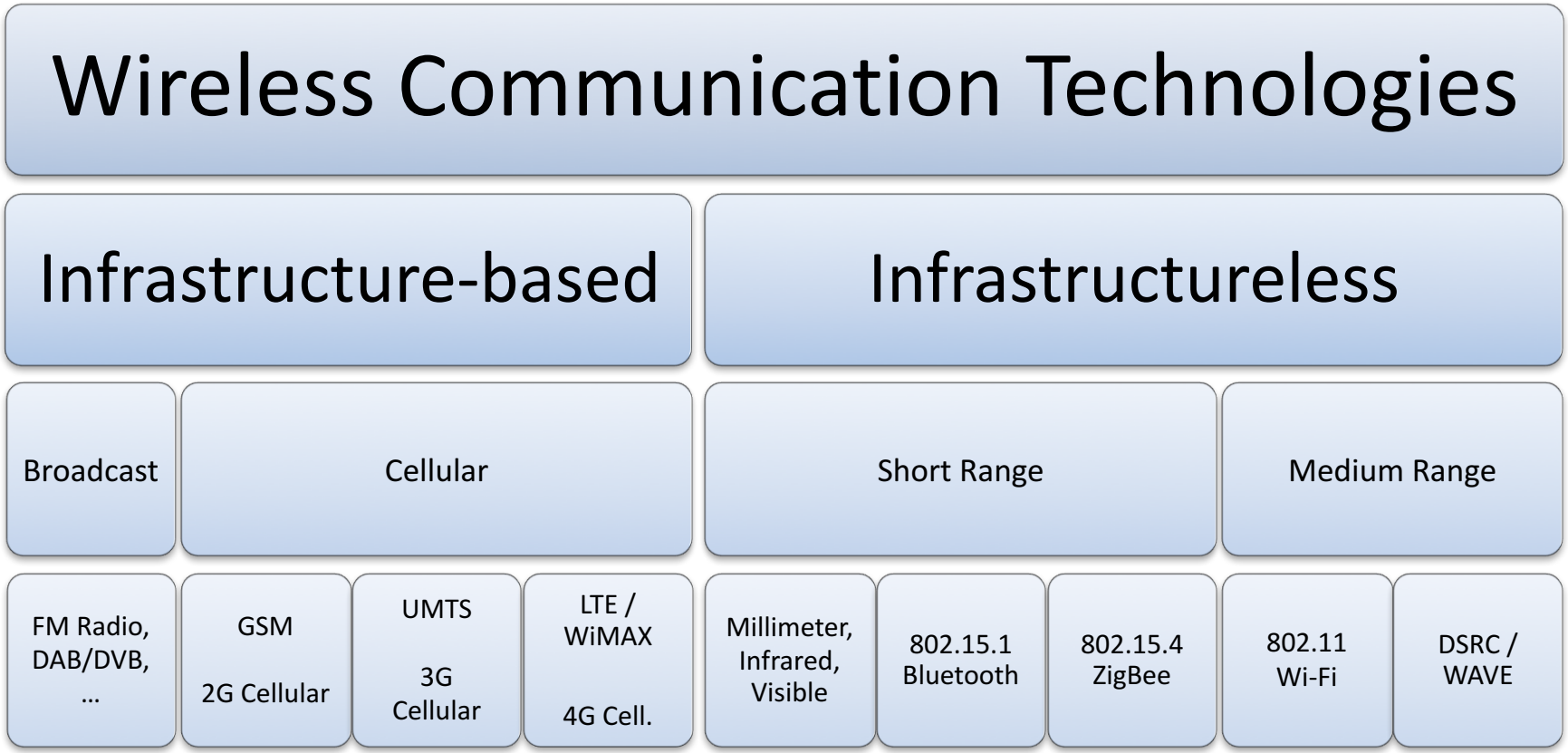
- Self organizing system
  - Channel access
  - Authentication
- Low latency
- Low data rate
- …

Motivation

- Challenges of C2X communication

Communication	• Highly varying channel conditions • High congestion, contention, interference • Tightly limited channel capacity
Networking	• Multi-Radio / Multi-Network • Heterogeneous equipment
Mobility	• Highly dynamic topology • But: predictable mobility • Heterogeneous environment
Security	• No (or no reliable) uplink to central infrastructure • Ensuring privacy

- Communication paradigms and media



[1] Dar, K. and Bakhouya, M. and Gaber, J. and Wack, M. and Lorenz, P., "**Wireless Communication Technologies for ITS Applications**," IEEE Communications Magazine, vol. 48 (5), pp. 156-162, May 2010

A (rough) outline of the Vehicular Networks topics

- Application: why VN?
- Communication: technologies, alternatives, protocols, challenges
- Simulation: evaluating vehicular networks without vehicles and without networks. Tools and models

APPLICATIONS

Monetary (and social) motivation

- Is road transportation getting “better”?
  - Safety
    - road fatalities (DEU, ITA, FRA, POL): roughly 4000 per year
    - decreasing, but accidents rather stable
    - healthcare and rehabilitation: up to 3% of the GDP
      - DEU and ITA: around 33 000 000 000 $ (33 billion $) each[1]
  - Traffic
    - in the EU, 14% of CO_2 emission is due to road transportation
    - congestion costs 1% of EU’s GDP[2]
      - 164 770 000 000 $ (164 billion $)

[1] ***“European status report on road safety: towards safer roads and healthier transport choices”***, Copenhagen, WHO Regional Office for Europe, 2009.

[2] ***“Roadmap to a Single European Transport Area - Towards a Competitive and Resource Efficient Transport System”*** European Commission, March 2011.

Are we improving the situation?

- Safety
  - passive systems
  - active systems
- Traffic
  - car pooling services
  - electric bikes
- Pollution
  - hybrid/electric vehicles
  - better combustion engines

