EINSTEIN CENTER Digital Future

Technische Universität Berlin

Lecture 1: Introduction

Introduction of the instructor and course

Prof. Sangyoung Park

Module ”Vehicle-2-X: Communication and Control“

Contents

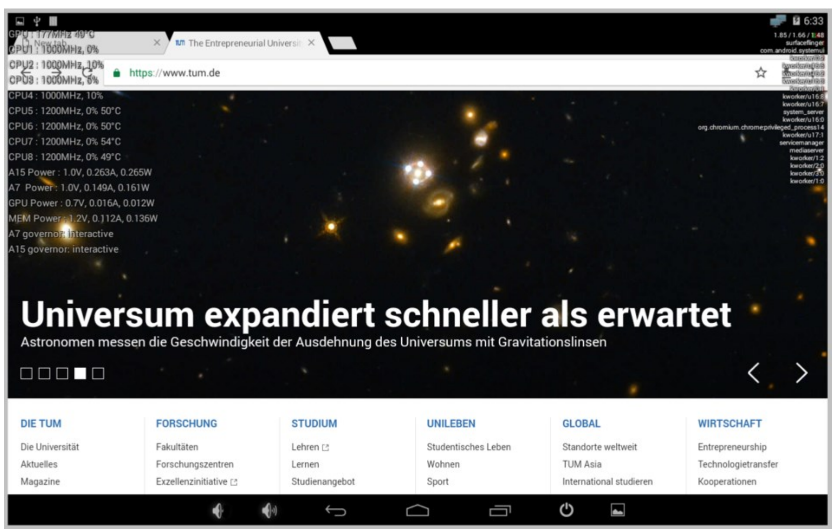
- Who am I?
- Who are you?
- Administrative information
- Motivation for the course
- Overview of the course contents
- Introduction to the tutorial setup

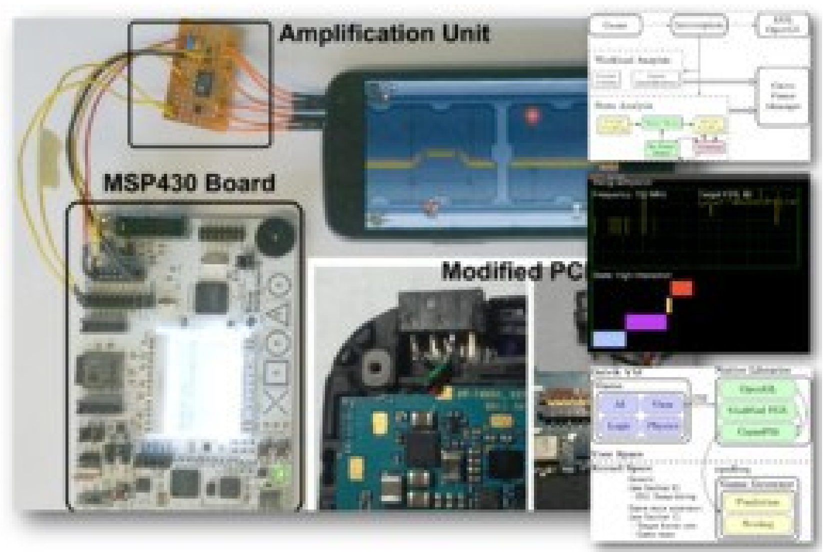
Prof. Dr. Sangyoung Park

- 2008 Bachelor of Science in Electrical Engineering,
  Seoul National University
  Department of Electrical Engineering
- 2014 Doctor of Philosophy (Ph.D.) in
  Electrical Engineering and Computer Science,
  Seoul National University
  Department of Electrical Engineering and Computer Science
- 2014-2018, TU Munich, Postdoc
- 10/2018 → **TU Berlin & Einstein Center, Juniorprofessur „Smart Mobiliy Systems“**
- Research
  Smart mobility systems
  Smart energy systems
  Battery system design and management

Selected Past Projects

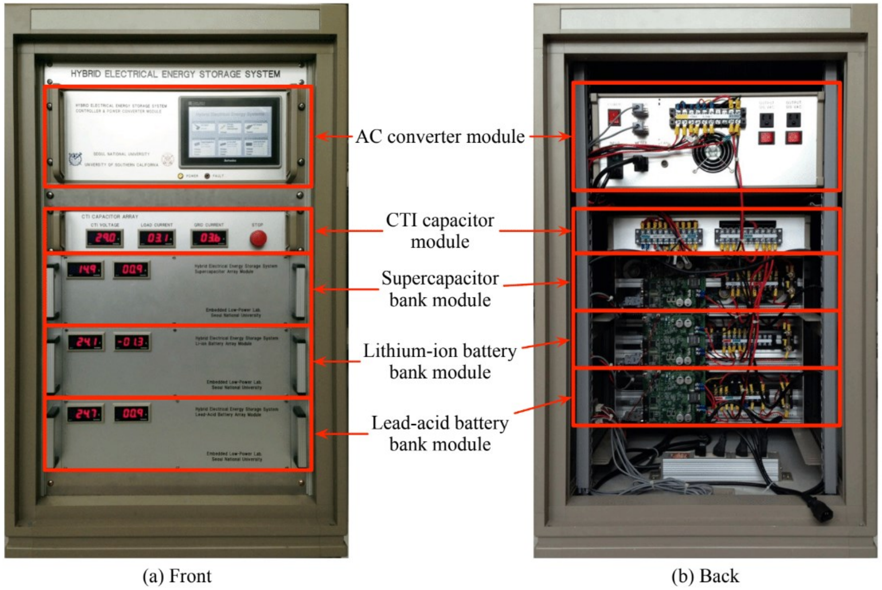
- Low power embedded systems
  - Power management of mobile web browsers (with Google Munich)
  - Mobile games
  - Measuring power consumption
  - Controlling voltage and frequency of processors for power reduction





Selected Past Projects

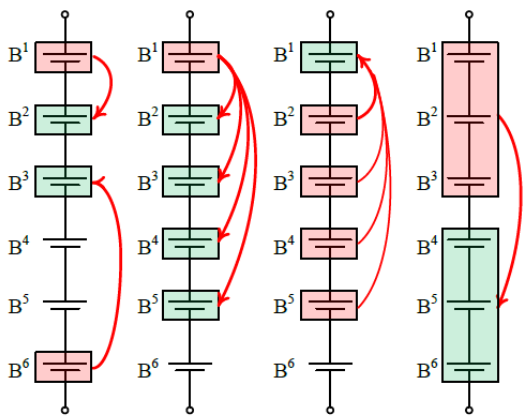
- Battery system design and management
  - Battery + embedded systems
  - Design optimization of battery systems
    - What if we mix Li-ion + lead-acid + supercapacitors



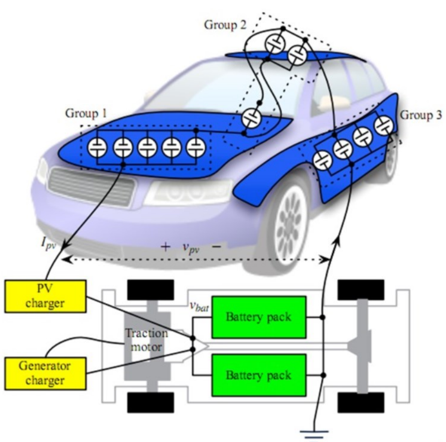
Hybrid energy storage system prototype

Electric Vehicle Energy Management

- How do we design battery packs?
  - Monitoring circuits
  - Charge management
- How about we put solar panels on vehicles?
- One person EV!



Active cell balancinig in EV battery pack



Renewable/EV integration

Chair of Smart Mobility Systems, Faculty V

Teaching and research activities

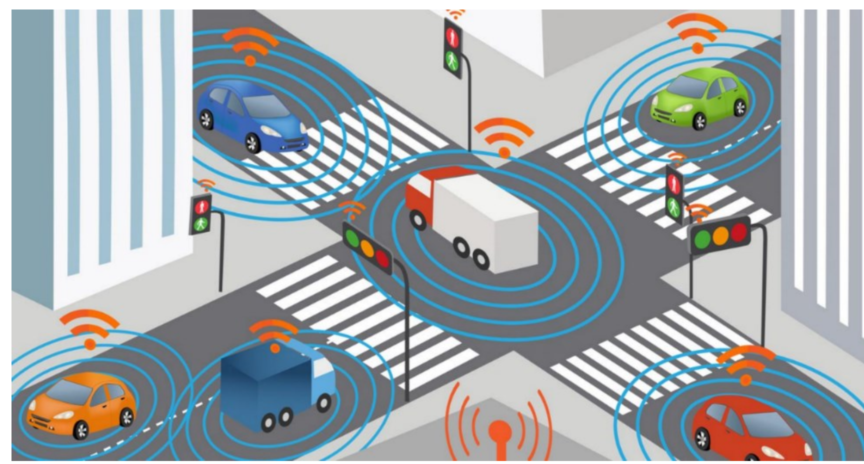
Chair of Smart Mobility Systems

- The Chair of Smart Mobility Systems (SMS) aims at developing designs and operation methodologies for future vehicles
- Team
  - Me!
  - One PhD candidate joining in Septeber, 2019
- Now I want to add „smartness“ to the research topic
- „Communication“ and „computation“

Chair of Smart Mobility Systems

- Cooperative control of vehicles for
  - Traffic smoothing
  - Fuel consumption reduction
  - Safety
- Traffic control using V2I capabilities
  - Traffic light control

eHighway (Siemens Mobility)



