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Toward Hybridized Cyber Physical Systems (H-CPS)

Falko Dressler

Turning Cars into Interconnected CPS

Towards Autonomous Driving

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Inter-Vehicle Networking for Situation Awareness

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Illustrations: C2C-CC

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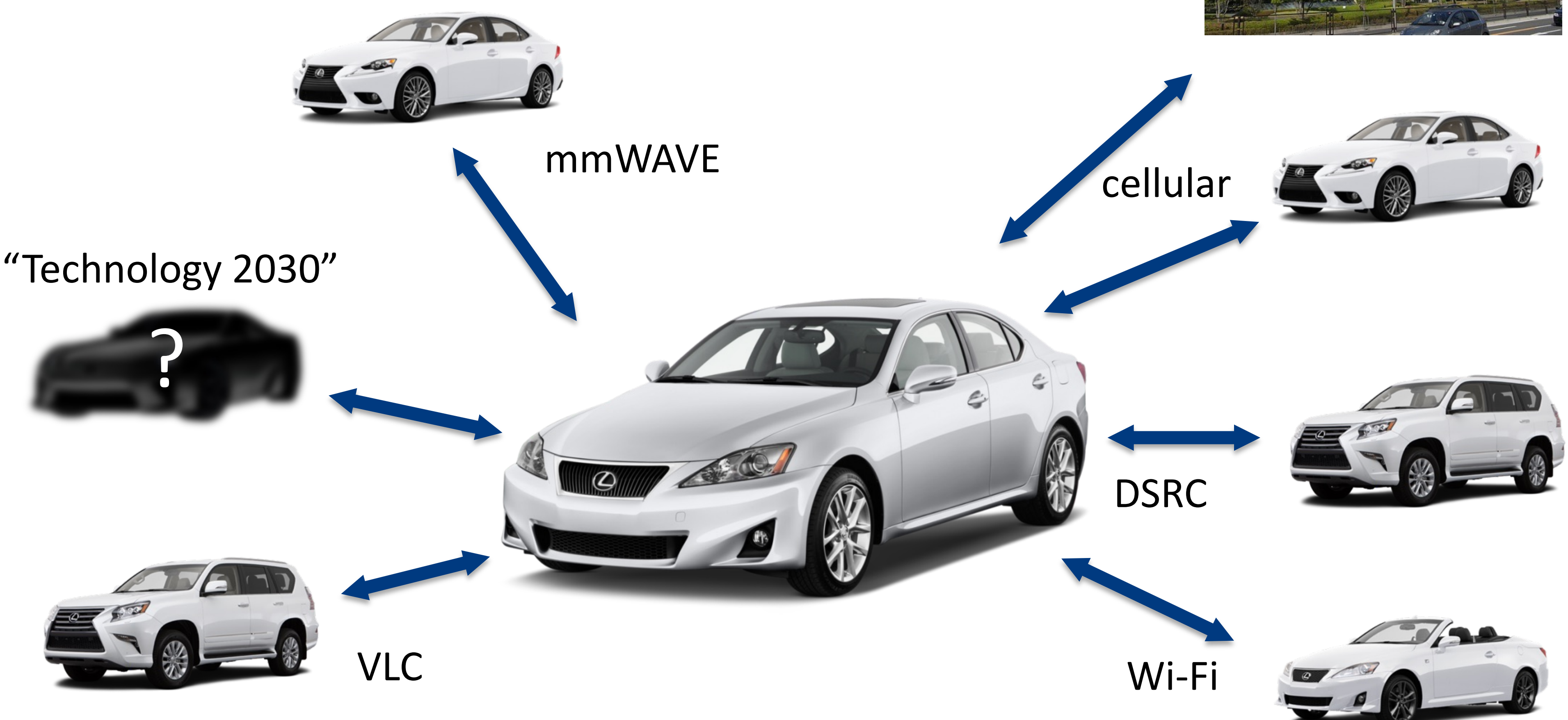
Towards Heterogeneous Vehicular Networks

- Many communication channels available
  - Which to pick when?



Vehicular Networking

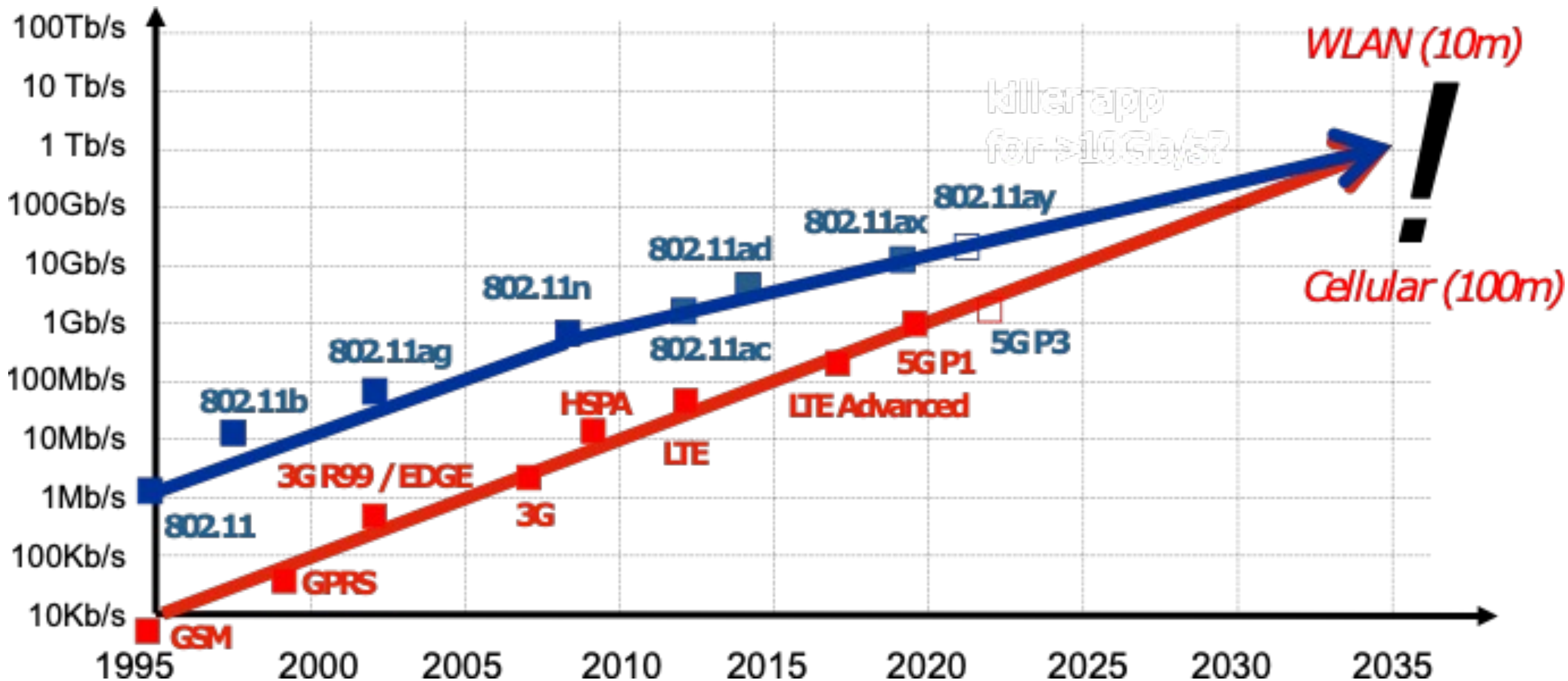
- IEEE DSRC/WAVE, ETSI ITS G5, ARIB T109
  - All build upon IEEE 802.11p
  - Dedicated spectrum for inter-vehicle communication
    in Europe (5.9 GHz), ~~the US (5.9 GHz)~~, and Japan (700 MHz)
- 5G C-V2X
  - 3GPP R15 “New Radio”
  - Major activities based on original LTE D2D
- Situation awareness as major year-one-application
  - Now also cooperative perception and cooperative maneuvering
- **But many fundamental research questions still unanswered**
  - **Scalability, real-time capabilities, heterogeneous technologies**

Christoph Sommer and Falko Dressler, Vehicular Networking, Cambridge University Press, 2014.

The New Challenge: Delays in the Order Milliseconds

Consumer Wireless: Huge Data Rates

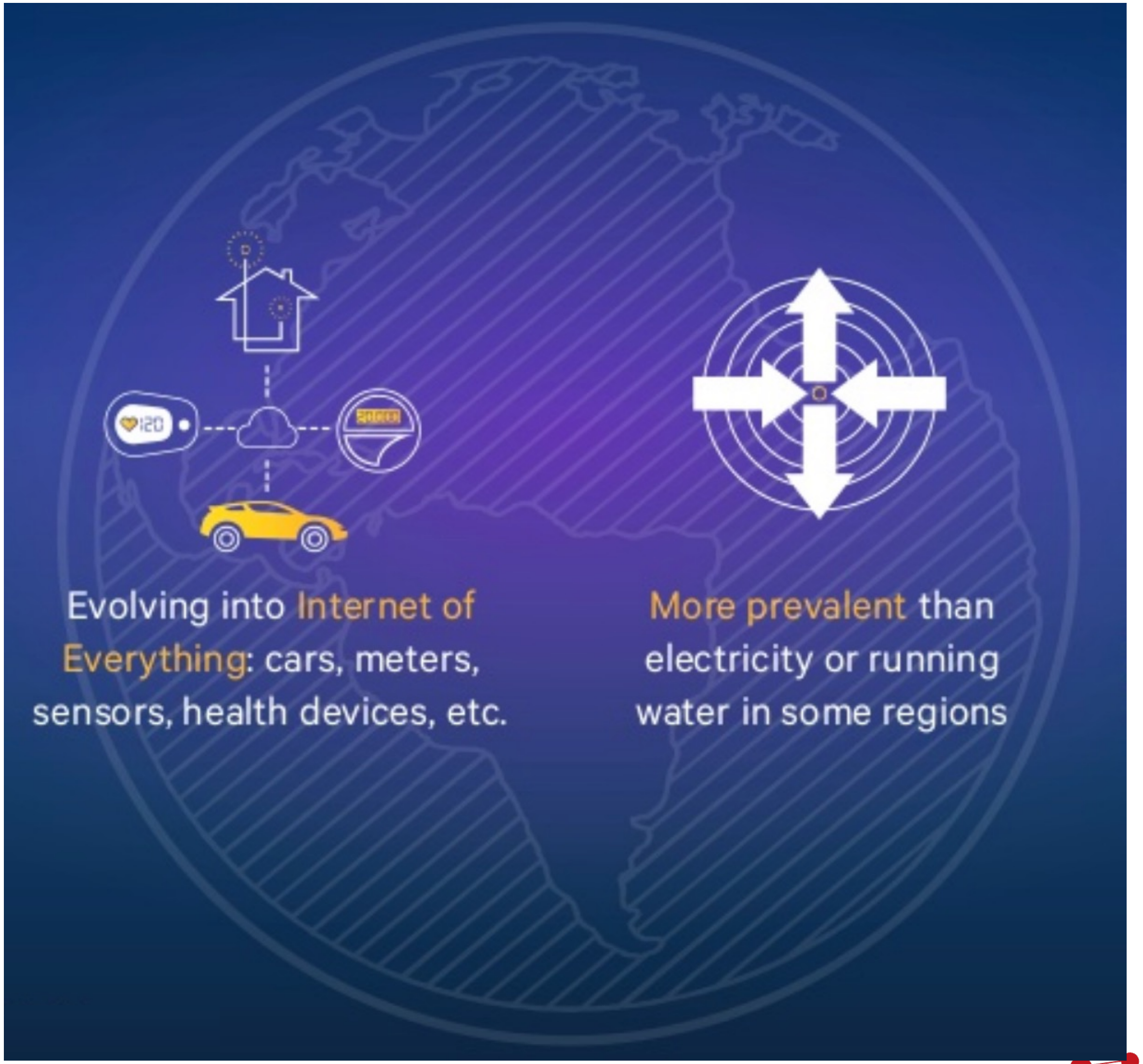
- 7 billion devices in 2014 → 500 billion devices in 2022