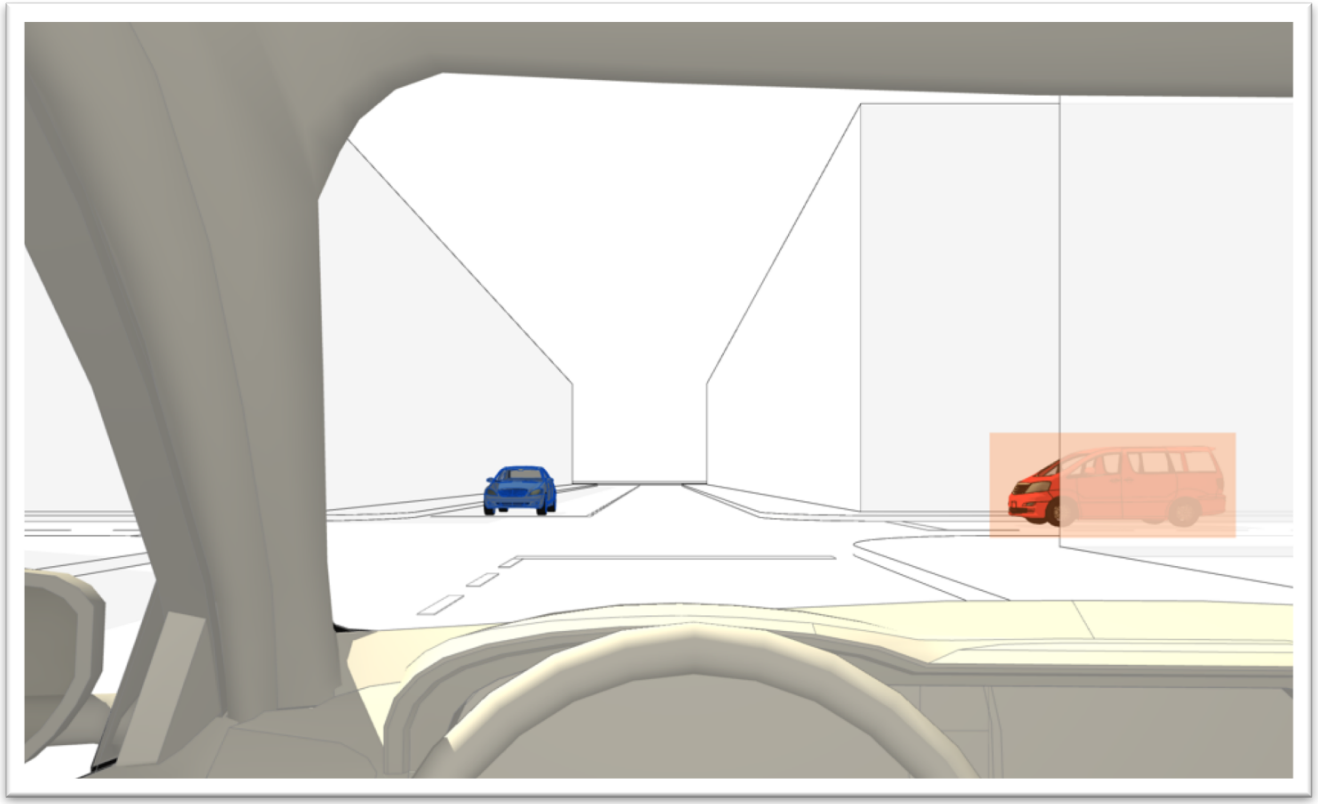
Image: Wikimedia Commons

Self/Autonomous vs. Cooperative

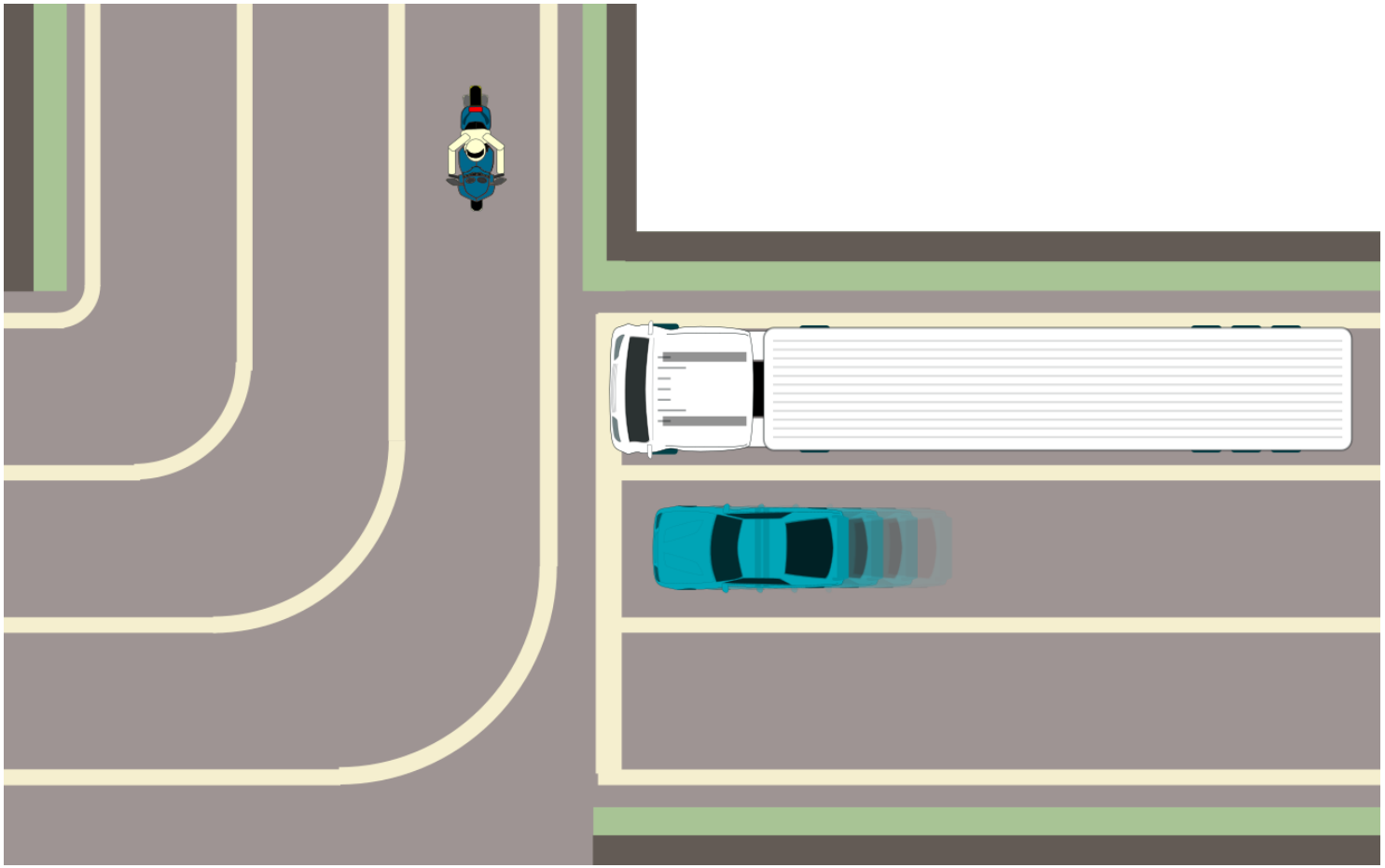
- Self-driving vehicles
  - New applications (Uber, improved car-sharing)
  - Improved safety
  - Not really the last/only step: somehow limited as humans