Master Thesis Topics @ SMS

- Vehicle platooning algorithms
  - Vehicle-2-X: Communications and Control
- Photovoltaic array optimization
- Battery management circuits
  - Cell balancing
- Modular battery pack designs

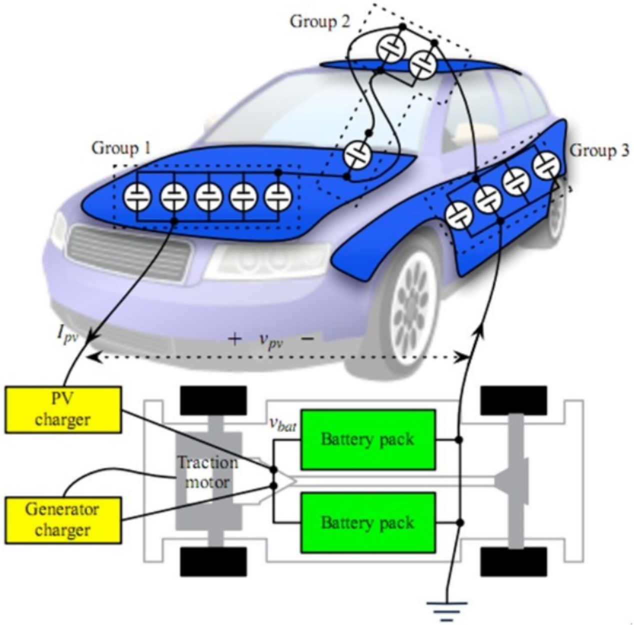
Master Thesis Topics @ SMS

- Vehicle platooning algorithms
  - Setup a simulation framework to evaluate existing platooning algorithms
  - Vehicle simulator (SUMO) + network simulator (OMNet++)
- (Potentially) propose a distance control algorithm for better
  - Maintaining inter-vehicle distance
  - Fuel consumption
- Preferred skills & knowledge
  - SW programming (C++)
  - Control theory

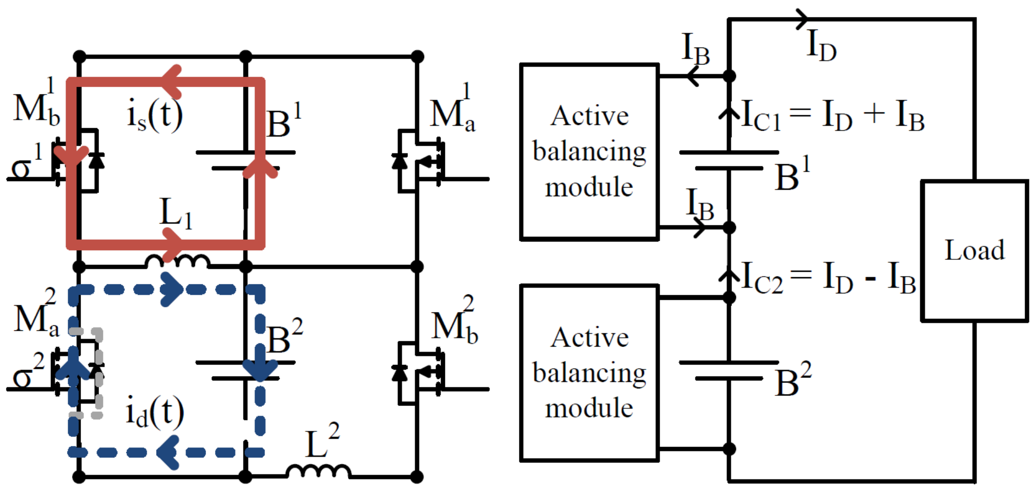
Source: https://www.scania.com

Master Thesis Topics @ SMS

- Photovoltaic array on vehicles
  - There is a prototype electric vehicle being built from scratch
  - The task would be to mount photovoltaic arrays on this vehicle
- Challenges
  - Photovoltaic arrays will not be flat
  - Hard to optimize the power output
  - Reconfiguration of the circuit architecture required
- Preferred skills & knowledge
  - Electric circuits design



- Active cell balancing circuit for aging mitigation
  - Large battery packs such as the ones for EVs require charge balancing circuits. The purpose of this master thesis is to implement such a circuit.
- Preferred skills & knowledge
  - Embedded system design, hardware design PCB design, basic programming skills



Einstein Center Digital Future (ECDF)

- Center for digitalization research in Berlin since April 3, 2017
  - Digital infrastructure
  - Digital health
  - Digital society
  - Digital industry and services
- Co-affiliations with TU, FU, HU,
  Beuth Hochschule, HTW, and UdK

Administrative Information

- Vehicle-2-X: Communications and Control
  - Some mathematical background
  - Minimum programming skills required, but assistantance will be provided
- Time & location
  - Part 1: 03.08.2019-06.08.2019, 9AM – 12PM
  - Part 2: 08.08.2019-11.08.2019, 6PM-9PM
- Credits
  - This course is split into two microcredit courses (1-0-0)
- Each lecture consists of 1.5 hours of lecture and 1.5 hours of tutorial
- Language: English

Evaluation

- There will be a quiz at the end of the course
- There could be a small programming task involving vehicle control over communication networks at the end of the course

Need Help?

- If you have questions, just email me
  - sangyoung.park@tu-berlin.de
- I am sitting in CSE R-315
- TAs will also be there to help you

Course Overview (Goal?)

Vehicles/Driver
- Dynamics
- Traffic flow

Communication
- Protocols
- Infrastructure

Cooperative control

Tutorial: Traffic and communication simulator

Course Overview (Goal?)

- To be honest...
  - I wanted to setup a simulation framework
  - Veins Simulator
  - I intend to investigate various problems related to intelligent transportation systems
  - Rather than covering individual topics in depth, I intend to cover the topic at appropriate depth to be able to investigate interesting research problems
  - The course materials maybe still immature
    - Give a lot of feedback!

Course Overview

- Vehicle/Driver behavior modeling
- Sensing and actuation intelligent vehicles
- Architectures for vehicular communication systems
- Vehicle longitudinal and lateral control
- Adaptive and operative cruise control
- Roadside and traffic control
- Energy and powertrain systems in intelligent automobiles and Electric vehicles

Connected Cars?

- “Cars equipped with internet access, and usually also with a wireless local area network”

Source: www.machinedesign.com

Is It Something Like This?

- Entertainment systems
- Watching movies while driving

Source: www.itp.net, „5G offers new capabilities to connected vehicles, says Gartner“

Much more Possibilities

- Often promoted using using the following videos
  - Automated intersection
    - https://www.youtube.com/watch?v=-yD09YjWKh8
  - Safety
    - https://www.youtube.com/watch?v=ReJOvW094_4

Why Intelligent, Connected Cars?: Background

- Advent of automobiles
  - Human mobility revolutionized
  - Roads were expanded and traffic regulations had been introduced
- Advancement of technology
  - Vehicle power, performance, and range have increased
  - Reshaped the way people live
- Technological sophistication
  - Leisure, comfort, sports, expression of image and personality

Why Intelligent, Connected Cars?: Background

- Technological advancement came with a price
  - Safety
  - Pollution
  - Energy demands
- In order to curb such effects
  - Regulations, laws, and standards have been developed
- Today, tremendous amount of engineering efforts are required to meet
  - Performance requirements
  - Safety requirements
  - Energy and environmental requirements

Why Intelligent, Connected Cars?: Background

- Use of microprocessors to in vehicles
  - ABS
  - Adaptive cruise control
  - Traction control
  - Navigation systems
  - Infotainment systems