G. Fettweis, “5G: And Its Impact on Electronics”, 5G Lab Germany

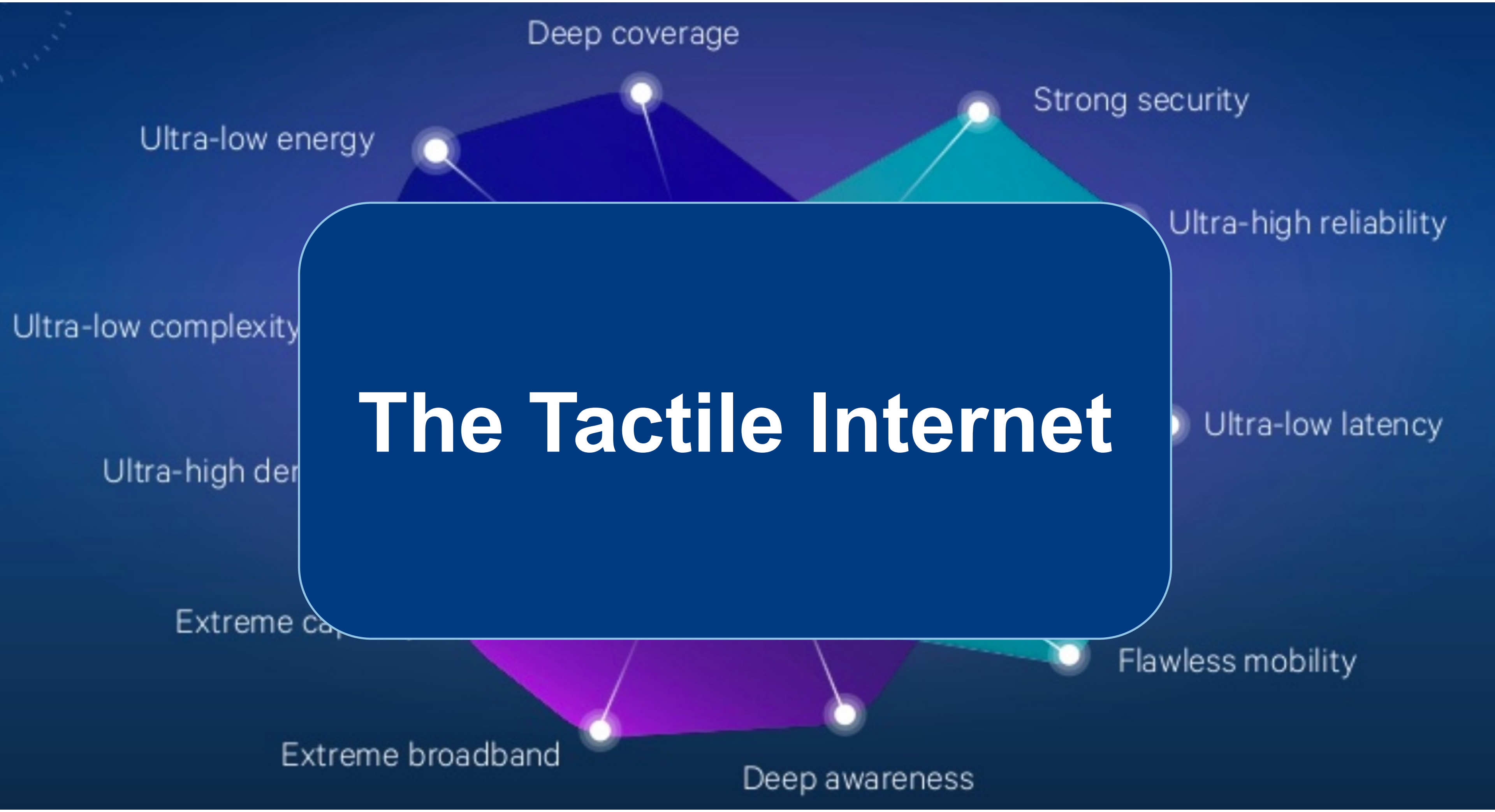
Towards 5G

The Internet of everything



Towards 5G and the Tactile Internet

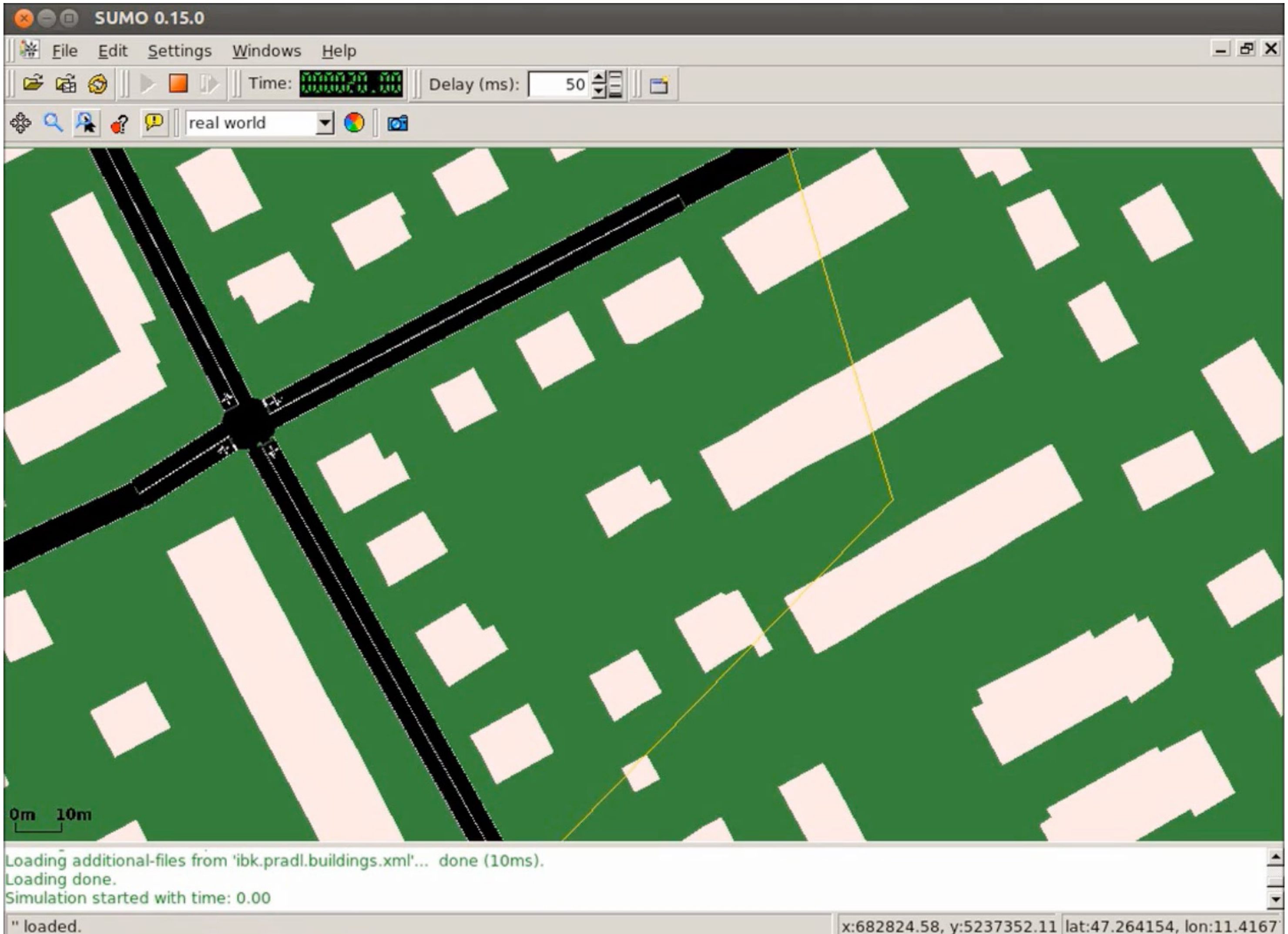
New Challenges



The Tactile Internet

Towards 5G and the Tactile Internet

Distributed Real-Time Control Systems

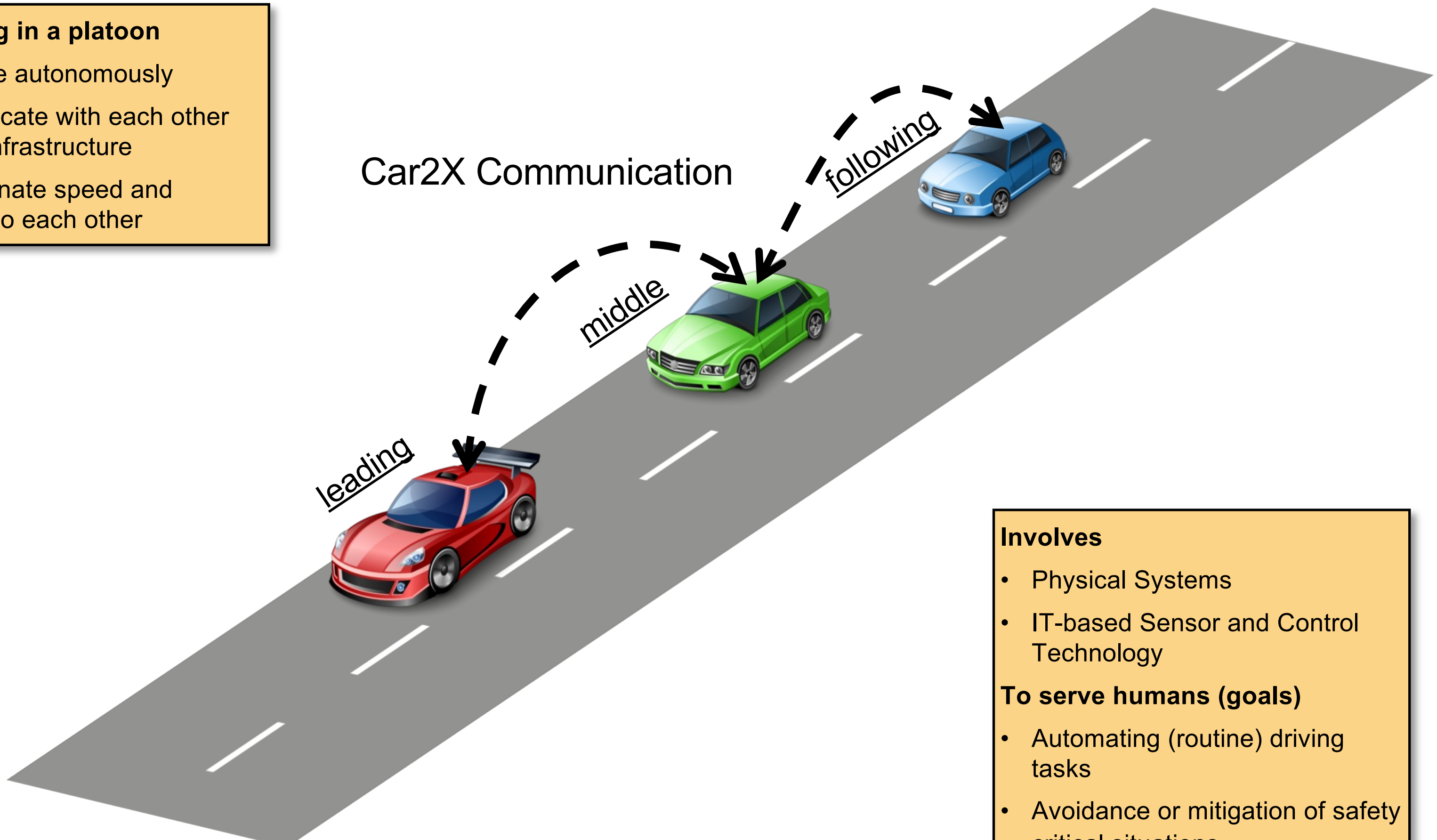


Human Interaction: Towards Deeply Integrated Hybridized Systems

Modern CPS: Platooning as a starting point

Cars driving in a platoon

- Cars drive autonomously
- Communicate with each other and the infrastructure
- To coordinate speed and distance to each other



Involves

- Physical Systems
- IT-based Sensor and Control Technology

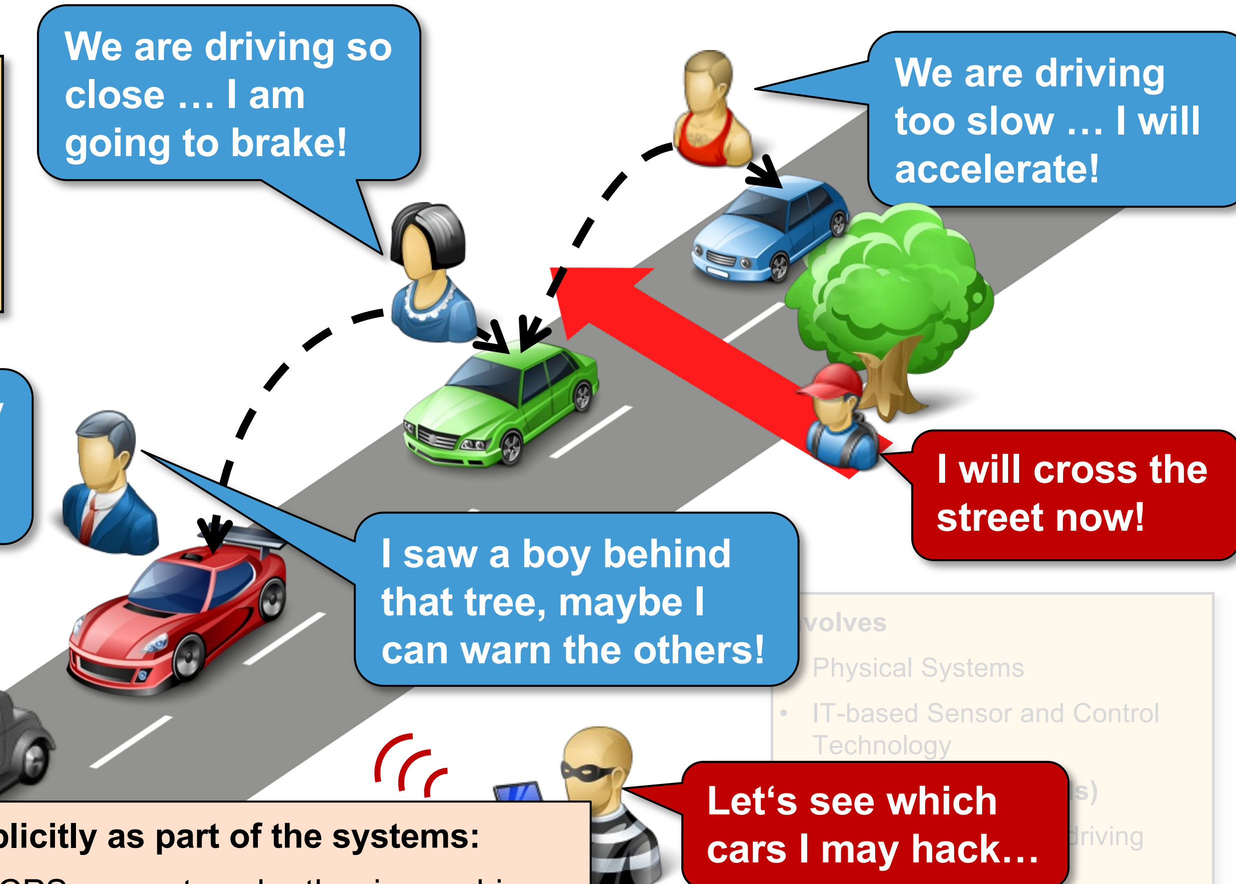
To serve humans (goals)

- Automating (routine) driving tasks
- Avoidance or mitigation of safety critical situations