Intersection collision avoidance

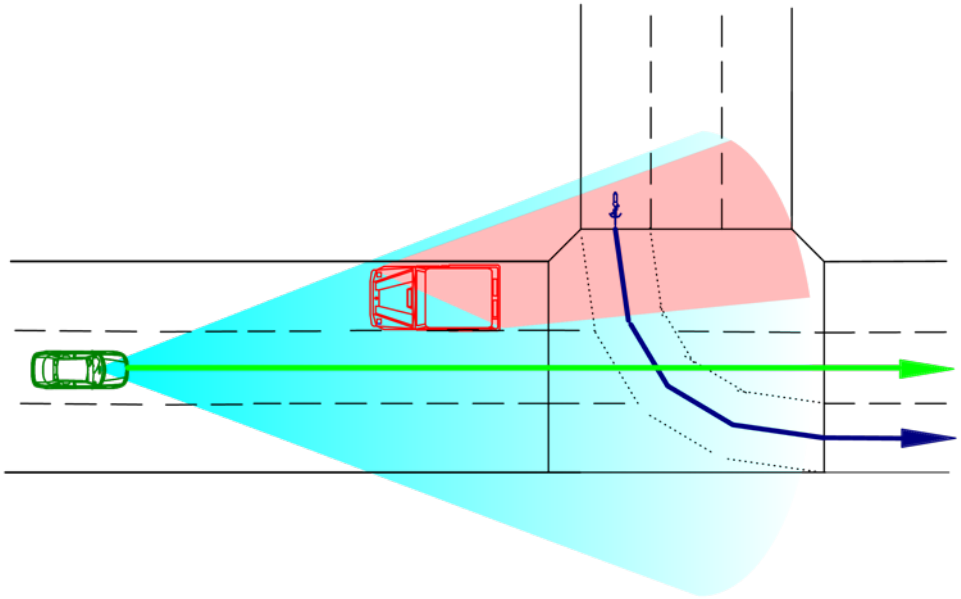
- Track ”invisible” or misbehaving vehicles
  - Predict their trajectory
  - Inform the driver or automatically take countermeasures



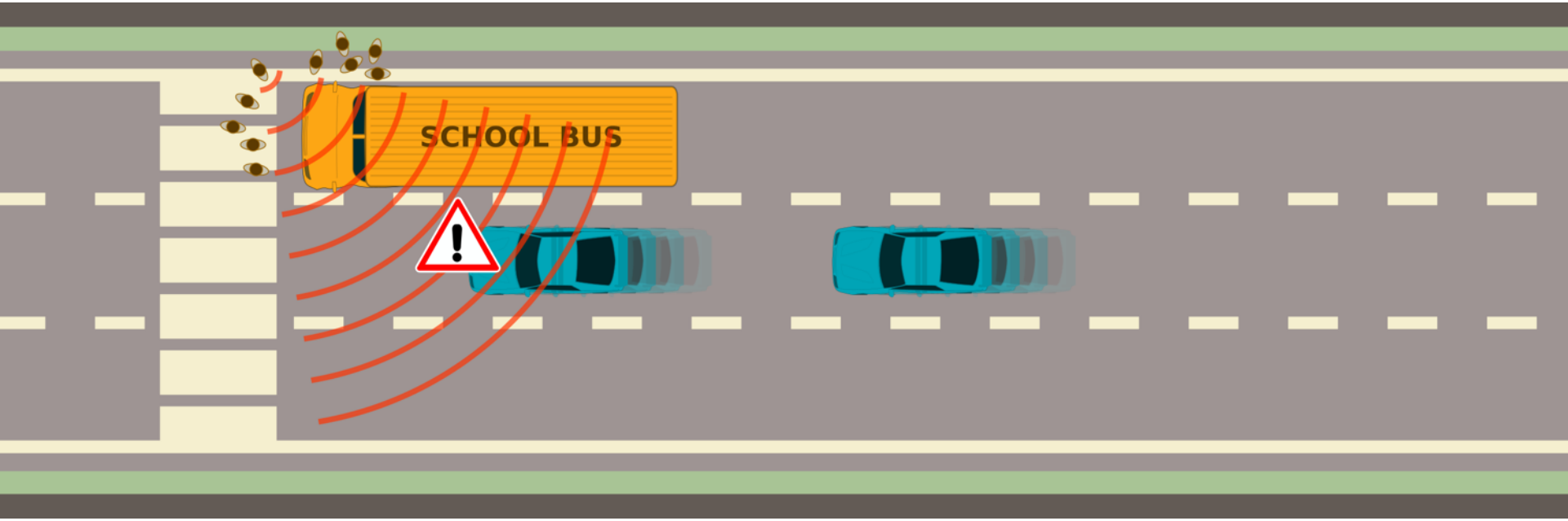
Intersection collision avoidance



- Cyclists / Motorcyclists
  - Sharing the road with vehicles
  - Safety particularly affected by blind spots

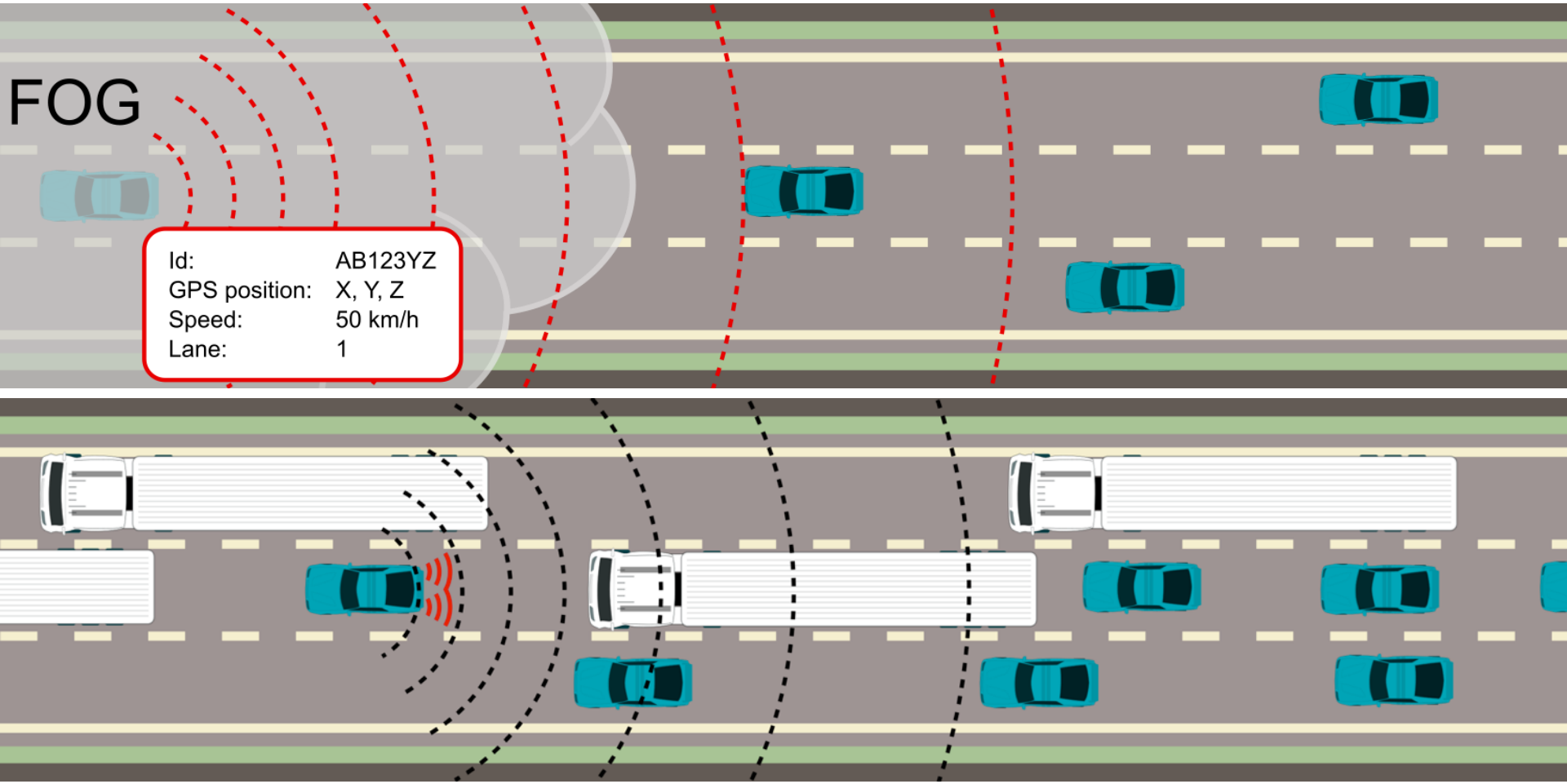


- Pedestrian
  - Not protected by a “chassis”
  - ~25% of the road casualties in the EU [1]