- Still, drivers are largely in charge of driving the vehicles

Prospects of Future Connected, Intelligent Vehicles

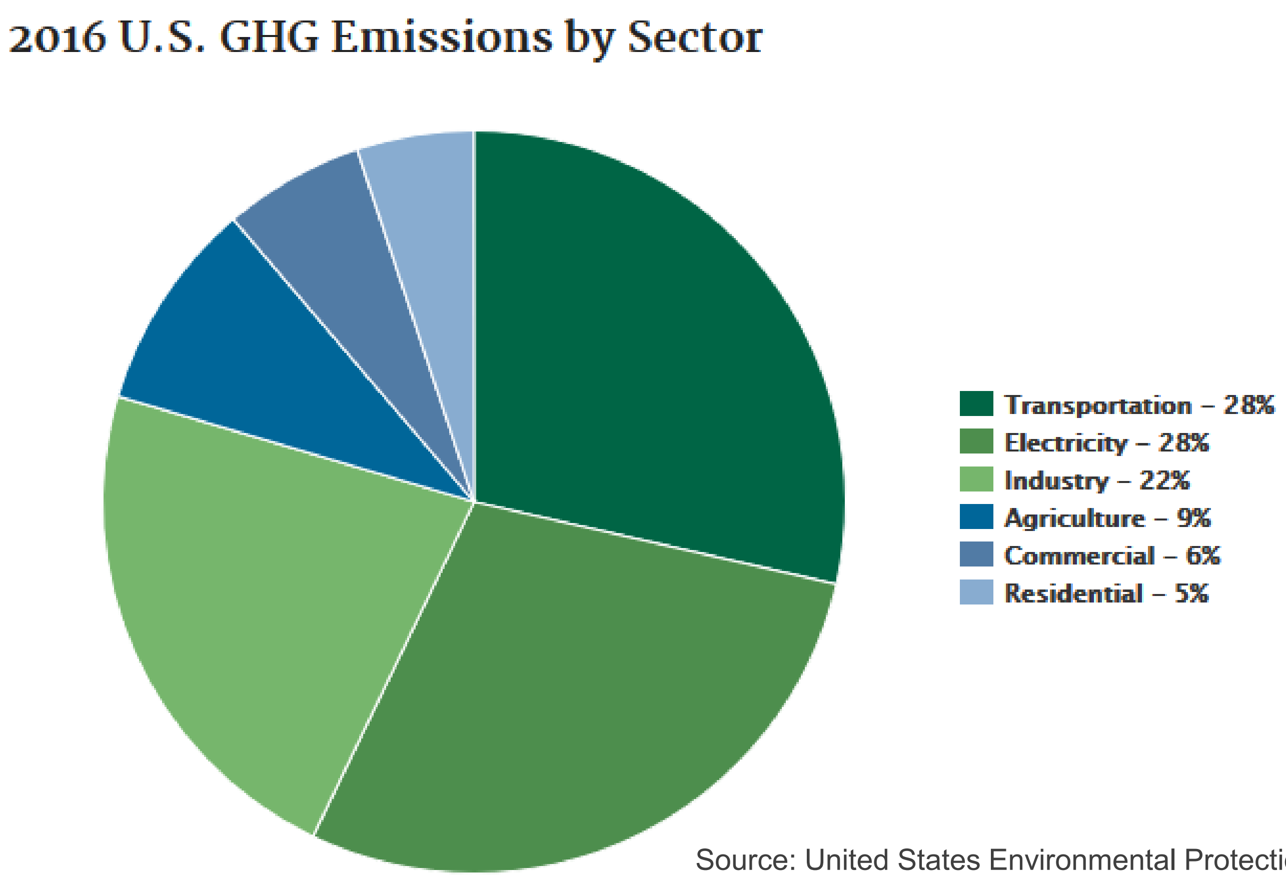
- The full potential of connected, intelligent vehicles are yet to be realized
- Implications in traffic safety
  - Traffic accidents caused 33,808 fatalities and 2.2 million injuries in the USA (2009)
  - Estimated economic loss of 230.6 billion USD
- However, it has been improving
  - Fatalities per 100 million-vehicle-miles-traveled has decreased from 1.73 in 1997 to 1.13 in 2009
- With the aid of electronic systems people are now aiming for zero fatality

Prospects of Future Connected, Intelligent Vehicles

- Counter measures in precrash, crash, postcrash is required to achieve the goal
  - Positioning, navigation, trajectory control
  - Driver assistance
  - Safety and comfort systems
  - Drowsy and fatigues driver detection

Prospects of Future Connected, Intelligent Vehicles

- Energy and environment
  - Transportation sector alone accounts for 28% of the global carbon emissions



Source: United States Environmental Protection Agency

Prospects of Future Connected, Intelligent Vehicles

- Intelligent vehicles are aimed at
  - Increasing safety
  - Improving fuel economy
  - Improve comfort of travel
  - Reduce environmental pollution

So What Exactly are Intelligent Vehicles?

- *„Guided or controlled by a computer; especially: using a built-in microprocessor for automatic operation, for processing of data, or for achieving greater versatility“* – Webster‘s Dictionary

- Intelligent vehicle
  - Performs certian aspects of driving either autonomously or assists the driver to perform his/her driving functions more effectively

What role does connectivity play?

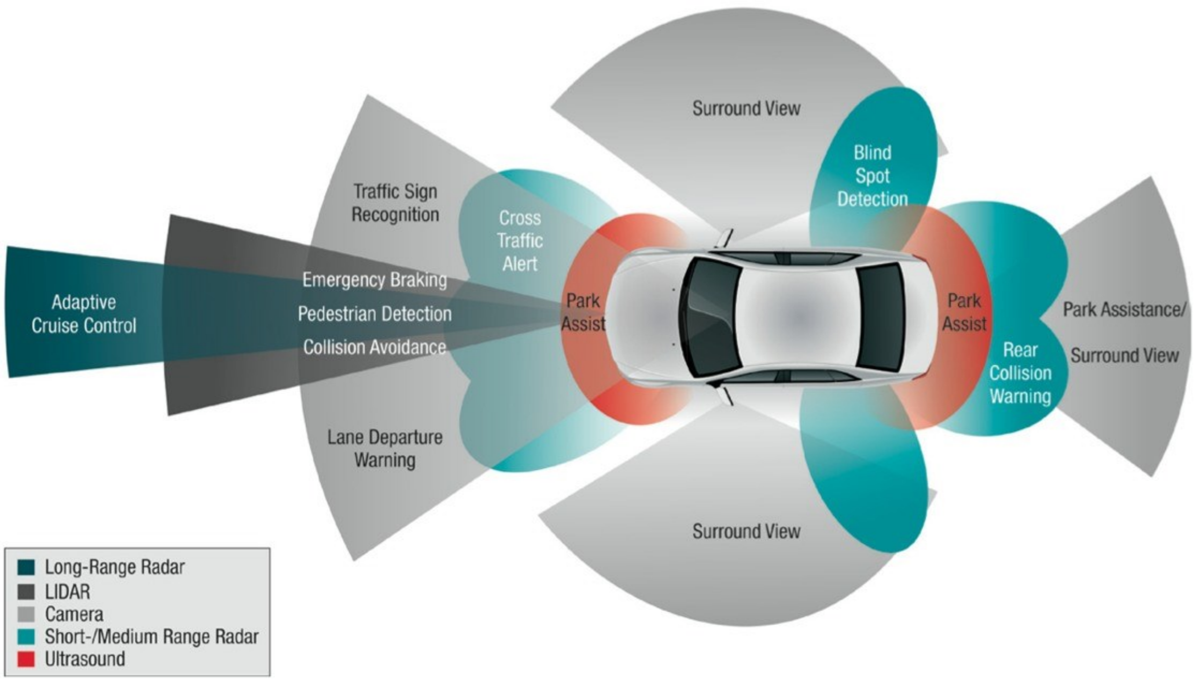
- Vehicular communication systems
  - Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications
- Advanced driver-assistance systems (ADAS)
  - Depend on sensory inputs from a vehicle has limitations in range and line of sight (also expensive)
    - Radar
    - LIDAR: can cost up to several 75,000 USD, now the cost has come down, but still expensive
    - Camera

Lidar

Radar

What role does connectivity play?

- Connectivity can greatly expand the range of sensors with the help of others
  - Information from other cars can extend the sensor outreach than any other on-board surround sensing