Adding complexity

Cars driving in a platoon

- Cars drive autonomously
- Communicate with each other and the infrastructure
- To coordinate speed and distance to each other



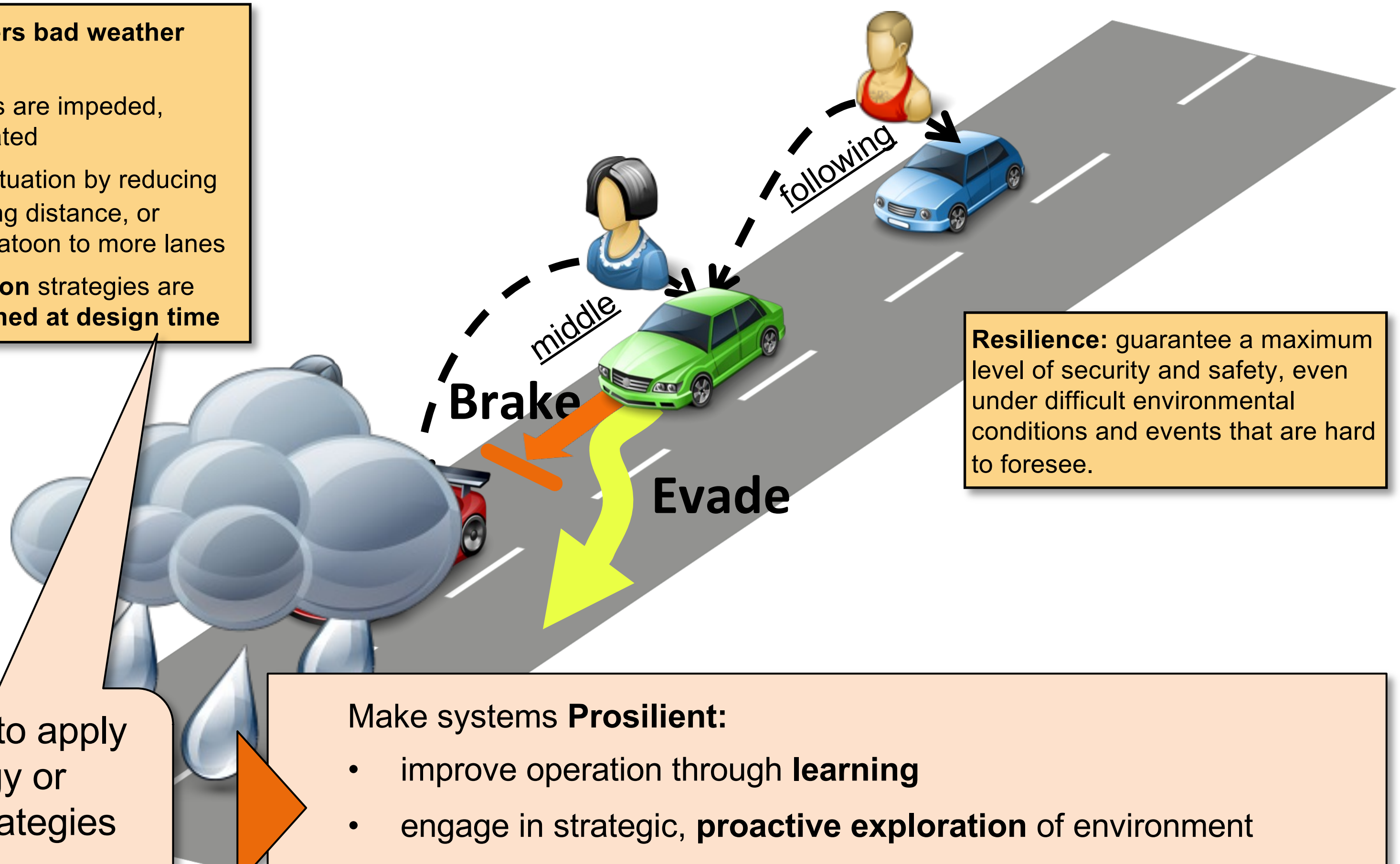
Consider humans explicitly as part of the systems:

- human beings and CPS support each other in reaching their goals
- cope with erratic/malicious behavior of humans

Towards Cyber Physical Social Systems

Platoon encounters bad weather conditions

- Camera sensors are impeded, brakes deteriorated
- **Adapt** to new situation by reducing speed, increasing distance, or distribution of platoon to more lanes
- So far, **adaptation** strategies are largely **determined at design time**



Resilience: guarantee a maximum level of security and safety, even under difficult environmental conditions and events that are hard to foresee.