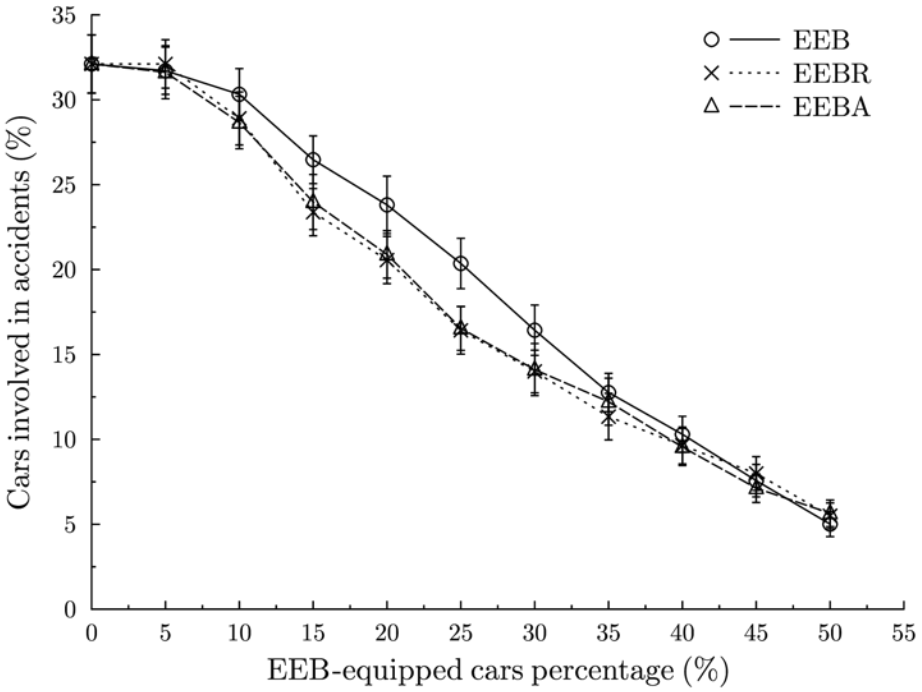


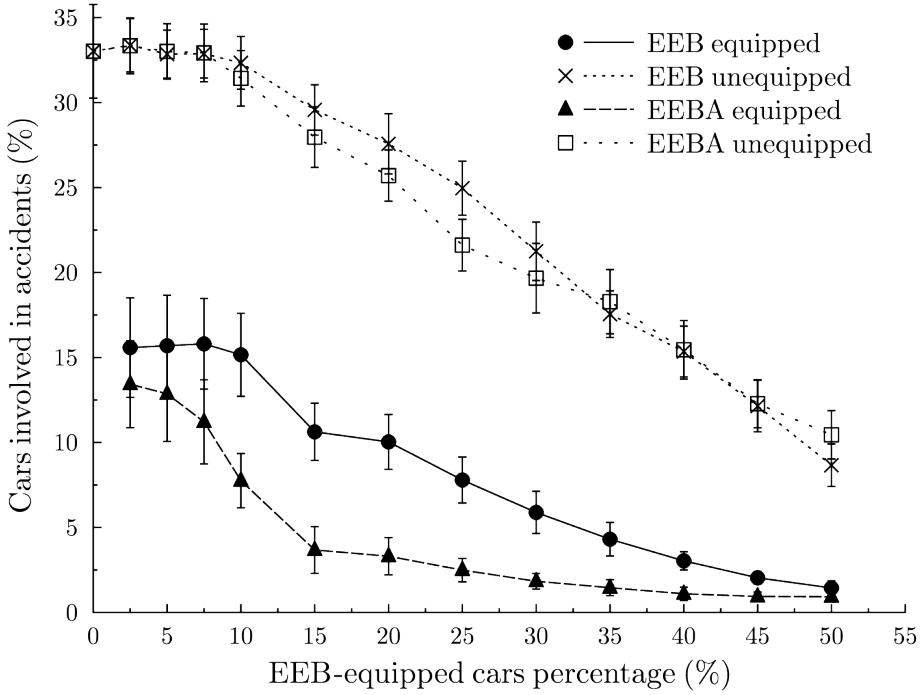
[1] ***“Annual Accident Report”*** European Commission, Directorate General for Transport, June 2016.