Source: https://mtri.org/automotivebenchmark.html

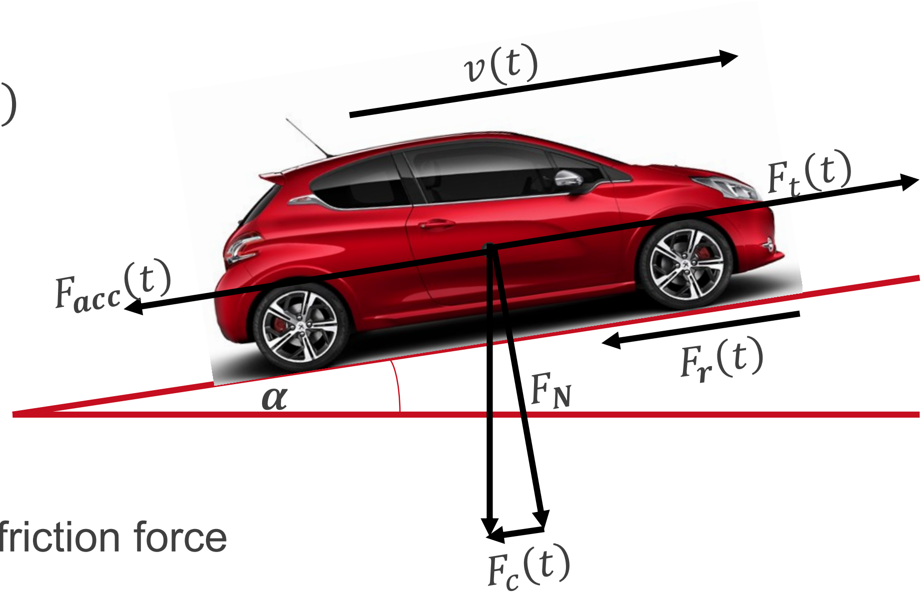
Vehicle Modeling

- $v(t)$ vehicle velocity
- $a(t)$ acceleration
- m_{tot} total vehicle mass

Vehicle Modelinig: Driving resistance equation

$$F_t(t) = F_{air}(t) + F_c(t) + F_r(t) + F_{acc}(t)$$

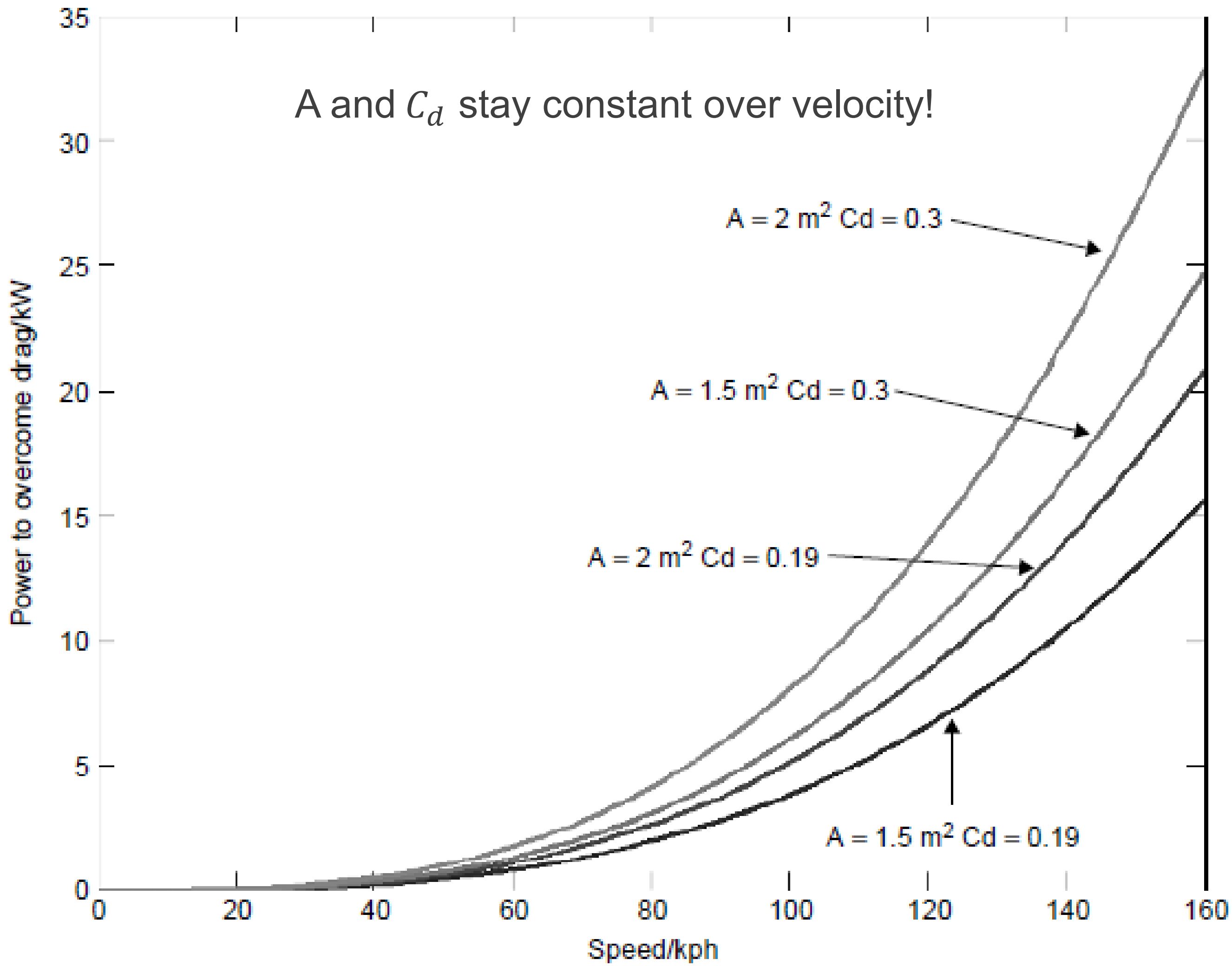
$$P_t(t) = F_t(t) \cdot v(t)$$



- $F_t(t)$ Traction Force
- $F_{air}(t)$ Aerodynamic drag, aerodynamic friction force
- $F_c(t)$ Climbing Force
- $F_r(t)$ Rolling resistance, rolling friction force
- $F_{acc}(t)$ Acceleration Force
- $P_t(t)$ Traction Power
- $v(t)$ Vehicle Velocity

Attention:
$P_t(t) \neq P_{motor}(t)$

Aerodynamic Drag



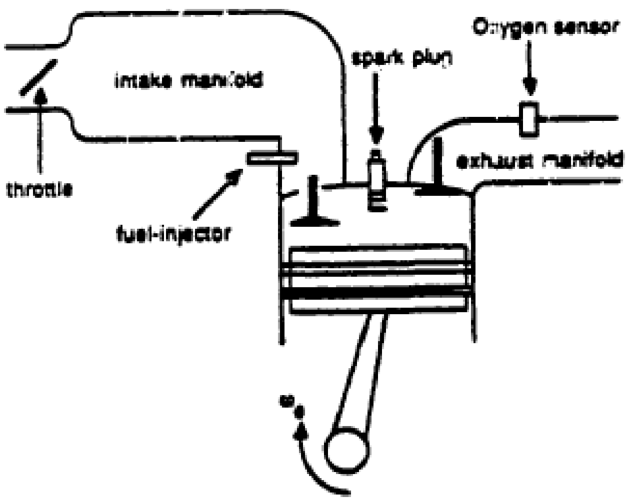
Larminie (2003), Electric Vehcile Technology Explained

Classification of Vehicle Dynamics

- Different vehicle models are used ***depending on the purpose***
- Longitudinal vehicle dynamics
  - Driving resistances/perf
  - Driving performance
  - Acceleration and braking
  - Fuel consumption, emissions
  - Longitudinal tire slip
- Lateral vehicle dynamics
  - Steering system
  - Cornering, driving agility
  - Lateral tire behavior
- Vertical vehicle dynamics
  - Axle & suspension system
  - Comfort behavior

Simplified Models for Longitudinal Control Design

- 12-state complex model (Hendrick et al., 1993)
  - Front wheel drive with V-6 engine
  - Four states for the engine
    - Manifold intake pressure/exhaust gas recirculation rate/engine speed/fuel flow
  - Two for the transmission
  - Six for the drive train
  - Two time delays associated with the engine



D.H. McMahon, et al., „Vehicle Modeling and Control for Automated Highway Systems“, American Control Conference, 1990

Simplified Models for Longitudinal Control Design

- Further simplified model (four state)
  - Assumptions
    - Time delays associated with power generation in the engine ar enegligible
    - The torque converter in the vehicle is locked
    - There is no torsion of the drive axle
    - Slip between the tires and the road is zero
  - State 1: vehicle speed v_x will be directly related to the engine speed w_e

$$\dot{\boldsymbol{x}} = \boldsymbol{v_x} = \boldsymbol{Rh\omega_e}$$

    where R and h are gear ratio and tire radius
  - State 2: mass of air in the intake manifold (m_a)
  - State 3: Engine speed (ω_e)
  - State 4: Brake torque (T_{br})

$$\dot{\boldsymbol{\omega}}_e = \frac{T_{net} - c_a R^2 h^2 \boldsymbol{\omega}_e^2 - R(hF_f + T_{br})}{J_e}$$

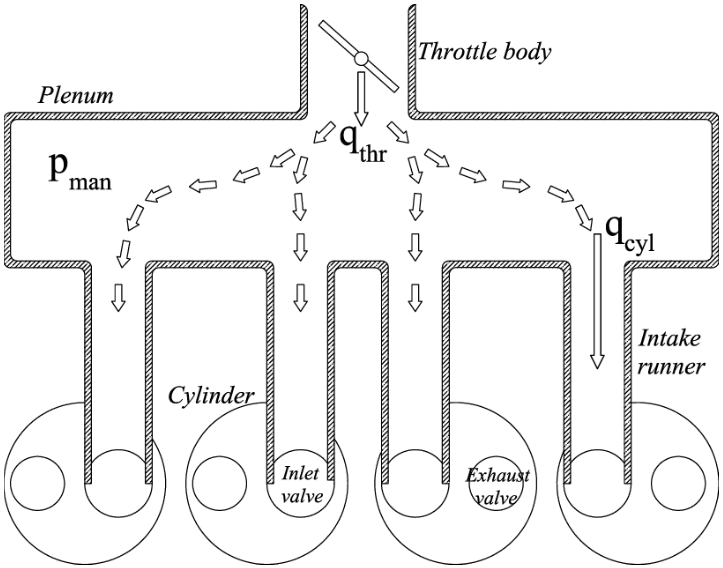
  - Where c_a is the aerodynamic drag coefficient, F_f is the rolling resistance, and $J_e = I_e + (mh^2 + I_\omega)R^2$ is the effective inertia reflected on the engine side

- Further simplified model (four state)

$$\dot{m}_a = \dot{m}_{ai} - \dot{m}_{ao}$$

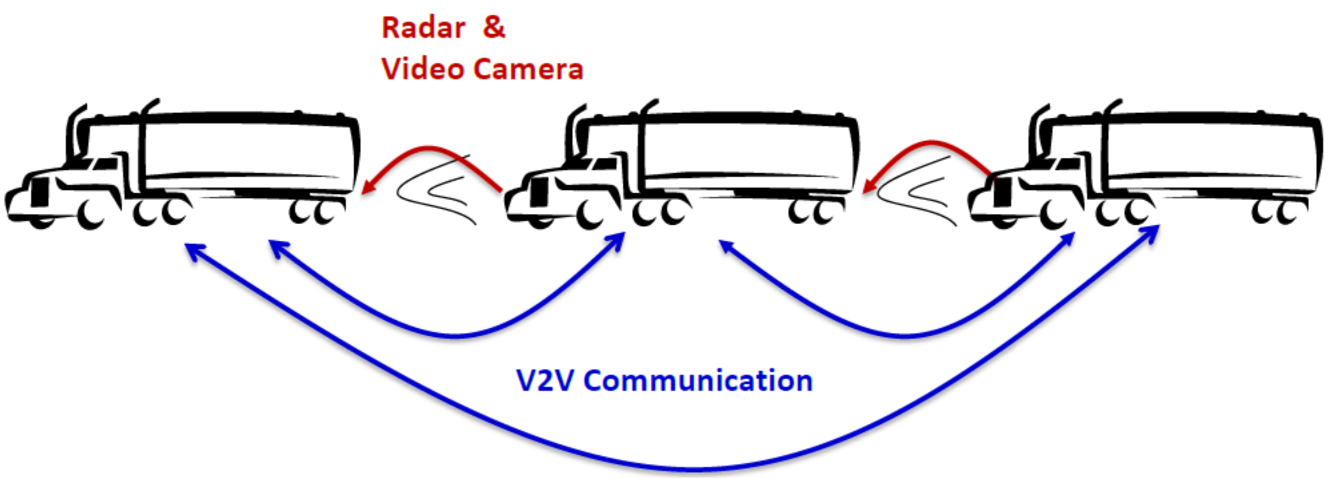
where $\dot{m}_{ai}$ and $\dot{m}_{ao}$ are the flow rate into the intake manifold, and out from the manifold