Learn when to apply which strategy or even new strategies at **runtime**!

Make systems **Prosilient:**

- improve operation through **learning**
- engage in strategic, **proactive exploration** of environment
- seek to **discover new opportunities** consciously taking risks

Towards Cyber Physical Social Systems

- CPSS comprises
  - immediately controlled cyber-physical components
  - IT-based sensor and control technology
  - humans
  - legacy systems

  } part of the system (not the environment)

- Accomplishing goals = **socio-technical challenge**
  - Properties and features attributed to the system as a whole
  - includes humans and other CPSS

- **Core aspect: Hybridization**
  - Transition from manual control to assistance systems to fully automated operation

Dressler, Falko, "Cyber Physical Social Systems: Towards Deeply Integrated Hybridized Systems," Proceedings of IEEE International Conference on Computing, Networking and Communications (ICNC 2018), Maui, HI, March 2018, pp. 420-424

Hard Real-Time Control vs. Human Reaction Times

Distributed Control

Platooning as one of the most challenging applications

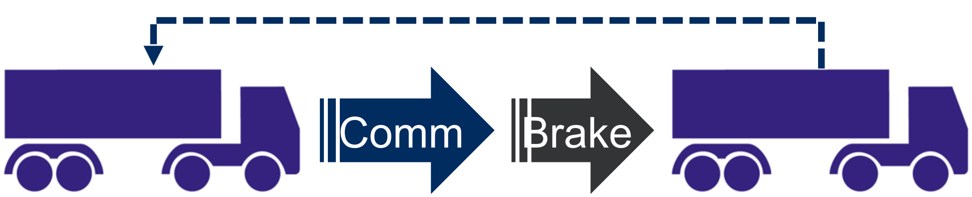
- A specific application: platooning
  - solve traffic congestion problems
  - decrease pollution
  - increase safety
  - decrease severe injuries/deaths
  - Avoid wasting driving time
- Research questions
  - Impact of platooning on network (and vice versa)
  - Develop protocols to better support platooning

Automated Car Following

- Manual driving (Dist: 2s ~ 50m @ 100km/h)

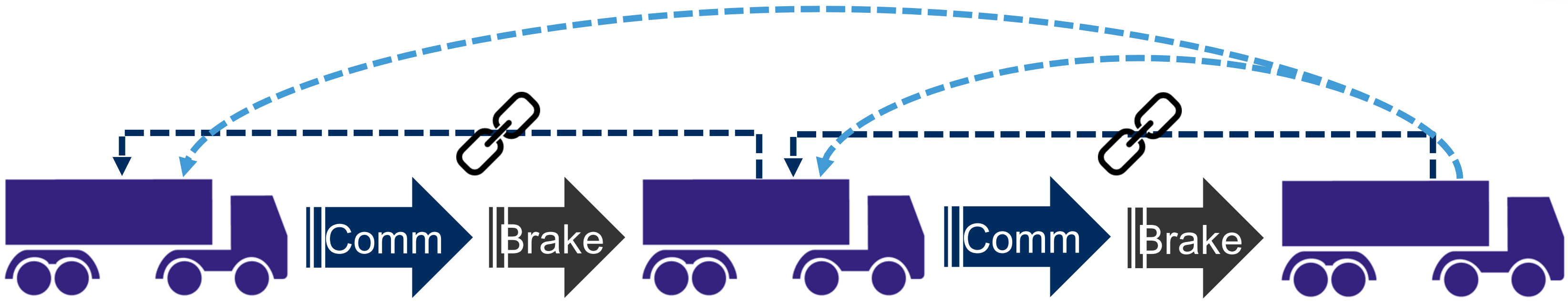
- ACC – Radar based (Dist: 1s ~ 28m @ 100km/h)

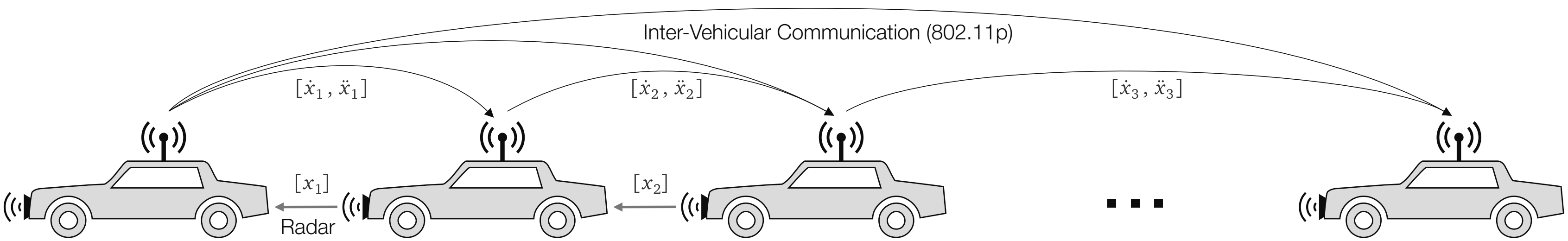
- Simple CACC – Radar + IVC (Dist: 0.6s ~ 16m @ 100km/h)



CACC / Platooning Controller

- Cooperative CACC (Dist: 0.2s ~ 5m @ 100km/h)

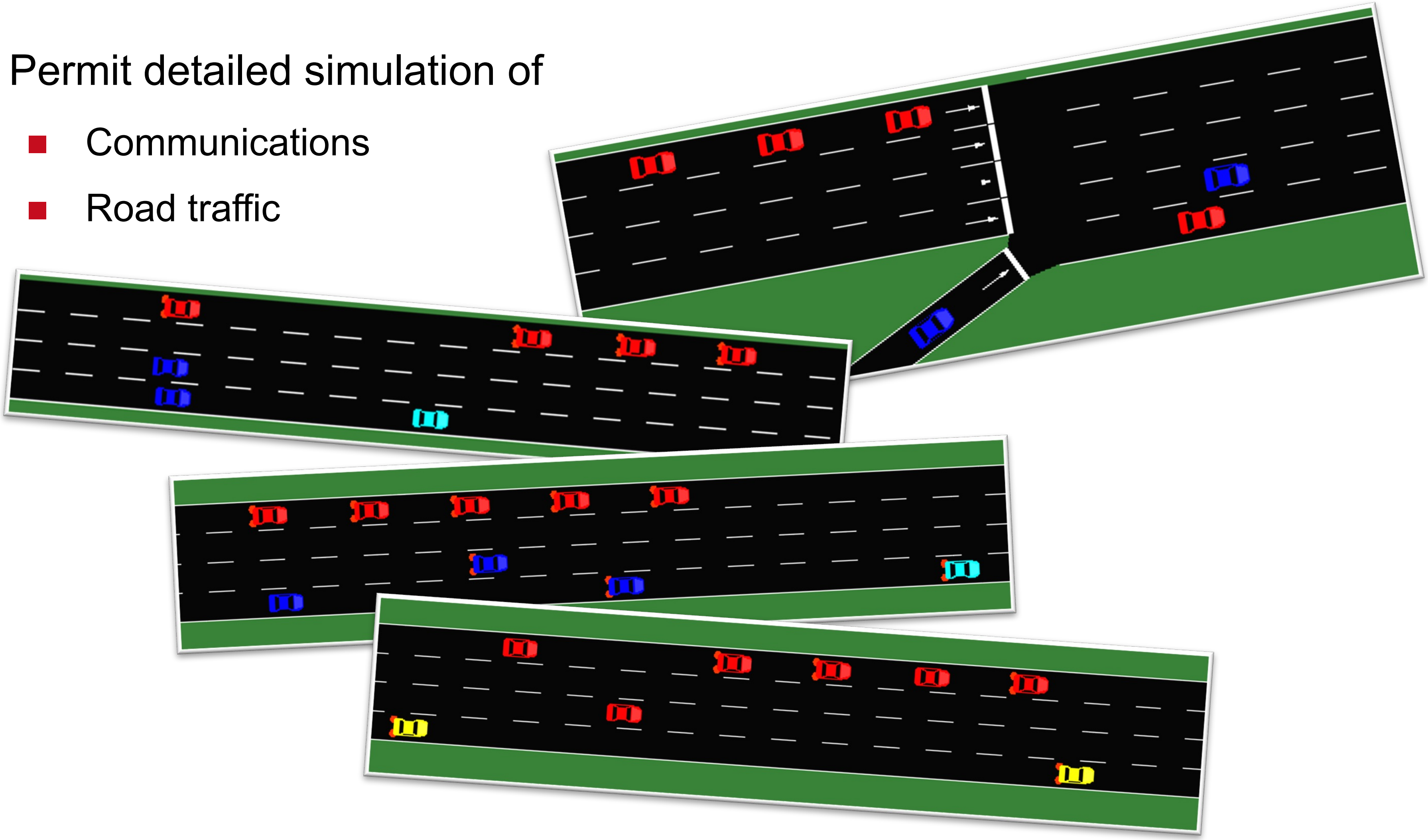




$$\ddot{x}_{i\_des} = \alpha_1 \ddot{x}_{i-1} + \alpha_2 \ddot{x}_l + \alpha_3 (\dot{x}_i - \dot{x}_{i-1}) + \alpha_4 (\dot{x}_i - \dot{x}_l) + \alpha_5 x_i$$

Simulation Framework

- Permit detailed simulation of
  - Communications
  - Road traffic



Michele Segata, Renato Lo Cigno, Tobias Hardes, Julian Heinovski, Max Schettler, Bastian Bloessl, Christoph Sommer and Falko Dressler, "Multi-Technology Cooperative Driving: An Analysis Based on PLEXE," IEEE Transactions on Mobile Computing (TMC), February 2022.