Low visibility and EEBL

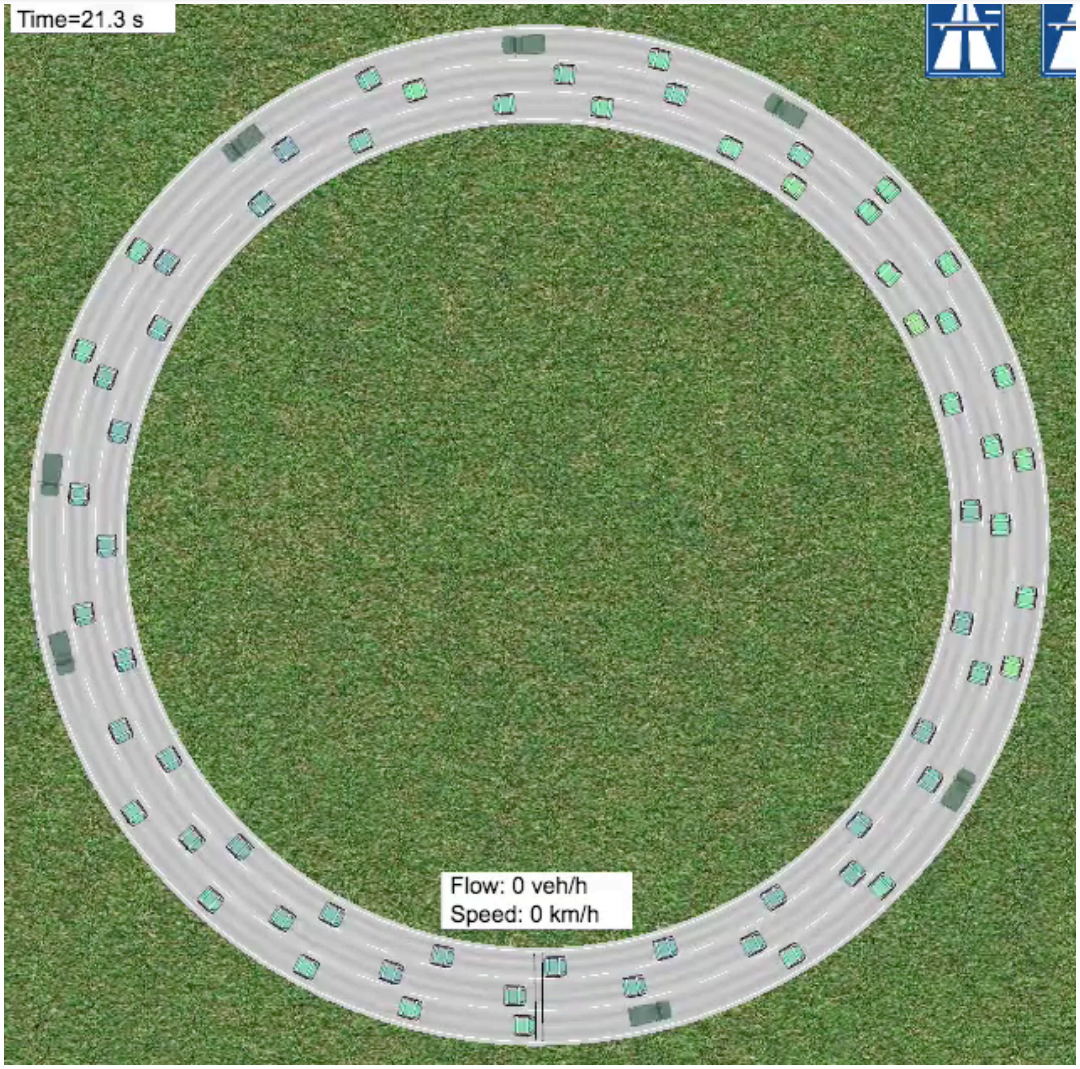


The benefits of EEBL





Traffic shock waves



[1] Credits: Martin Treiber, http://www.traffic-simulation.de

Platooning

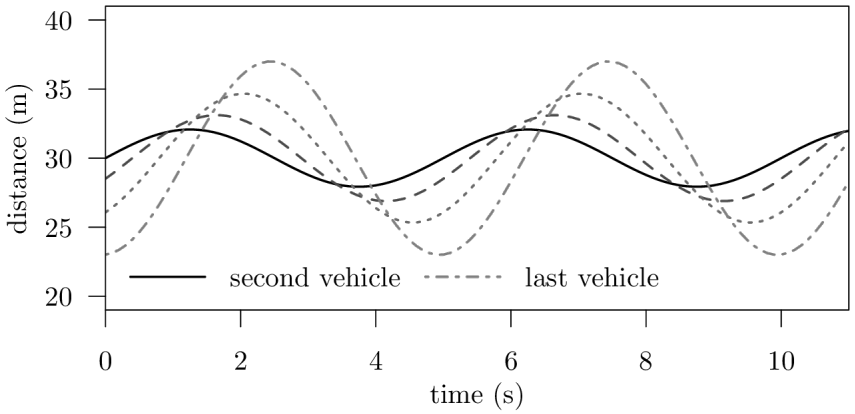
- Platooning: semi-autonomous driving
  - vehicles form a road-train, automatically following each other

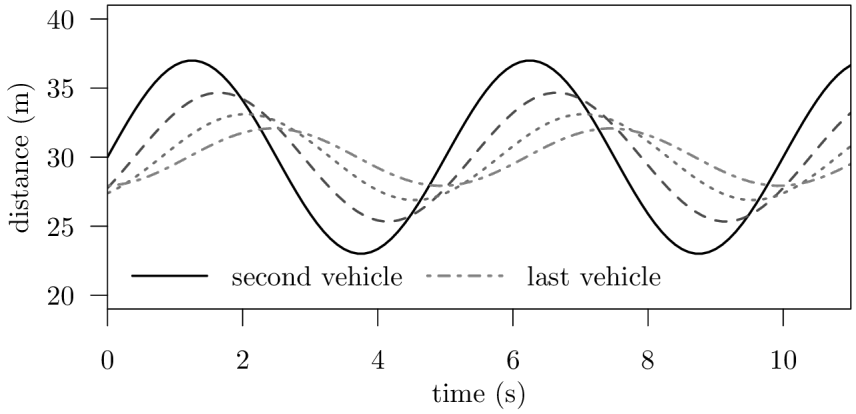
- Advantages in terms of
  - freeway capacity
  - fuel saving
  - safety
  - driving experience

Image: Volvo SARTRE Project

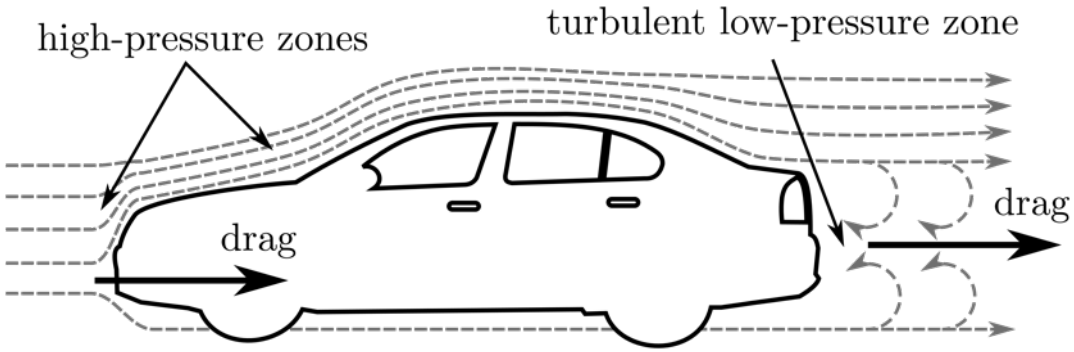
Platooning

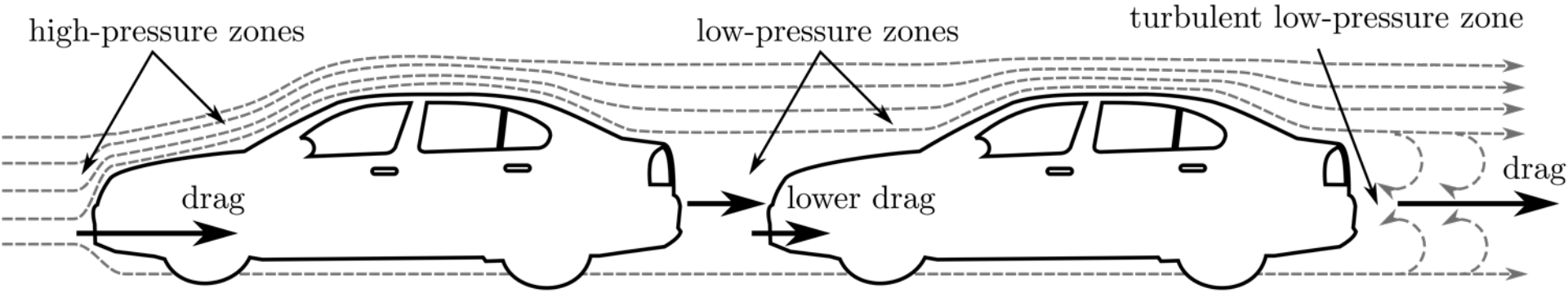
- Adaptive Cruise Control (ACC)
  - radar/lidar based
  - can't see farther than one vehicle ahead
  - constant time headway
  - string-unstable for small time headway