- What is a manifold?
  - Part of engine that supplies the fuel/air mixture to the cylinders
  - $\dot{m}_{ai} = MAXTC(\alpha)PRI(m_a)$
  - $P_m V_m = m_a R_g T$
  - $\tau_{br}\dot{T}_{br} + T_{br} = T_{br,cmd} = K_{br}P_{br}$



Longitudinal Control System Design

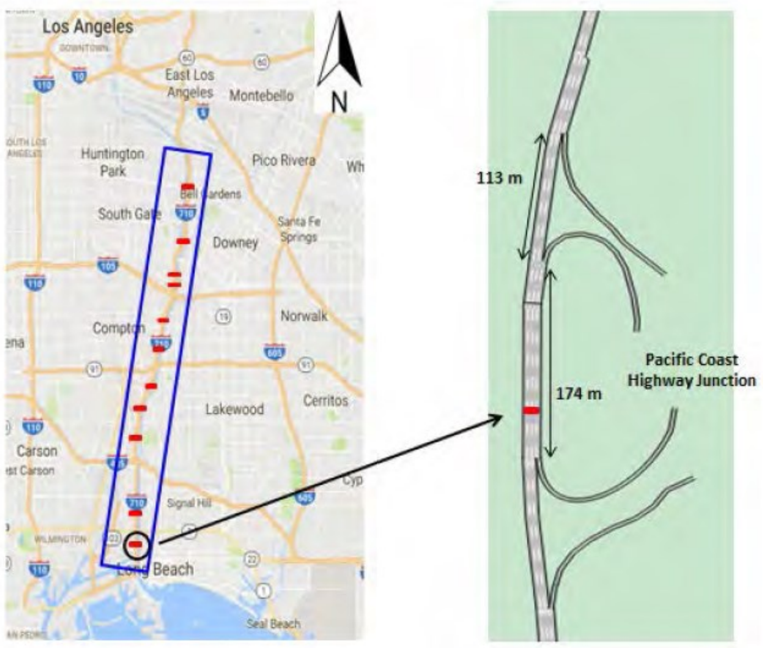
- California PATH program example
  - Truck platooning project
    - Coordinatinig driving of clusters of heavy trucks using automatic control of their speed and separation
    - Wireless vehicle-2-vehicle communication to enable close coordination
    - Loose coupling by cooperative ACC or tighter coupling with constant clearance gap



S.E. Shladover, „Introduction to Truck Platooning“, ITS World Congress, 2017

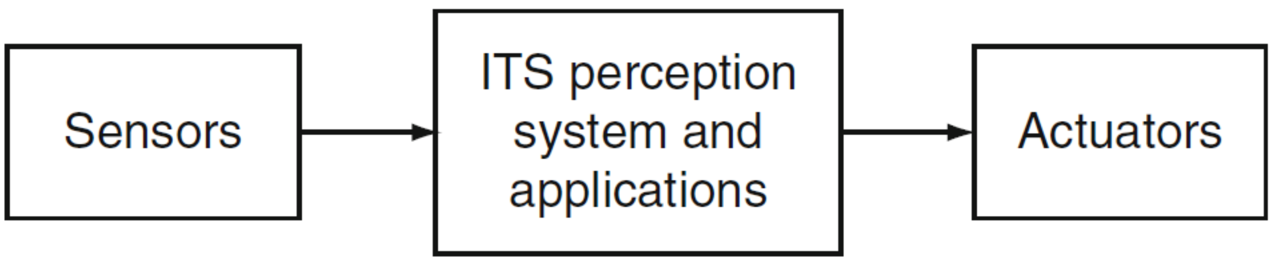
Longitudinal Control System Design

- Why platooning?
  - Aerodynamic drag reduction
  - Three heavy trucks at a gap of 6 m, resulting in the improvement of fuel consumption by 10% on the average
  - Simulation on urban traffic
    - I-710 from Long Beach to LA
    - 2.5% Fuel savings from traffic smoothing
    - 0.5% from aerodynamic drag reductions



Sensing and Actuation in Intelligent Vehicles

- Vehicles today can ***sense*** the environment and ***act*** using electronic systems
  - Engine control and ABS (Anti-lock brakinig system) are now industry standards
- Electronic systems offers
  - Miniaturization
  - Cost reduction
  - Increased functionality
  - Quality of the componnet



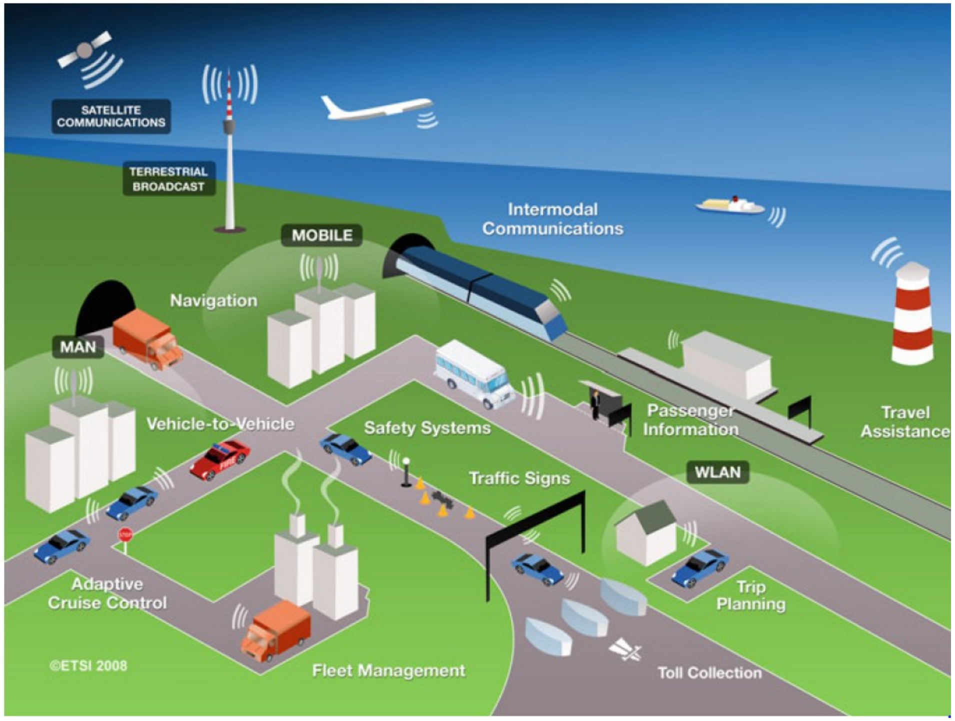
Source :Hand book of Intelligent Vehicles

Types of Sensors

- General in-vehicle sensors
  - Yaw rate sensor
  - Accelerometer
  - Wheel speed sensor
  - Steering angle sensor
- Perception sensors
  - Radar
  - Long-range
  - Laser scanners
    - Equipped only in expensive vehicles
- Vision systems
  - CCD and CMOS camera
  - IR vision
  - Stereo vision

Types of Sensors

- Ultrasonic sensors
- Wireless communication
  - DSRC (dedicated short range communcations): short to medium (1000 m) V2V, V2I



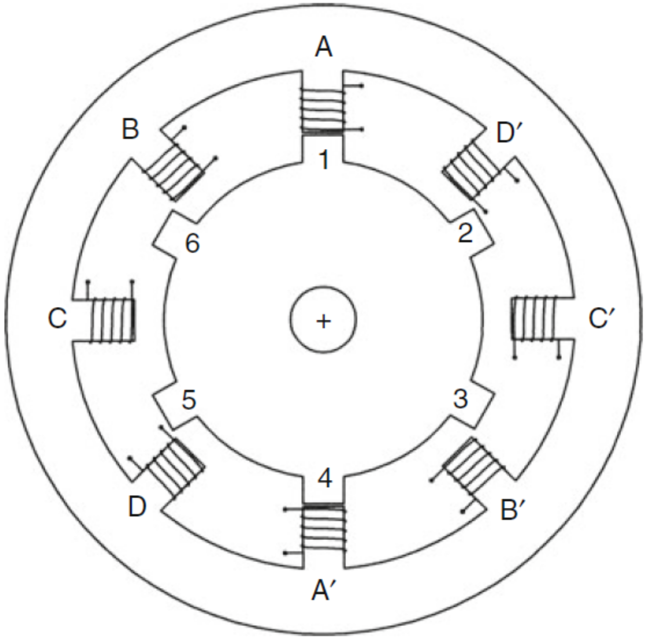
Types of Sensors

- Wireless communication
  - WAVE (Wireless Access in Vehicular Environments): IEEE 1609
  - Continuous Air Interface Long and Medium Range (CALM): ISO 2007; ISOTC204 WG16)
  - CAR 2 CAR Communication Consortium (C2C2CC)