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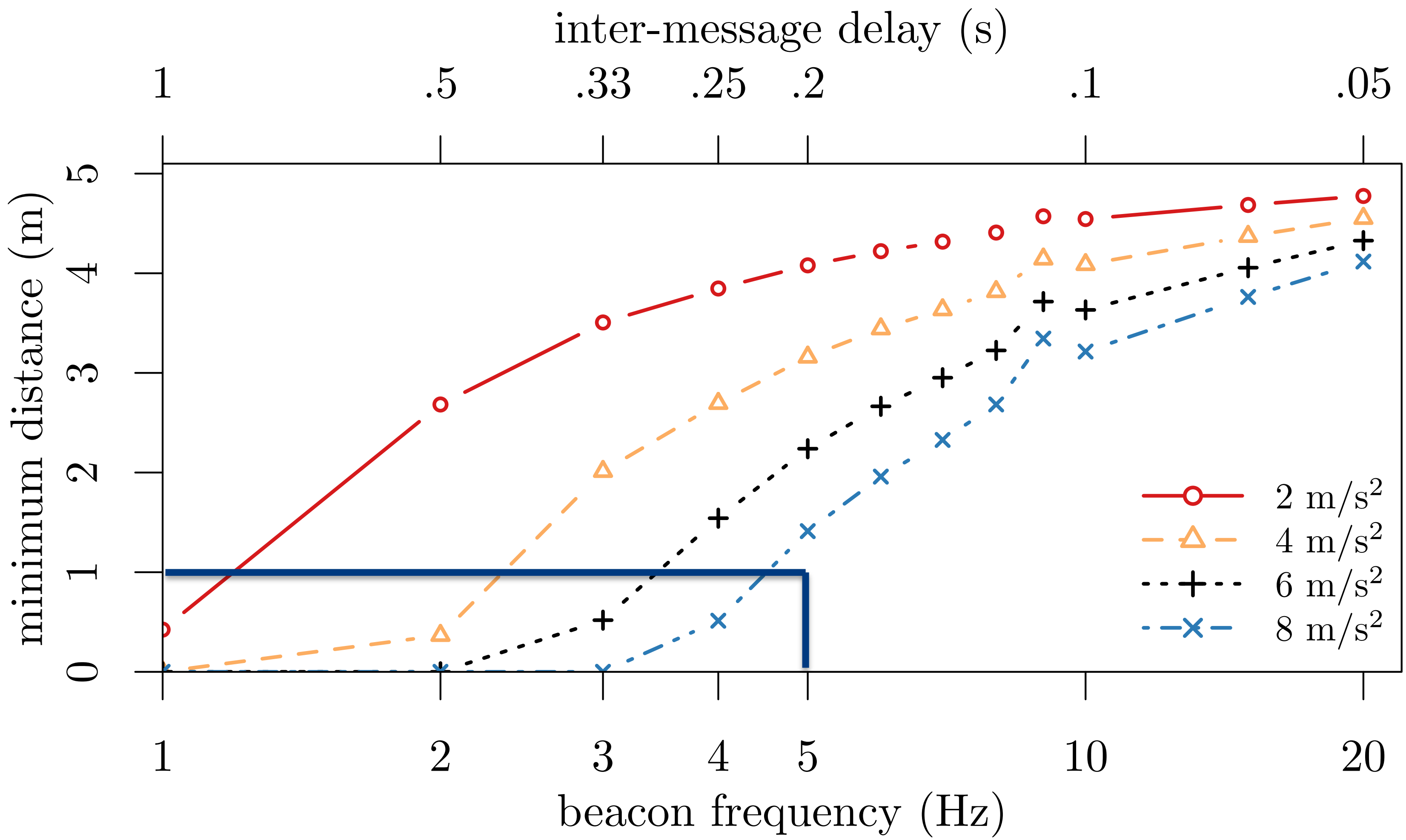
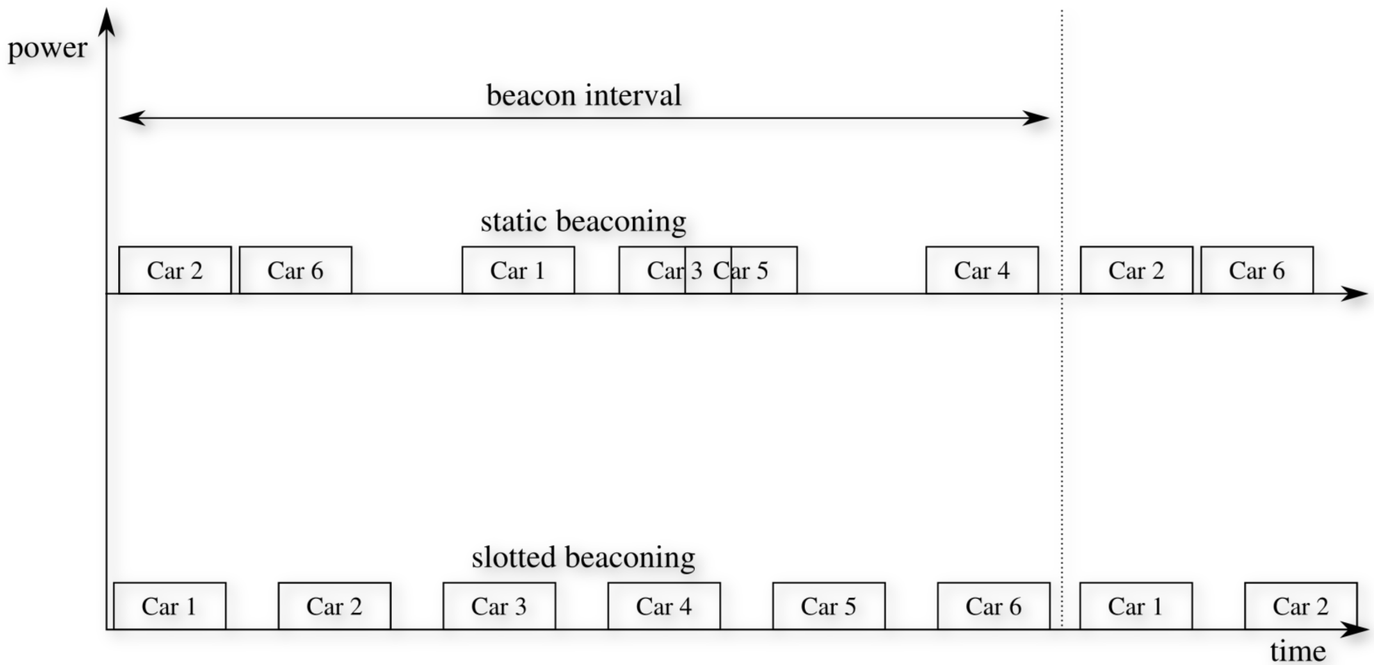
Platooning Braking – Minimum Distance



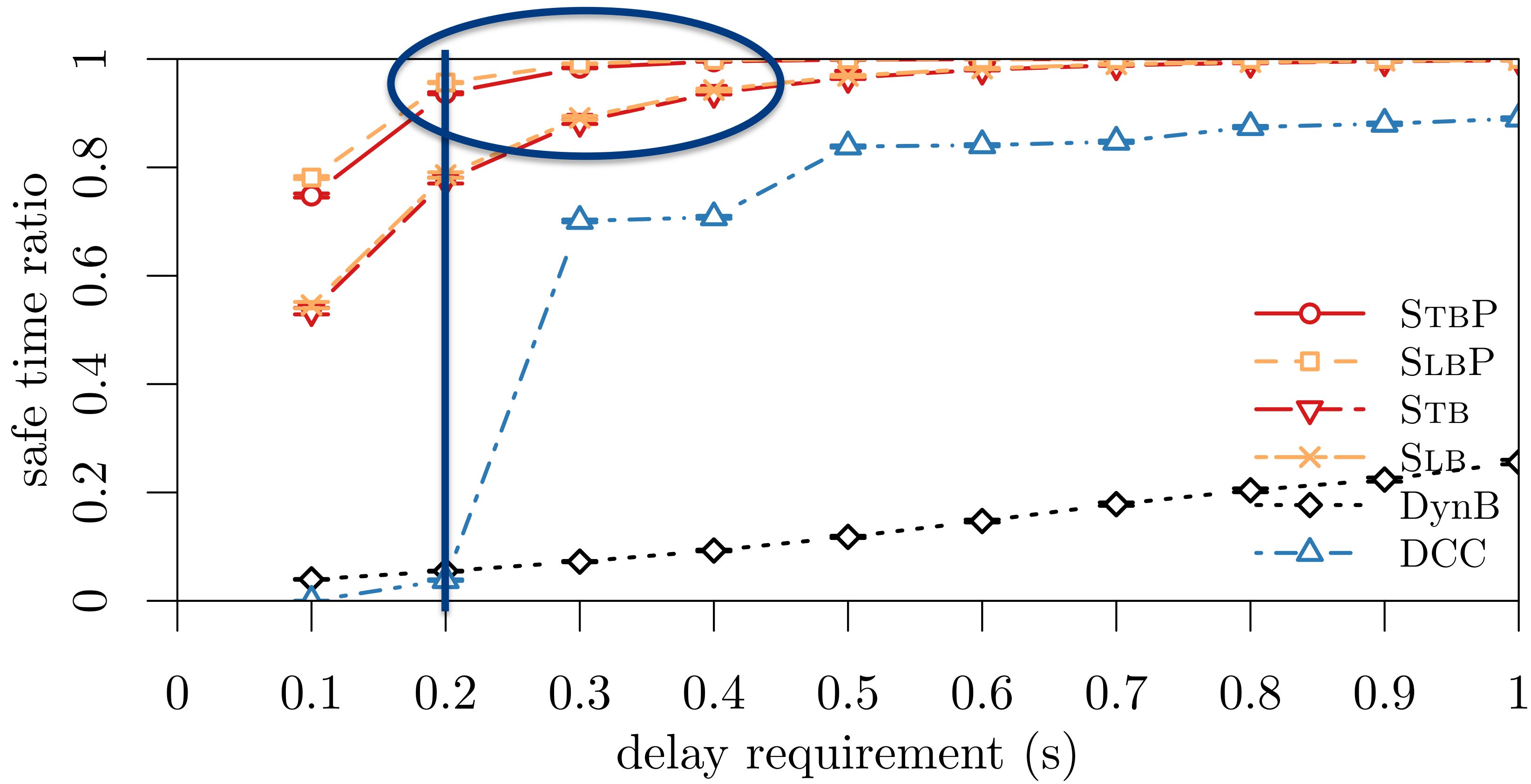
Michele Segata, Bastian Bloessl, Stefan Joerer, Christoph Sommer, Mario Gerla, Renato Lo Cigno and Falko Dressler, "Towards Communication Strategies for Platooning: Simulative and Experimental Evaluation," IEEE Transactions on Vehicular Technology, vol. 64 (12), pp. 5411-5423, December 2015.