Air drag reduction

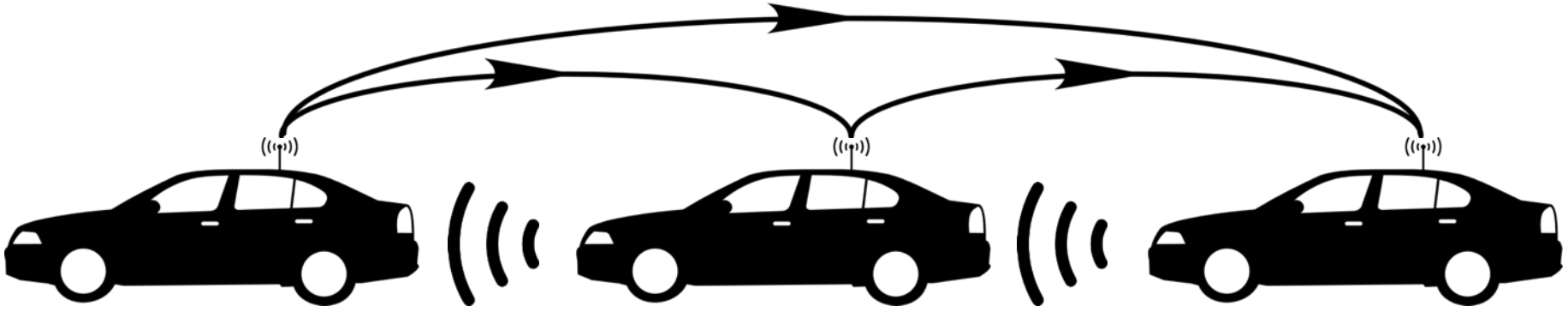




Going cooperative

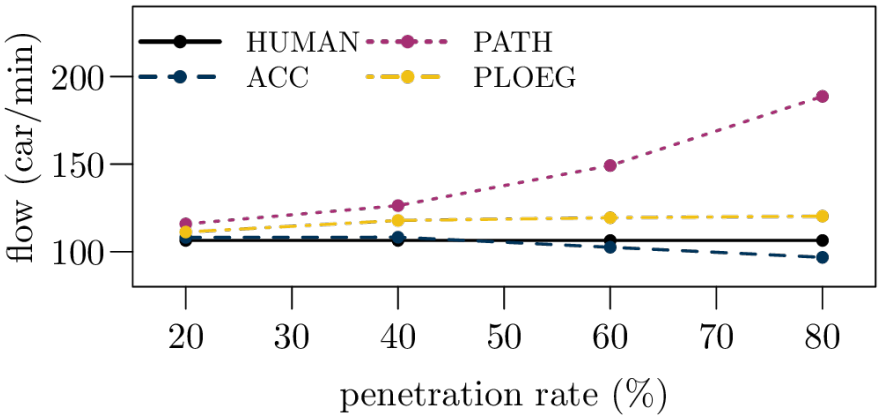
- Cooperative Adaptive Cruise Control (CACC)
  - exploits radar/lidar and wireless communication
  - highly reduces inter-vehicle gap (constant spacing possible)
  - different proposed solutions:
    - logic control topology (predecessor-following, leader- and predecessor-following, bi-directional, all to all, …)
    - substantial changes in performance and requirements

- Platoons need to be created, modified, disrupted

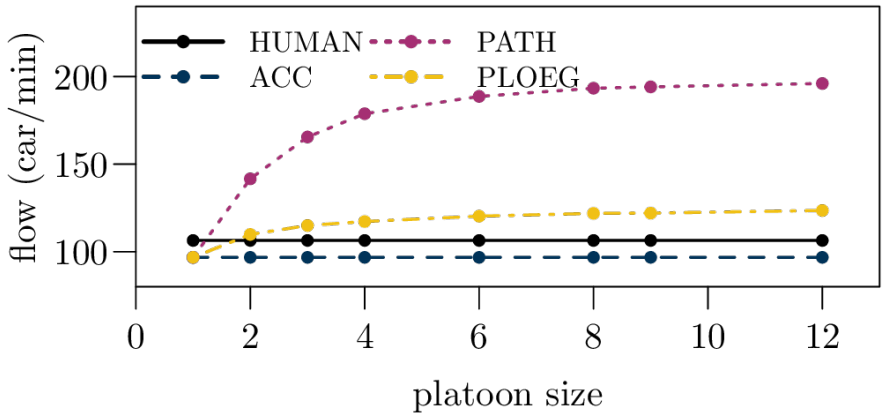


Impact on traffic

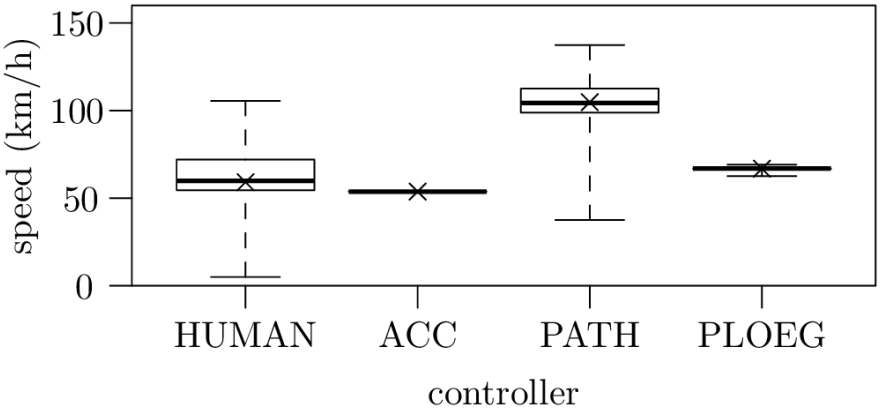
[1]



[2]



[3]