Types of Actuators

- Electric Motors
  - DC motors
  - Stepper motors

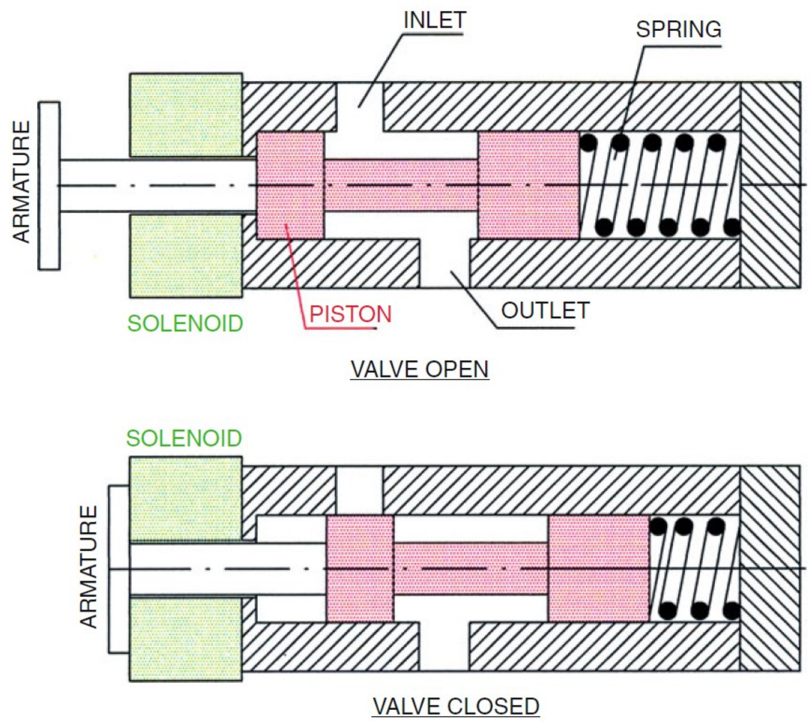
Smart coolant pump by Continental using a DC motor



Stepper motor

Types of Actuators

- Solenoid valves
  - Electric current through coil determines the position of the valve



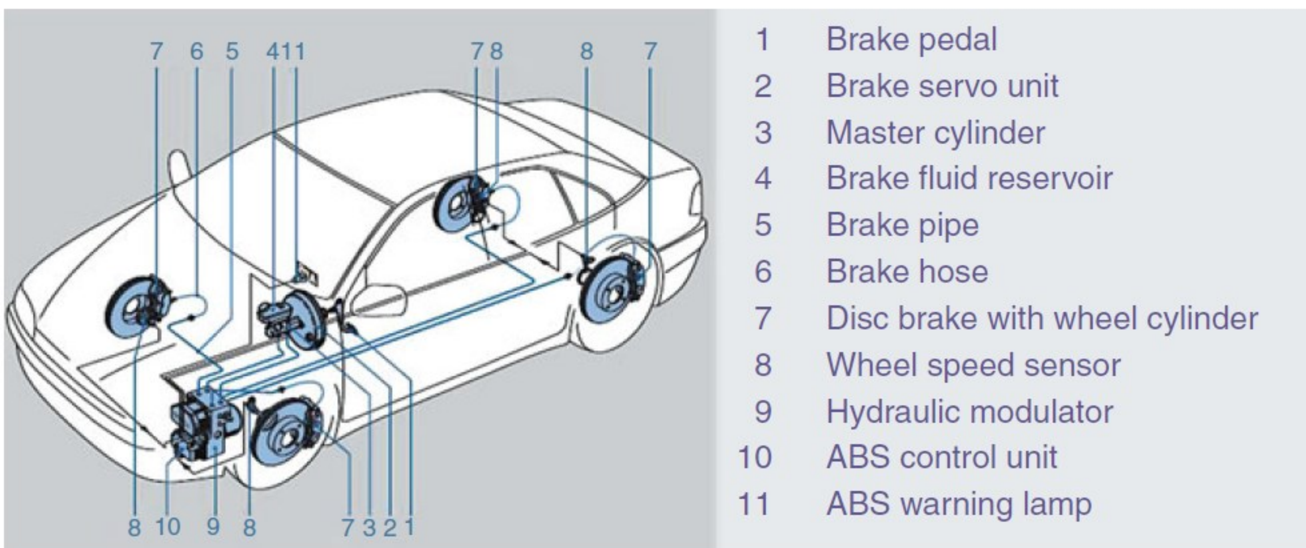
Solenoid valve example

Types of Actuators

- Pneumatic and hydraulic actuators
  - Compressed air or pressurized fluid into rotary or linear motion
- Piezoelectric actuators
  - Piezoelectric effect: pressure -> electricity
  - Reverse piezoelectric effect: electricity -> mechanical motion
  - High precision fuel injection systems

Sensor-Actuator Systems

- Antilock braking systems (ABS)
  - Prevents wheel skidding during braking
  - Use of ECUs (electronic control unit)
  - Wheel speed sensor, hydraulic brake valves



Sensor-Actuator Systems

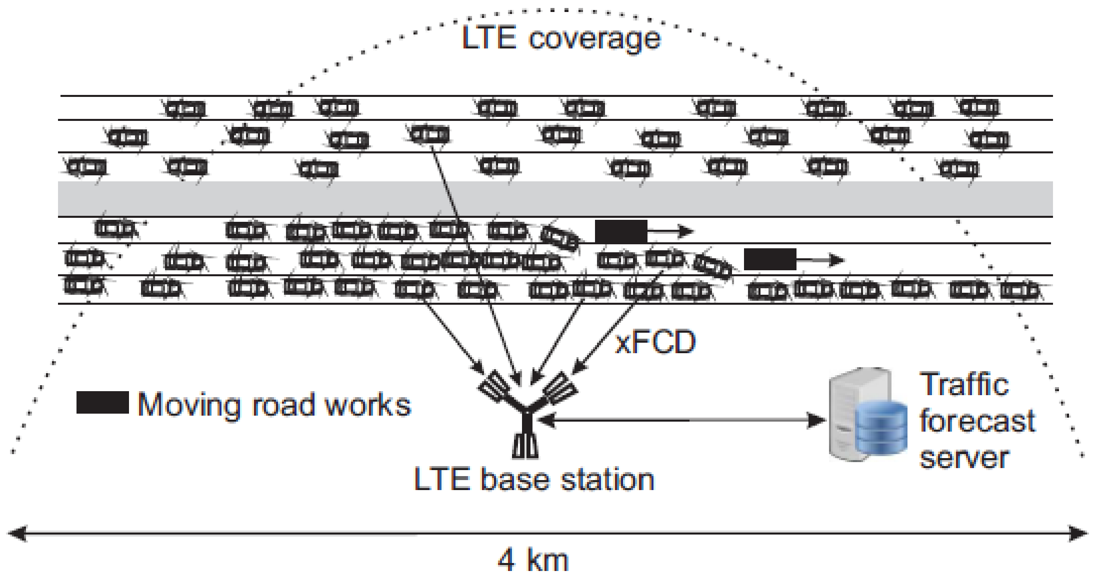
- Electronc Stability Systems (ESC)
  - Uses the same or similar components to ABS
  - Ensures the stability of the vehicle by comparing the steering wheel angle and the gyroscopic sensor readings

- Adaptive Cruise Control (ACC)
  - Uses radar or other sensor to detect a slower moving lead vehicle and decelerate

- Assisted steering and steer-by-wire systems
- Brake-by-wire systems
- And.. autonomous vehicles?

Architectures for Communication Systems

- Vehicle-to-infrastructure (V2I) communications
  - Traffic prediction, management
  - Safety systems: latency of 100 ms? LTE?
  - Content dissemination
  - Wi-Fi based vs cellular-based systems?