Communication Protocols

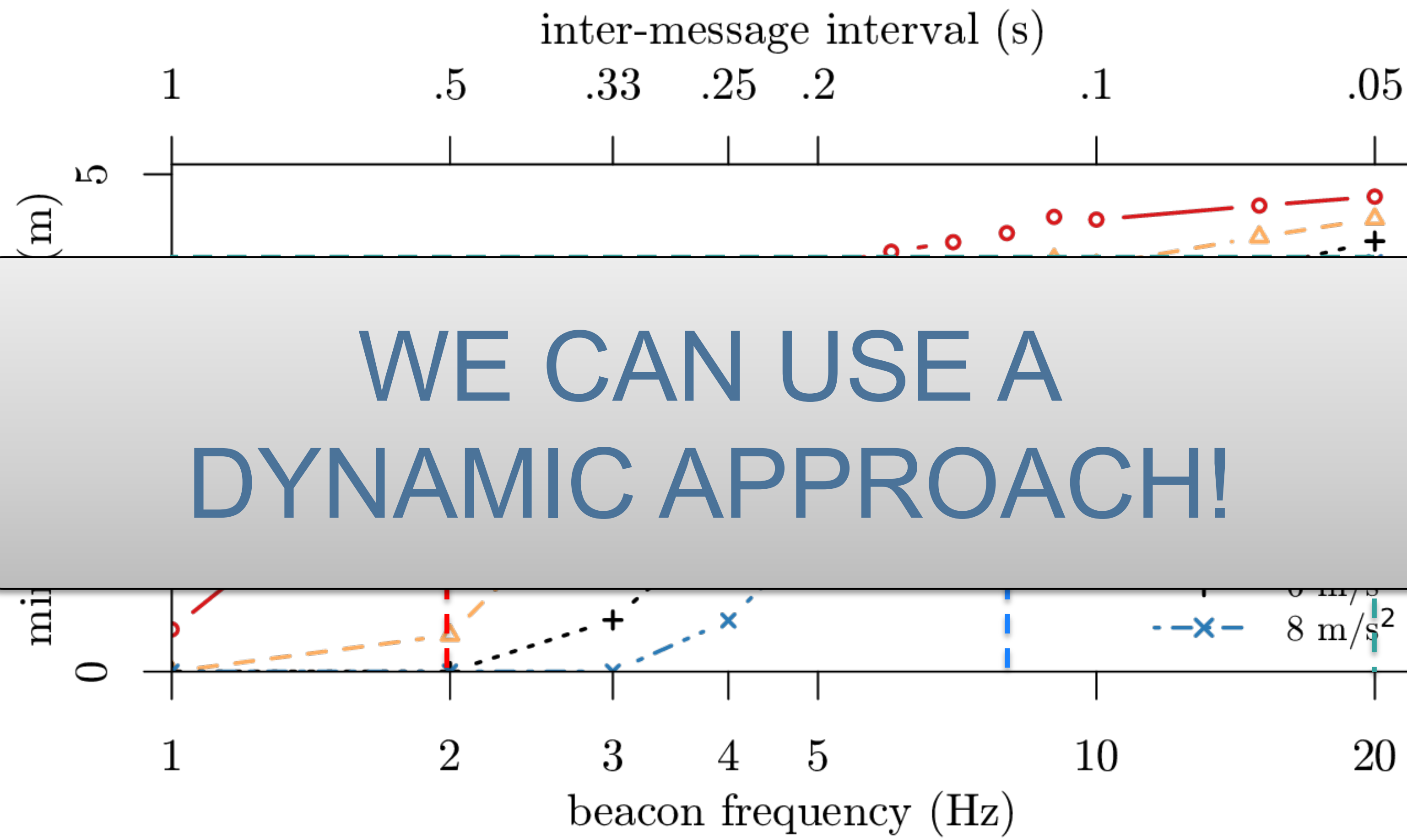
- Develop and test 4 different protocols
  - Random transmission (static beaconing)
  - Synchronized transmission (slotted beaconing)
  - Both w/ and w/o transmission power control



Protocol Performance for 640 Cars



Emergency Braking Requirements



WE CAN USE A DYNAMIC APPROACH!

Jerk Beaconing

- Jerk:
  - physical quantity measuring variation of acceleration over time

$$\Delta_a = a(t) - a(t_{\text{sent}})$$

  - using an estimation of jerk we compute the beacon interval

$$\Delta_{\text{msg}}(\Delta_a) = \max\left(e^{-q|\Delta_a|^p} \cdot \max_{\text{bi}}, \min_{\text{bi}}\right)$$

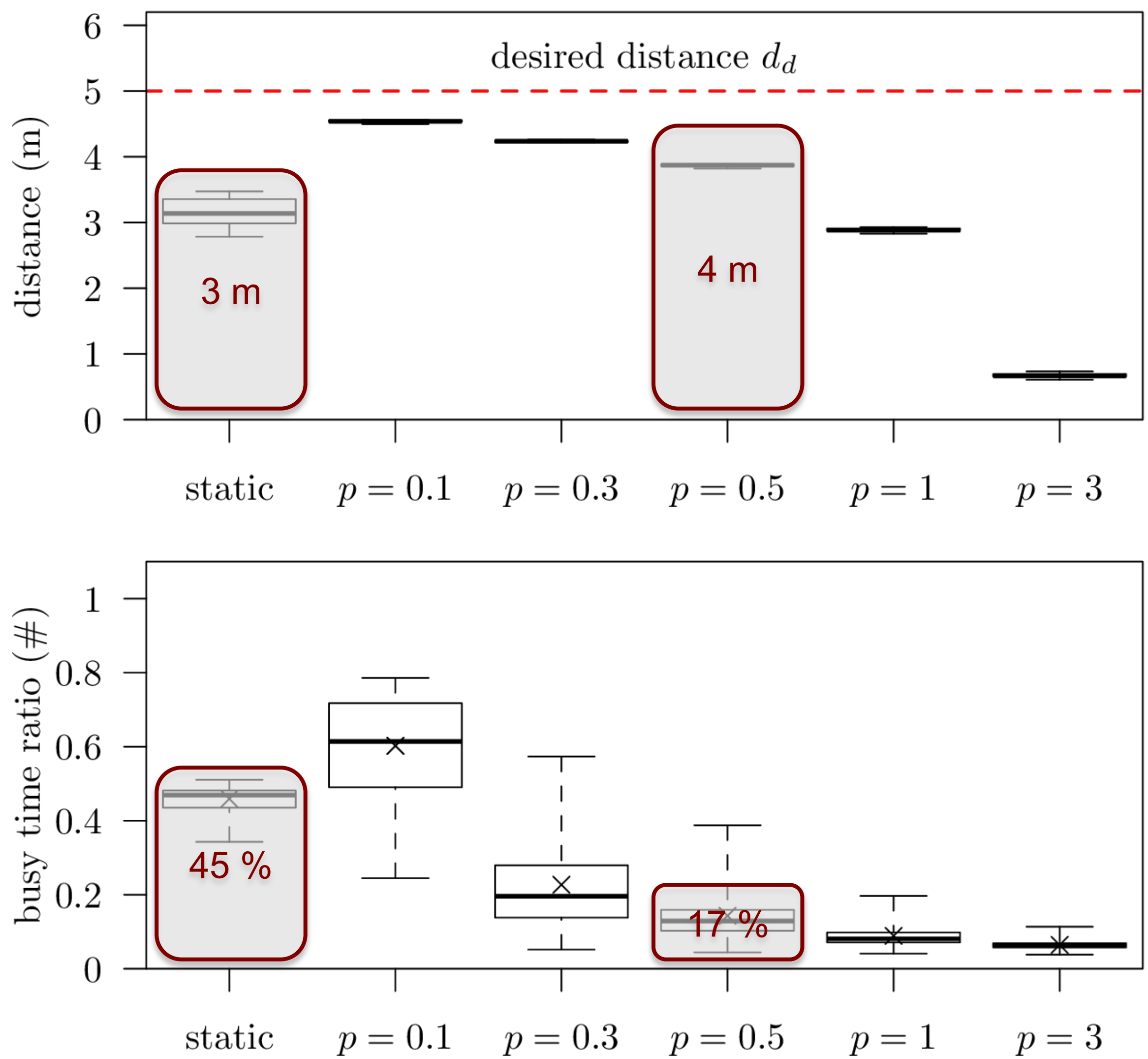
Sensitivity of the approach

Change of acceleration (jerk)

  - tunable parameters:
    - minimum beacon interval
    - maximum beacon interval
    - sensitivity

Michele Segata, Falko Dressler and Renato Lo Cigno, "Jerk Beaconing: A Dynamic Approach to Platooning," Proceedings of 7th IEEE Vehicular Networking Conference (VNC 2015), Kyoto, Japan, December 2015, pp. 135-142.

Performance (challenging scenario with 640 cars)



Next Steps

- There's life after static beaconing even for platooning, but
  - jerk beaconing still a heuristic proof of concept
  - can we theoretically link control requirements, beacon interval, and inter-vehicle gap? → optimal beacon rate for target requirement
  - how can we handle network failures?

- More Options: **Getting Heterogeneous**
  - Communication between platoon lead and all followers: radio broadcast
  - Communication to the next car: visual light communication (VLC)

Max Schettler, Agon Memedi and Falko Dressler, "Deeply Integrating Visible Light and Radio Communication for Ultra-High Reliable Platooning," Proceedings of 15th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2019), Wengen, Switzerland, January 2019.

Muhammad Sohaib Amjad, Max Schettler, Sigrid Dimce and Falko Dressler, "Inband Full-Duplex Relaying for RADCOM-based Cooperative Driving," Proceedings of 12th IEEE Vehicular Networking Conference (VNC 2020), Virtual Conference, December 2020.