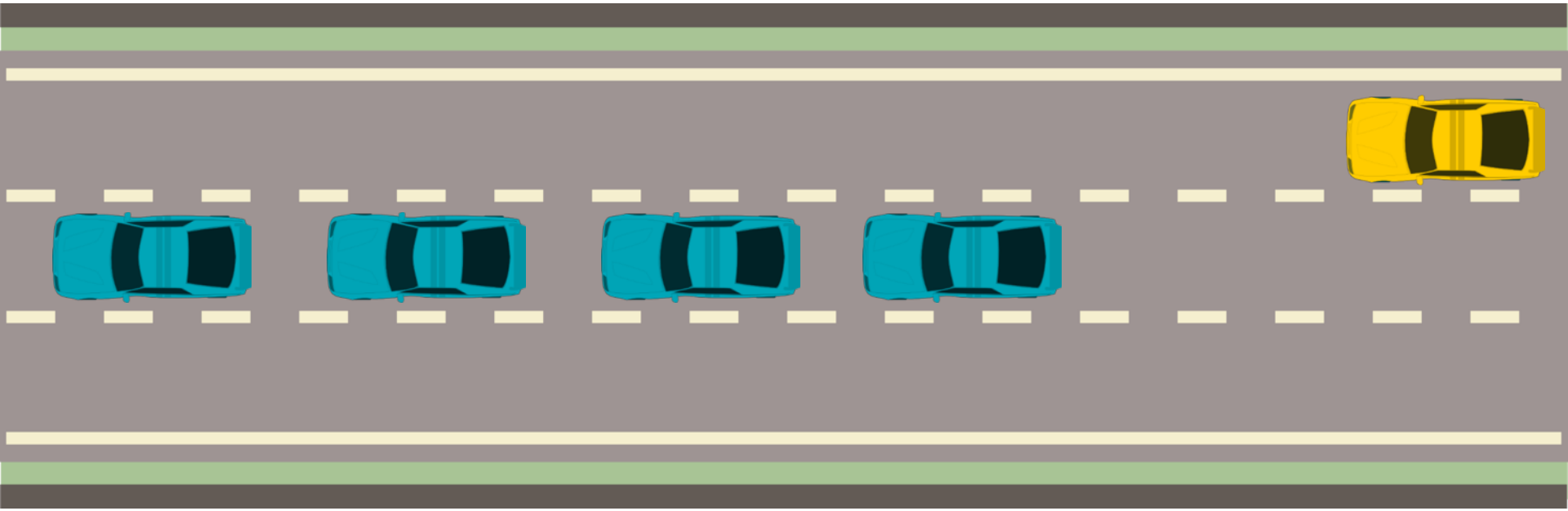


[1] 6-car platoon.

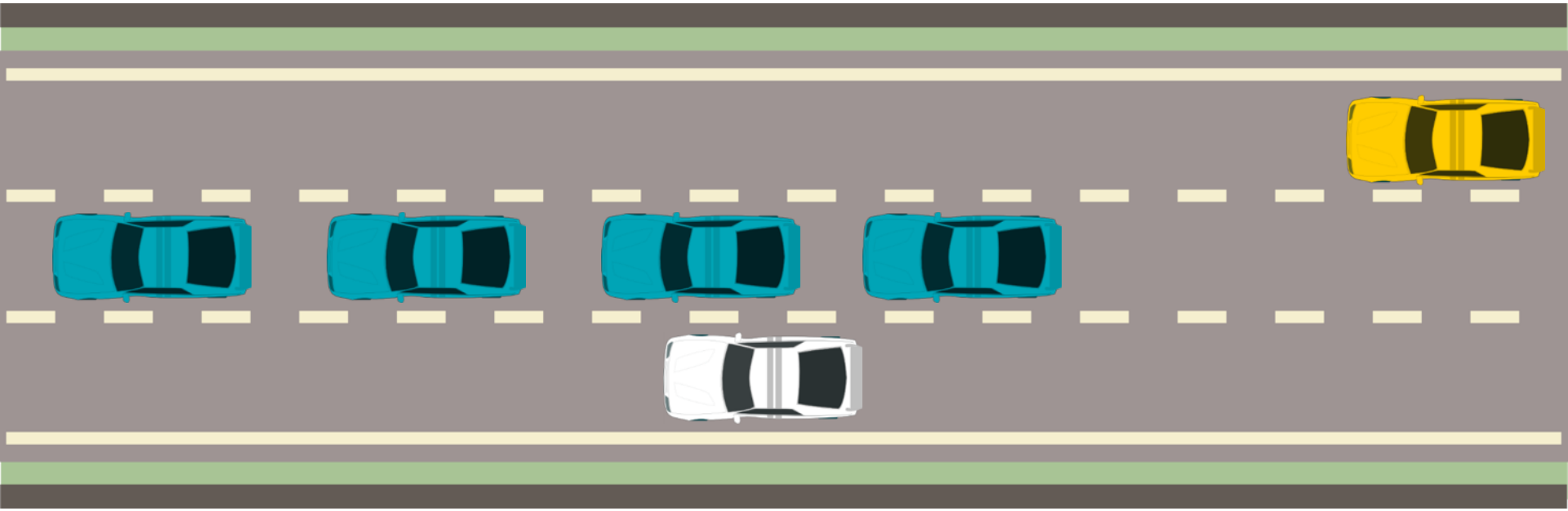
[2] 80% penetration rate.

[3] 6-car platoon, 80% penetration rate.

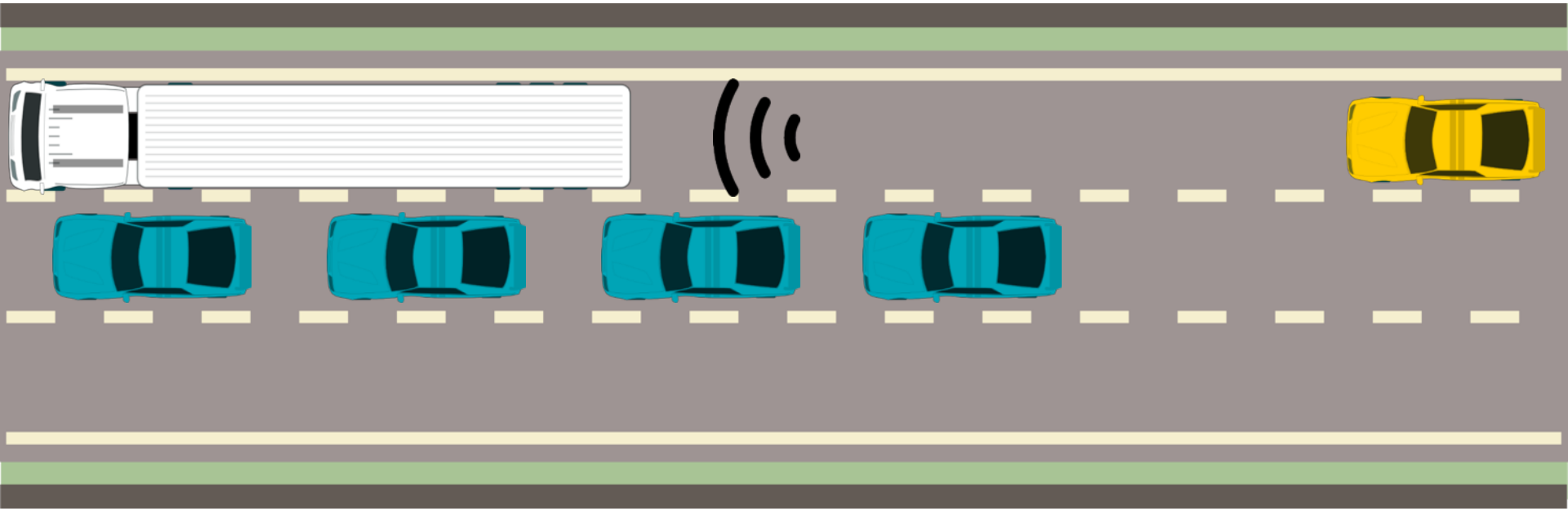
- Join-at-middle:



- Join-at-middle: human-driven car interference

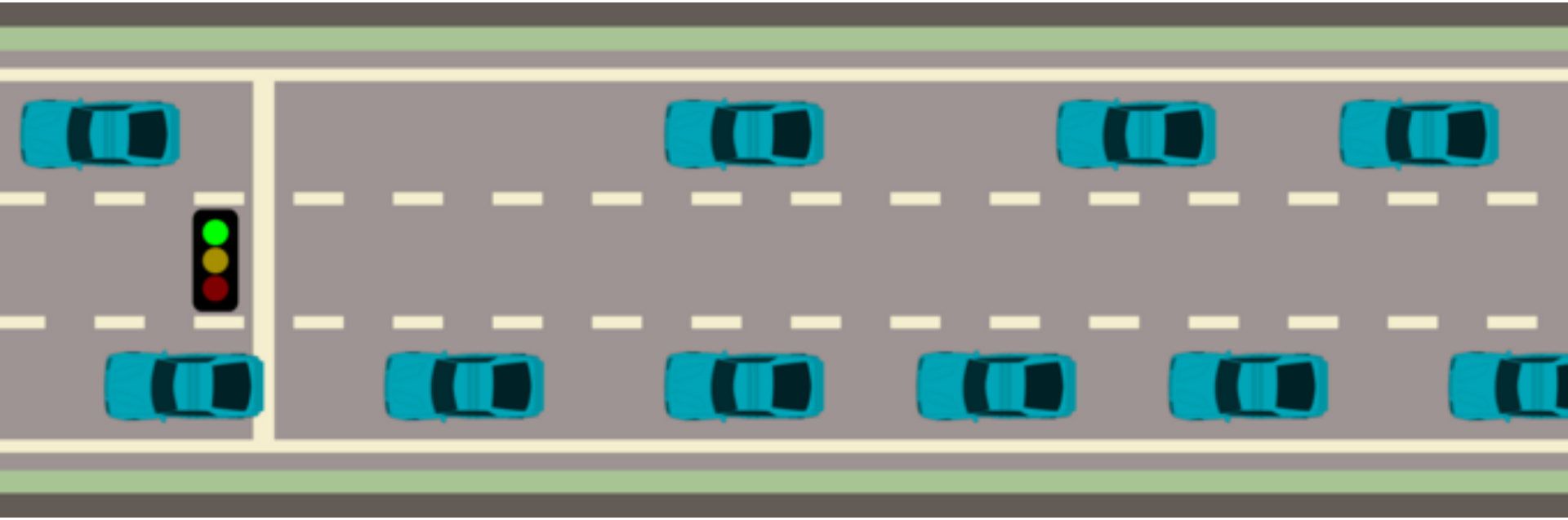


- Join-at-middle: slow vehicle interference

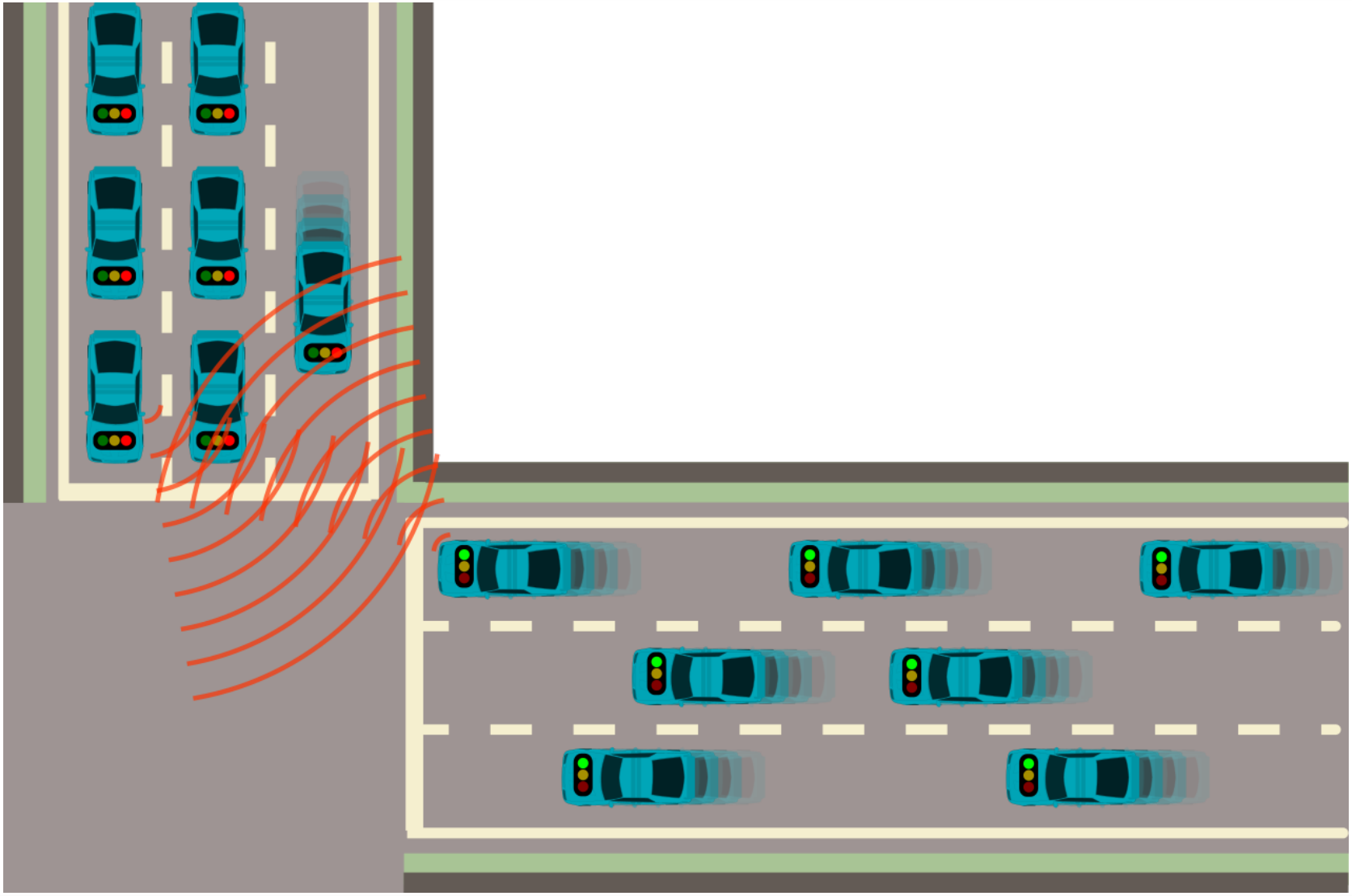


Intelligent/cooperative traffic lights

- Coordinated start at traffic light
- Avoid waste of time due to human imperfection



Virtual traffic lights



Traffic information systems

Inter-vehicle gaming