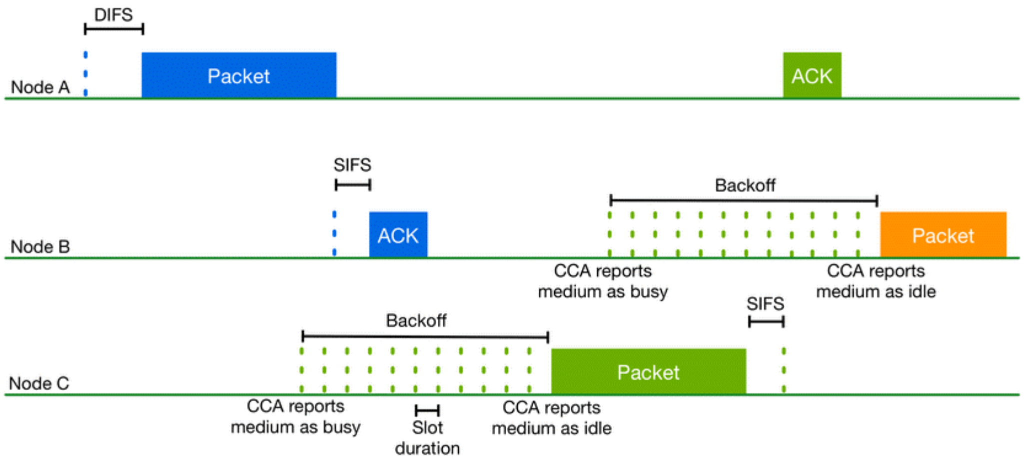
Source: C. Ide, et al., „Interaction between Machine-Type Communcation and H2H LTE Traffic in Vehicular Environments, IEEE VTC19

Architectures for Communication Systems

- Vehicular ad hoc networks (VANETs)
  - Real-time communication among vehicles
  - Little or no permanent infrastructure
  - Safety
  - https://www.youtube.com/watch?v=14fOqMBn9aw

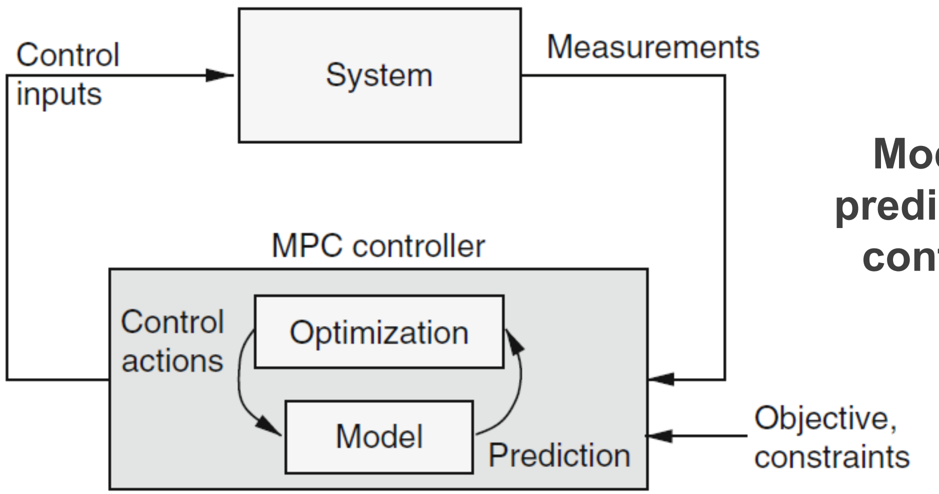
Architectures for Communication Systems

- Protocols, algorithms, routing and information dissemination
  - IEEE standards for DSRC MAC
    - IEEE 802.11p (WiFi-p)
    - IEEE 1609.4
  - MAC for multichannel
  - Multichannel coordination
  - TDMA-based VANET MAC protocols vs CSMA/CA
    - For vehicles, latency and reliability might be more important that throughput



Hierarchical, Intelligent, and Automatic Controls

- Positioning, navigation, and trajectory control
- Methods
  - Static feedback control
    - PID controllers
  - Optimal control and model predictive control
    - Optimizes a performance function: fuel consumption, safety distance, etc.
    - Online optimization using rolling horizons approach



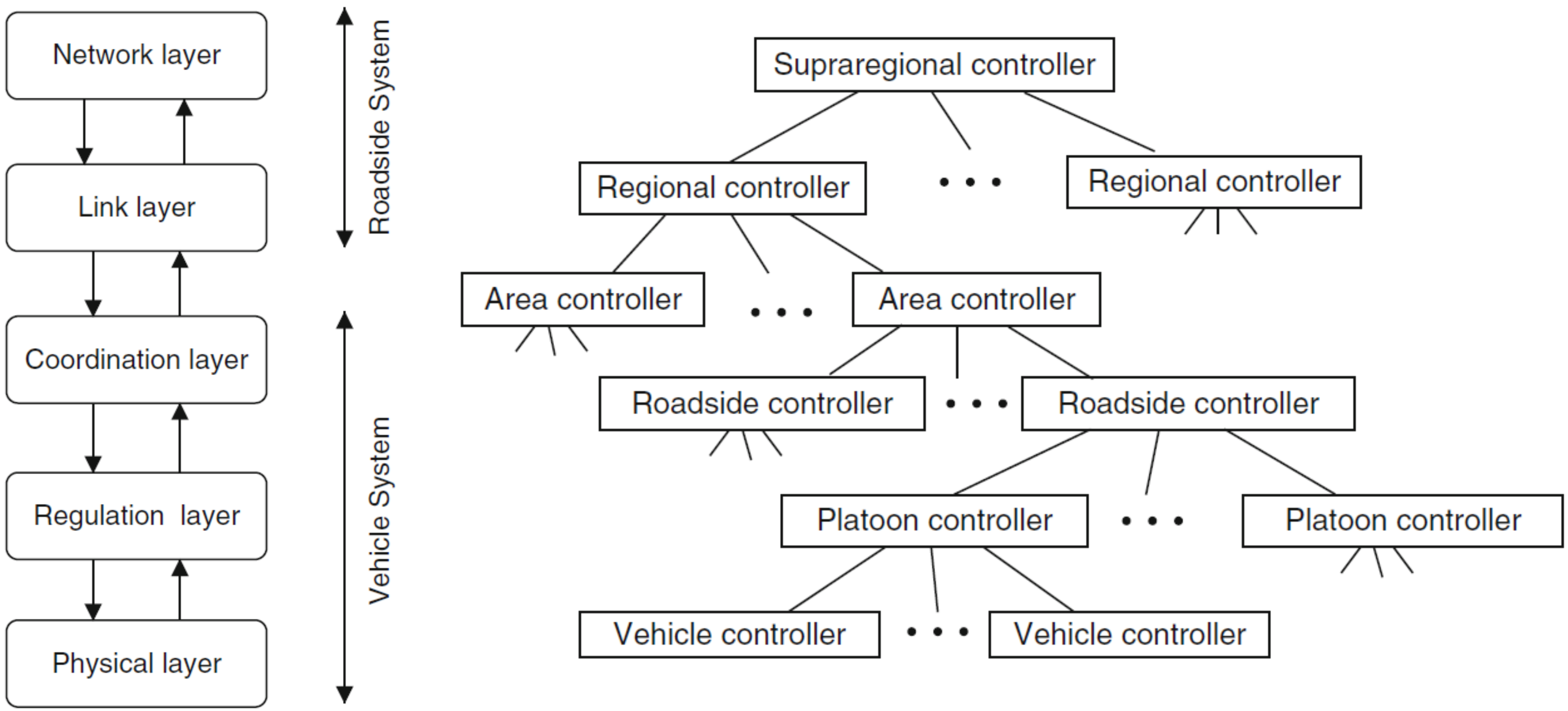
Model predictive control

Hierarchical, Intelligent, and Automatic Controls

- Methods
  - Artificial intelligence (AI) techniques
    - Mimics how humans solve problems
    - Case-based reasoning
    - Fuzzy logic
    - Rule-based systems
    - Artificial neural networks
    - Multi-agent systems

Hierarchical Control

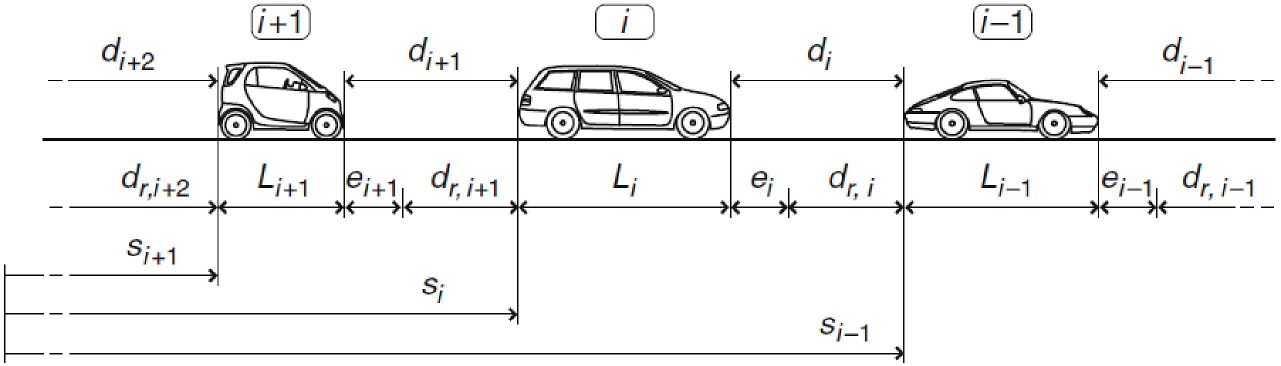
- PATH example



Path architecture

Vehicle Following Control

- Distance error for i-th vehicle:
- $e_i(t) = d_i(t) - d_{r,i}(t)$
- Where $d_{r,i}(t)$ is the desired headway of vehicle i that follows from the so-called spacing policy
- The control objective would be to $\lim_{t\to\infty} e_i(t) = 0$ under the presence of disturbances
  - Changes in the velocity of other vehicles, initial velocity differences, etc.