Modeling Human (Driver) Behavior

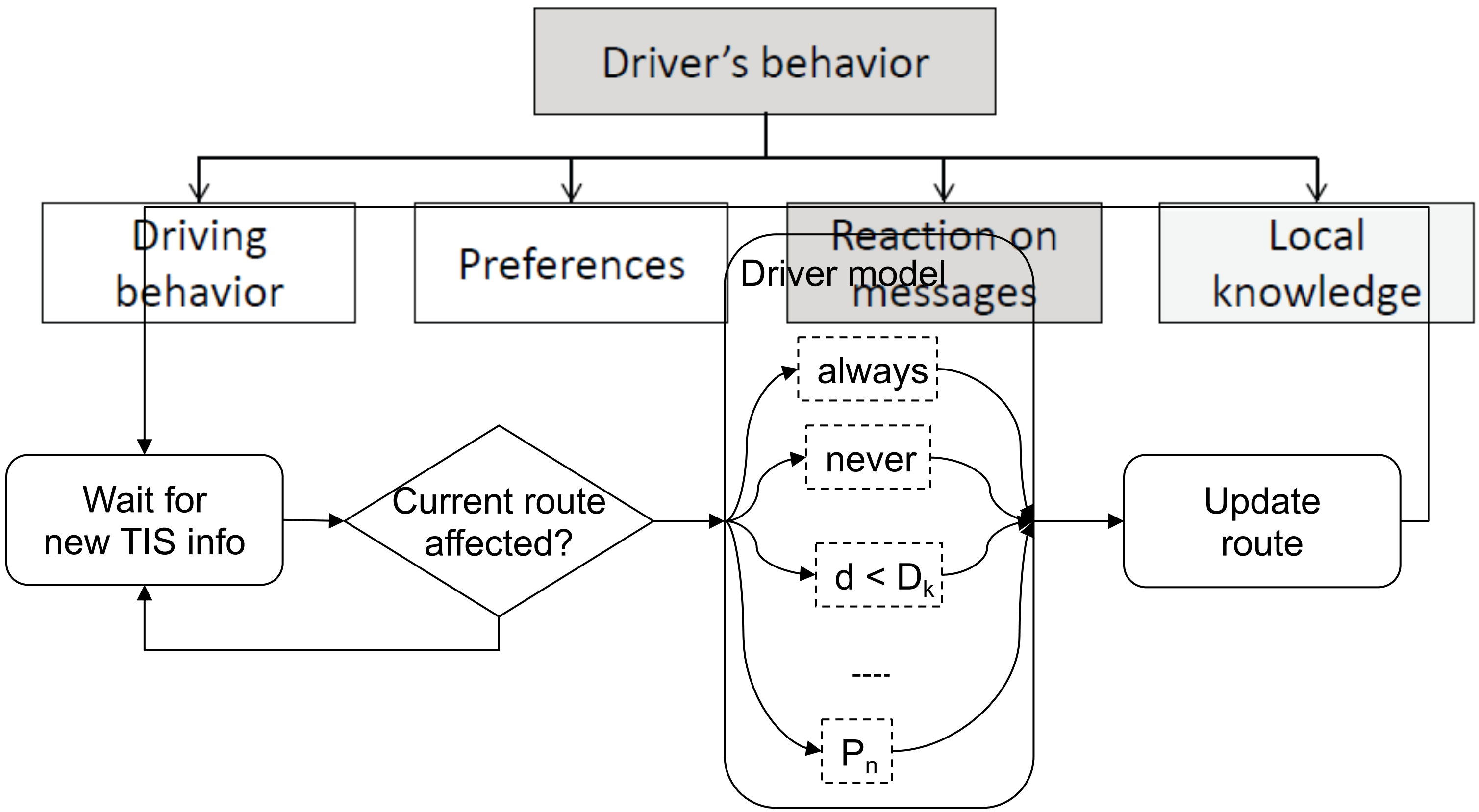
The Human and the Self-Driving Car

- Rethinking our interaction with the car (and the machine in general)
- Taking over control at any time?
  - The human driver (perhaps) is too slow!
  - The human driver (potentially) has experience!

- Are you a good driver?
  - 90% of all drivers believe they are better drivers than 70% of all others
- Dunning–Kruger effect
  - Cognitive bias, wherein persons of low ability suffer from illusory superiority when they mistakenly assess their cognitive ability as greater than it is
  - Confucius (551–479 BC): “Real knowledge is to know the extent of one’s ignorance”
  - William Shakespeare (1564–1616): “The fool doth think he is wise, but the wise man knows himself to be a fool”

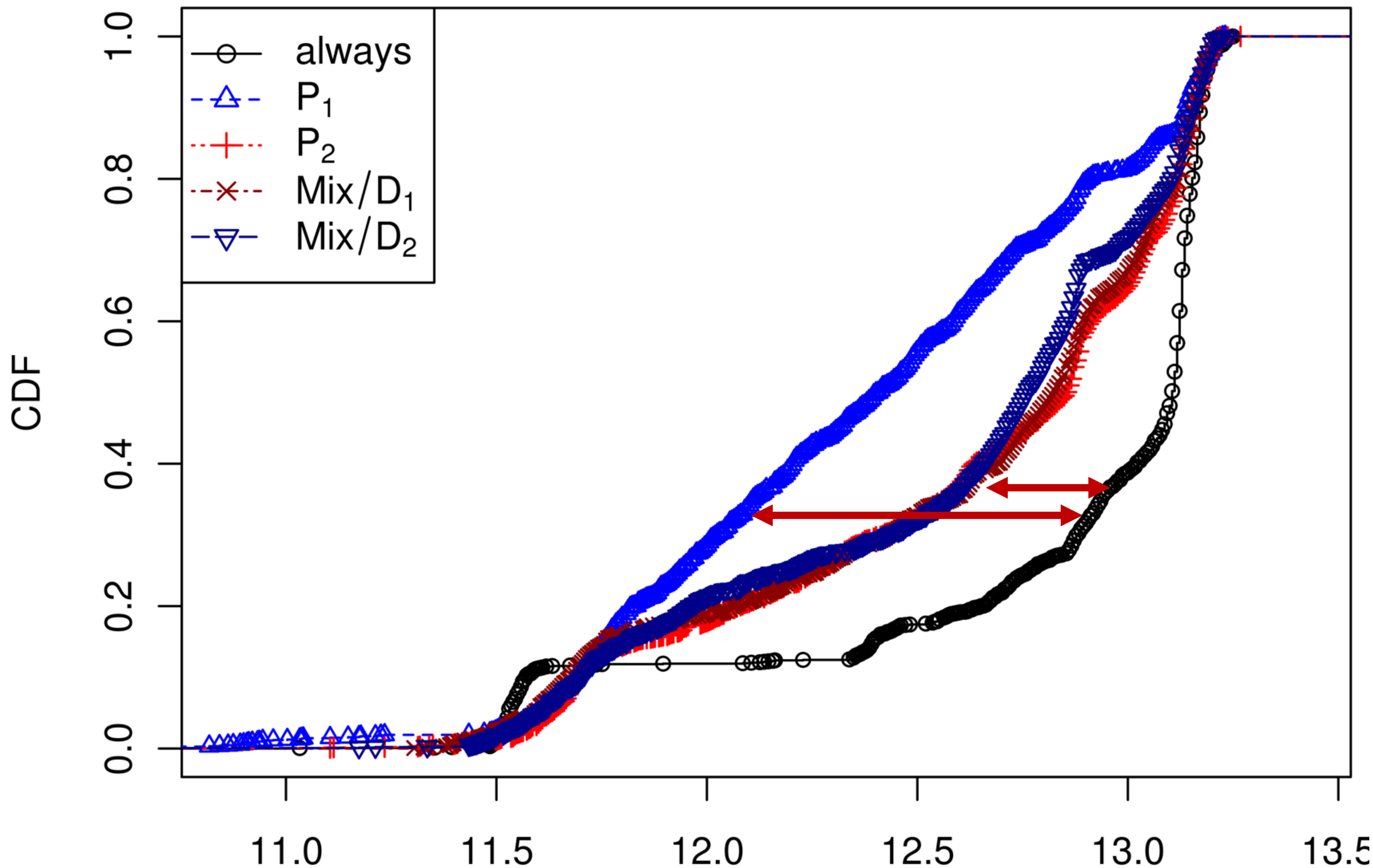
Modeling

- Accuracy of technically optimal solutions and imperfect driver behavior



F. Dressler and C. Sommer, "On the Impact of Human Driver Behavior on Intelligent Transportation Systems," Proceedings of 71st IEEE Vehicular Technology Conference (VTC2010-Spring), Taipei, Taiwan, May 2010

Does it matter?



Integrating Vulnerable Road Users

Road Traffic Safety & Vulnerable Road Users (VRU)

- Road traffic continuously growing

- ADAS → Safety increase for cars
  - Sensors
  - Vehicular Networking (V2X)

- ~50% of crash victims are VRUs
  - E.g., cyclists

- How can we improve their safety?

Assistance Systems for Bicycles

- Project “Safety4Bikes”
  - Assistance system for bicycles
  - Sensors: Warn cyclist about dangerous situations
  - V2X: Inform other vehicles

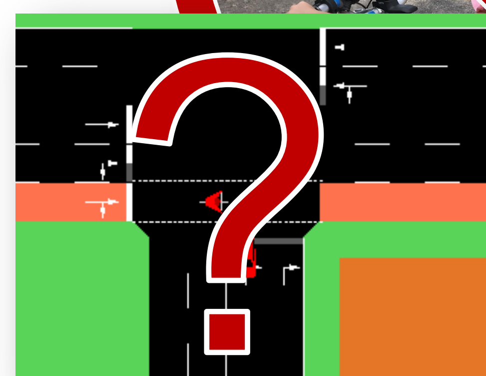
- Tests / Evaluation
  - Real-world experiments

    \+ Realistic environment & cycling behavior

    \- Dangerous for test subjects
  - Simulation studies

    \+ No risk for test subjects

    \- Realistic cycling behavior?



Virtual Cycling Environment (VCE)

- Integration of cyclist into V2X simulation
  - Simulated 3D environment
  - Virtual Reality (VR) technology
  - Off-the-shelf bicycle

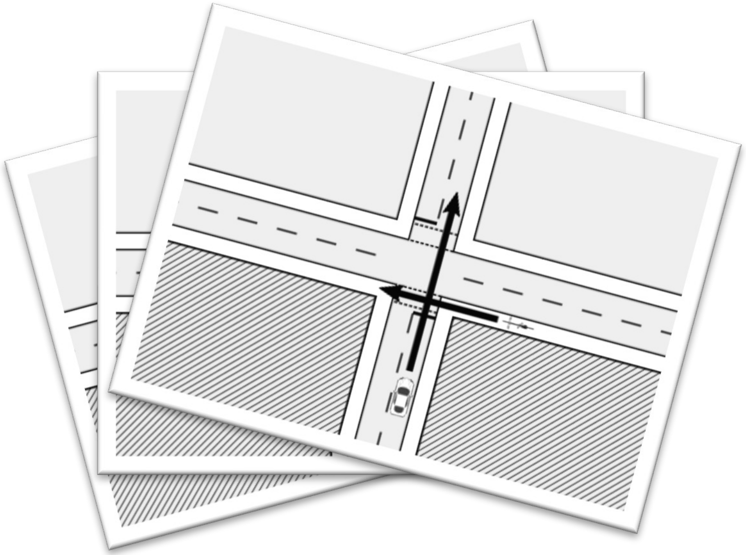
- Realistic cycling behavior
  - Interactive experiments
  - V2X simulation studies
- Safe for test subjects

→ Testing assistance systems for bicycles

Julian Heinovski, Lukas Stratmann, Dominik S. Buse, Florian Klingler, Mario Franke, Marie-Christin H. Oczko, Christoph Sommer, Ingrid Scharlau and Falko Dressler, "Modeling Cycling Behavior to Improve Bicyclists' Safety at Intersections – A Networking Perspective," Proceedings of 20th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2019), Washington, D.C., June 2019.

System Demonstration – Overview

- Methodology
  - Recorded cycling behavior (traces)
  - Integration into V2X simulation study
- Scenario: Intersection
  - Obstruction of Line-of-Sight (LOS)
- Safety improvement by V2X?
  - Awareness of vehicles



Requirements

- Warn of possibly dangerous traffic situations
- Give directional cues / hints about such dangerous situations
- Indicate distance to danger
- Intuitive

→ Haptic signals

- Control vibrations individually
  - Left, right, both
- Configuration of warning times and vibration pattern

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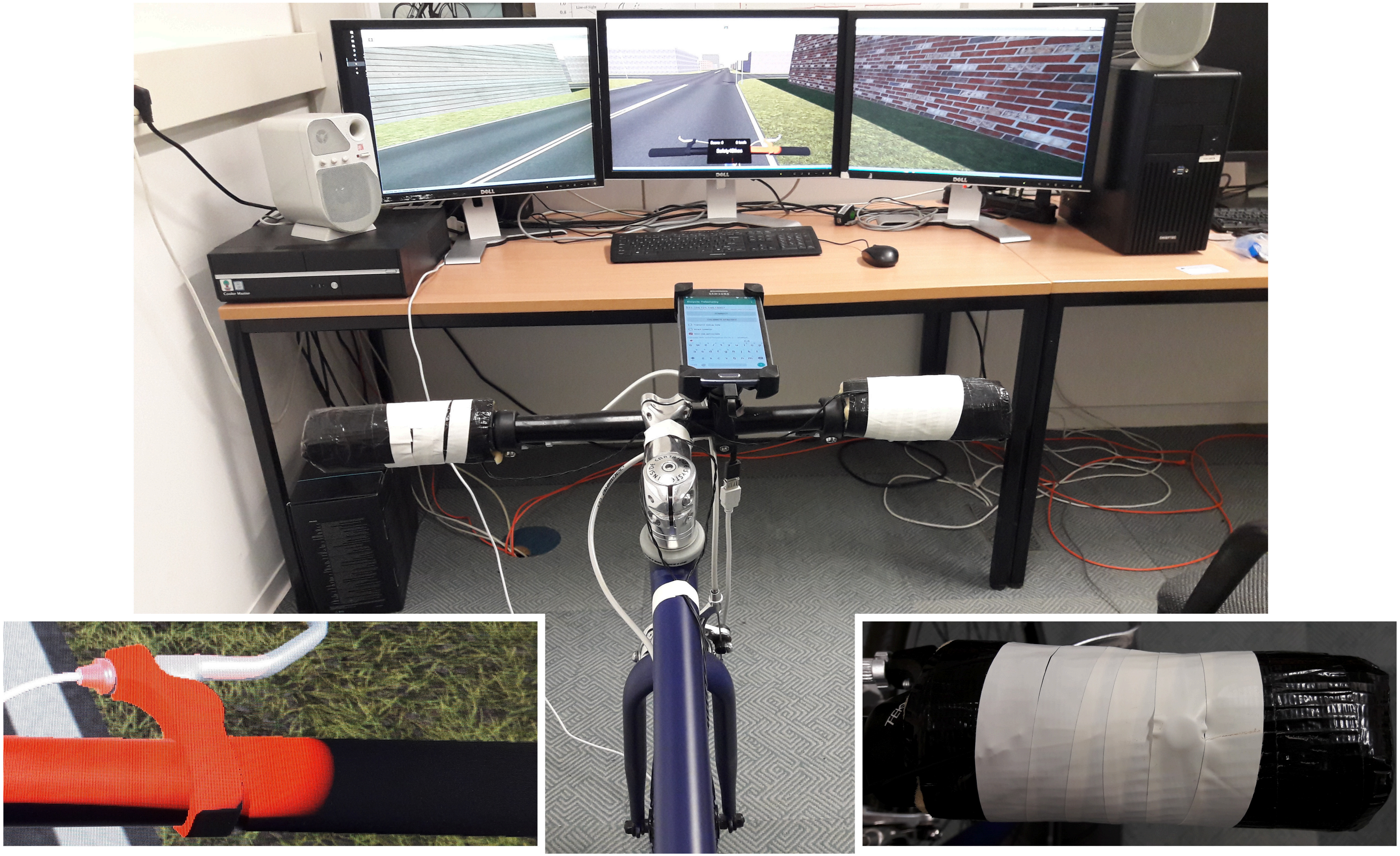
Hardware Implementation



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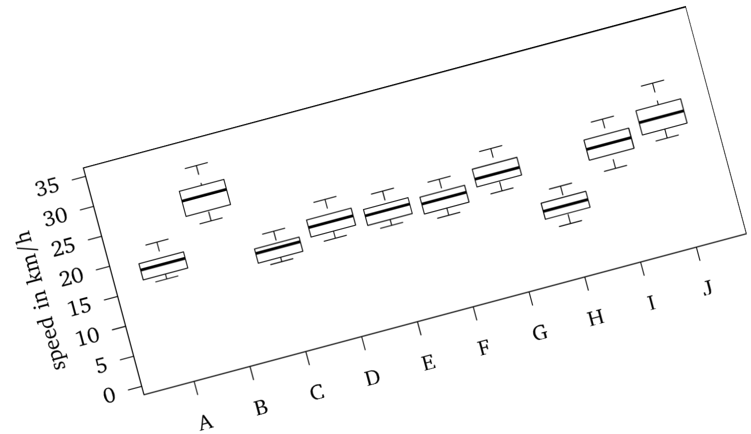
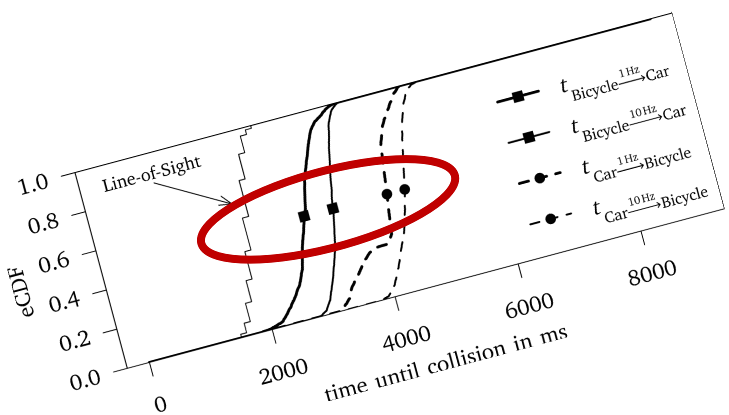
System Demonstration – Insights

- Recorded cycling traces → open data
  - Different scenarios
  - Different cyclists
- Veins: Simple V2X warning system
  - IEEE 802.11p, simple 1-hop messages
  - Static beaconing
  - TX power: Car vs. bicycle
- Safety improvement by V2X
  - 1-2s additional awareness time
  - Depends on wireless effects & cycling behavior





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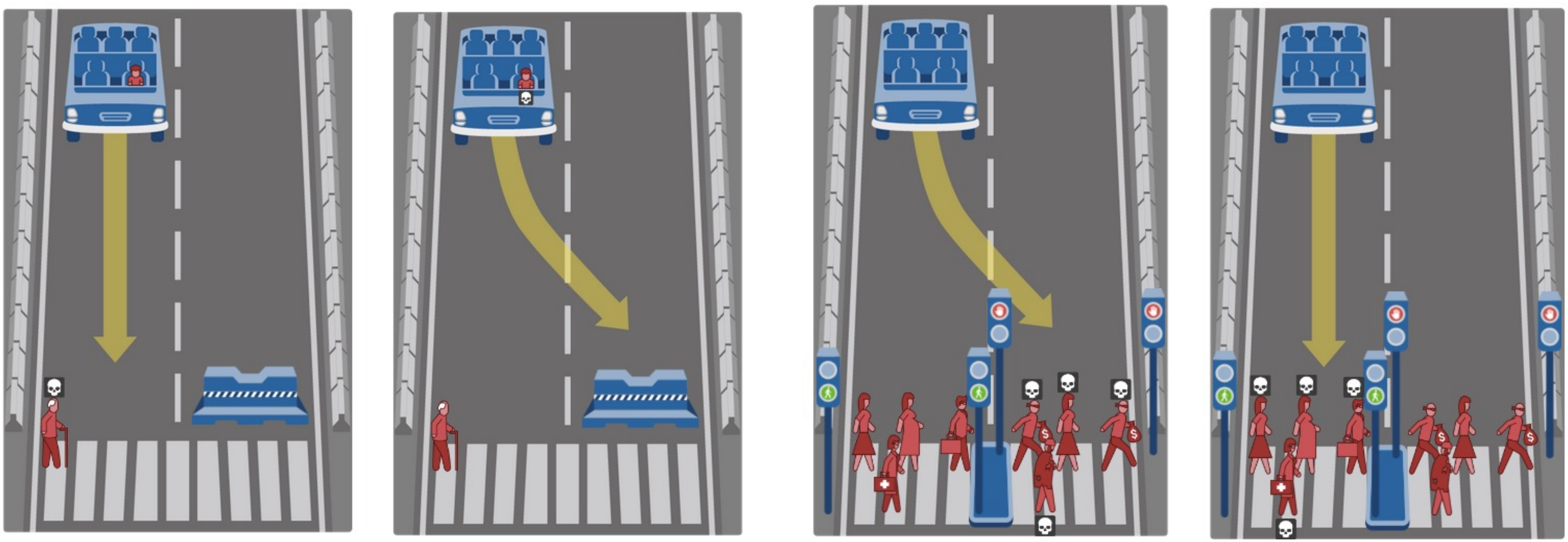
The Final Frontier: Public Acceptance

Ethical Decision Making

- Moral Machine @ MIT



http://moralmachine.mit.edu/

Motion Sickness

- Feeling well while driving
  - The new carsickness of automated driving
  - Driverless vehicles could bring back unpleasant childhood memories

Alternative activity that increases the frequency and severity of motion sickness	U.S.	China	India	Japan	U.K.	Australia
Reading	14.0	10.8	11.1	8.4	9.9	8.3
Texting*	6.4	10.8	8.2	5.5	3.6	5.1
Watching movies/TV	7.8	11.7	13.4	9.2	5.4	7.3
Working	6.2	5.6	17.7	1.0	6.4	6.5
Playing games	2.6	1.4	2.3	1.8	2.5	2.5
Total	*37.0*	*40.3*	*52.7*	*25.9*	*27.8*	*29.7*

Motion Sickness in Self-Driving Vehicles (Sivak and Schoettle), Report No. UMTRI-2015-12, April 2015.

Wrap-Up

Conclusion

- Challenges and opportunities of cooperative automated driving
  - Capabilities and complexity of ADAS is improving
  - Cooperation by means of vehicular networking
- Complex assistance systems
  - Networked control systems
  - Heterogeneous communications as a (possible) solution
- Human interaction
  - Many pros (experience) and cons (reaction times)
  - And the issue of public acceptance as a showstopper

- **… as can be seen, there are many open challenges and questions for another decade of interesting research ☺**