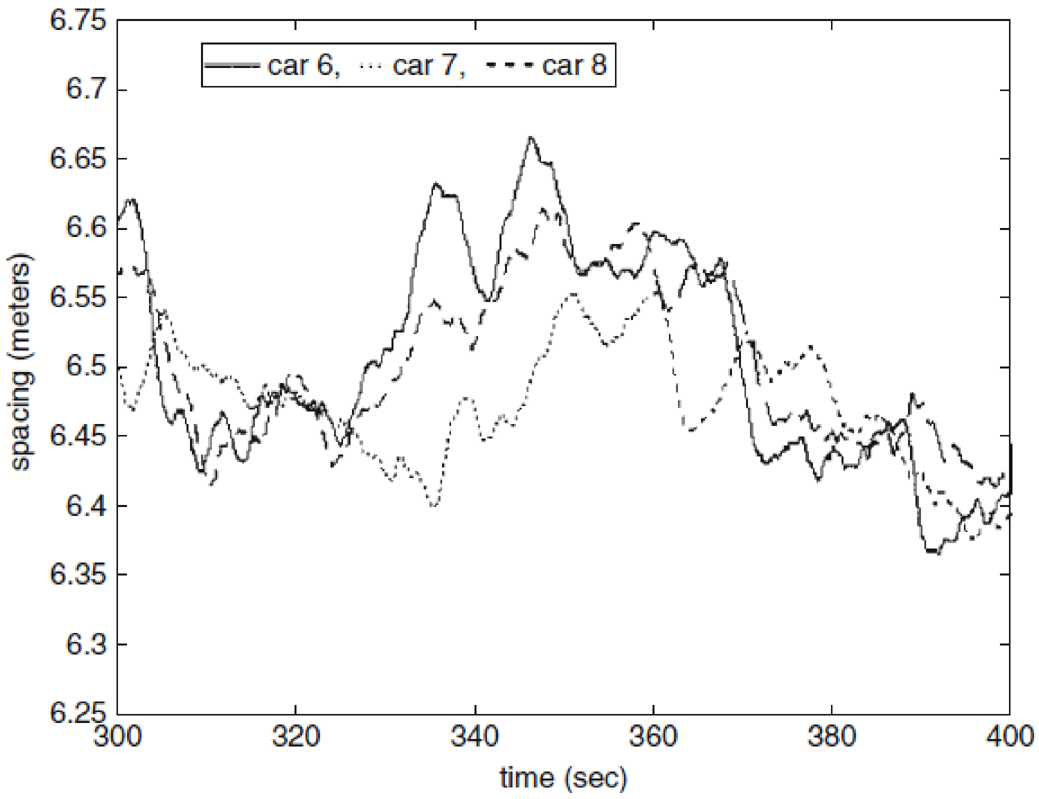


Longitudinal Control System Design

- Upper-level controller
  - Determines the desired acceleration of each car
  - Maintain constant small spacing between the cars
  - Ensure string stability of the platoon
- Lower-level controller
  - Throttle and brake actuator inputs are determined
  - Tries to track the desired acceleration determined by the upper-level controller

Longitudinal Control System Design

- Inter-vehicle spacing results



Source: Hanbook of Intelligent Vehicles

Longitudinal Control System Design

- What about string stability?
  - How do you define the stability of a platoon?
  - We should ensure that vehicles in a platoon do not crash into each other

Traffic Modeling/Driver Behavior Modeling

- Two extremes
- Empty lane (left): Vehicles move at desired speeds, no interaction among vehicles
- Fully congested lane (right): Queueing theory

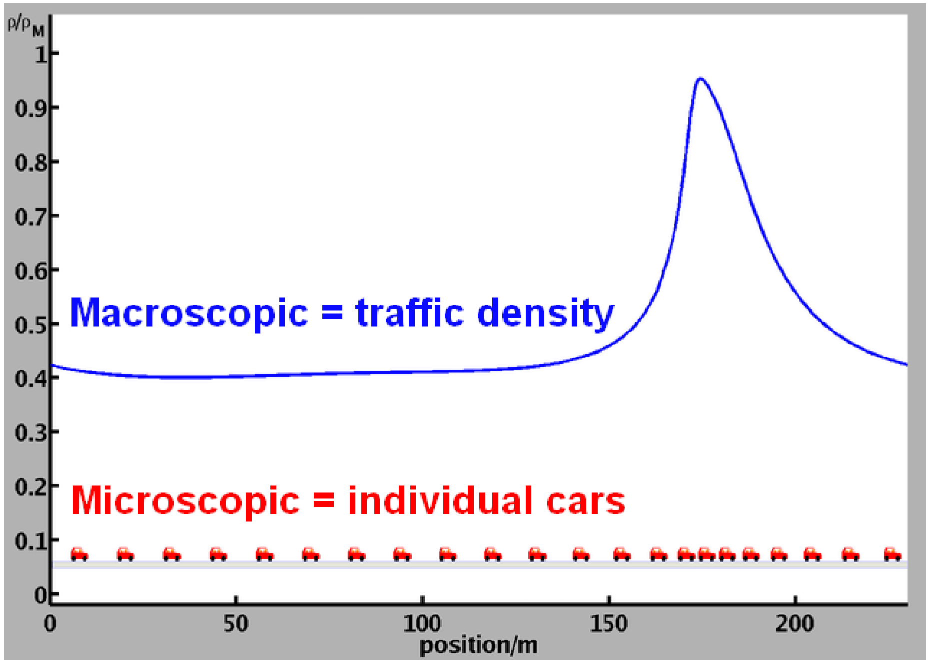
Source: B. Seibold, “A mathematical introduction to traffic flow theory”

Traffic Modeling/Driver Behavior Modeling

- In reality, it is somewhere it between
  - Vehicles interact which each other and we have to consider flow
  - https://www.youtube.com/watch?v=Suugn-p5C1M

Traffic Modeling/Driver Behavior Modeling

- Macroscopic modeling
  - Concerned with average behavior, such as traffic density, average speed and module area
- Microscopic modeling
  - Car following model: driver adjusts his or her acceleration according to the conditions in front



Source: B. Seibold, "A mathematical introduction to traffic flow theory"

Why Traffic/Driver Modeling?

- We can investigate various effects
  - Non-homogenous vehicles (trucks + passenger vehicles)
  - Aggressiveness of a driver
  - Can perform simulation studies!
  - What is the difference in traffic flow if we use autonomous driving??

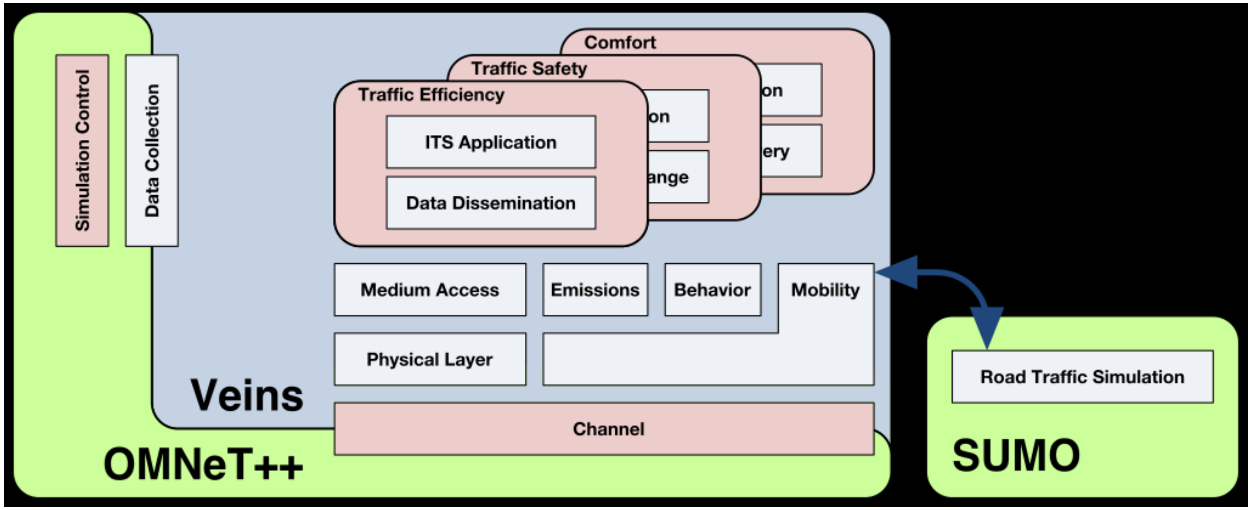
- Our goal of the course would be to investigate such effects

Roadside Control and Traffic Signal Control

- Traffic lights have a huge impact on traffic control
- Fixed time control
  - Fixed green-red timings and non-adjutable
- Coordinated control
  - „Green wave“ for traveling vehicles
- Adaptive control
  - Use of cameras, motion sensors, RFID tags, etc., to monitor the traffic flow and adaptively control the timings

Tutorial Setup

- Veins simulator
  - Traffic simulator + network simulator
  - SUMO: Simulation of urban mobility
  - OMNet++
    - Discrete event simulator for networks
- What can we test?
  - To be elaborated at Tutorial parts



Source: Veins simulator website

Course Schedule

Weeks	Lecture	Tutorial
1	Introduction & Course Overview	Introduction to software setup
2	Vehicle dynamics and modeling	SUMO simulator tutorial
3	Microscopic Traffic Modelinig	SUMO simulator tutorial
4	Sensing and actuation in intelligent vehicles	OMNeT++ introduction
5	Architectures for vehicular communication systems (1)	Vehicle-2-Infrastructure example
6	Architectures for vehicular communication systems (2)	Veins simulator architecture: custom application
7	Longitudinal control of vehicles	Platooning example
8	Fuel-Economy and EV energy consumption	Traffic light control

References

- Azim Eskandarian, Handbook of Intelligent Vehicles, Springer, 2012
- Mario Hirz, „Automotive Engineering, Focus: Basics of Longitudinal Vehicle Dynamics“
- W. Chen, Vehicular Communications and Networks: Architectures, Protocols, and Networks