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
  Ensuring safety through V2X
  Electric vehicle energy management

Einstein Center Digital Future (ECDF)

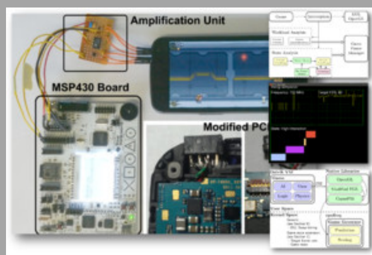
- Center for digitalization research in Berlin since April 3, 2017
  - Digital infrastructure
  - Digital health
  - Digital society
  - Digital industry and services
- Co-affiliations with TU, FU, HU, Beuth Hochschule, HTW, and UdK

Chair of Smart Mobility Systems, Faculty V

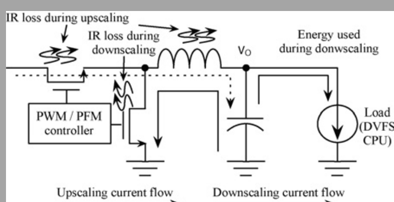
Teaching and research activities

Research Interests

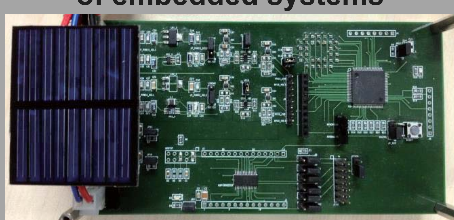
Low-Power Embedded Systems



Smartphone power management



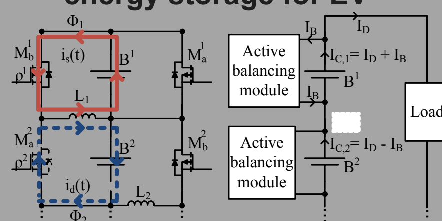
Modeling power consumption of embedded systems



Energy harvesting for embedded systems

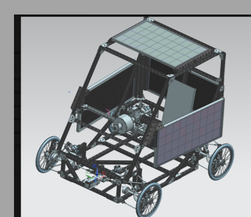
Electric Vehicles

Hybrid electrical energy storage for EV



Cell balancing for EV battery packs

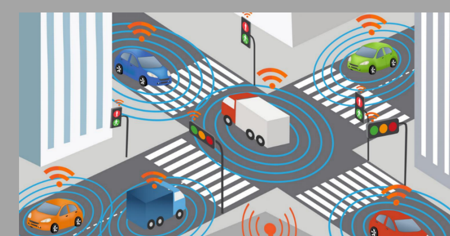
PV panels for electric vehicls



Smart Mobility

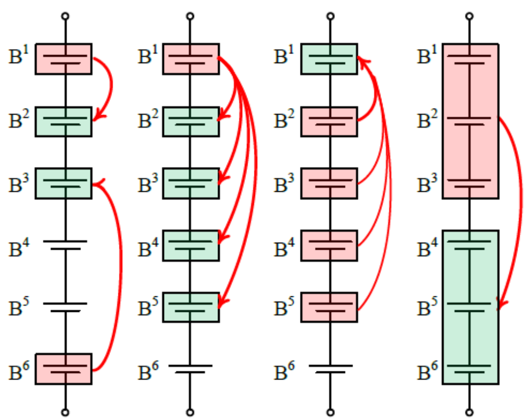
Since joining TU Berlin in Oct. 2018

Cooperative vehicle control over V2X

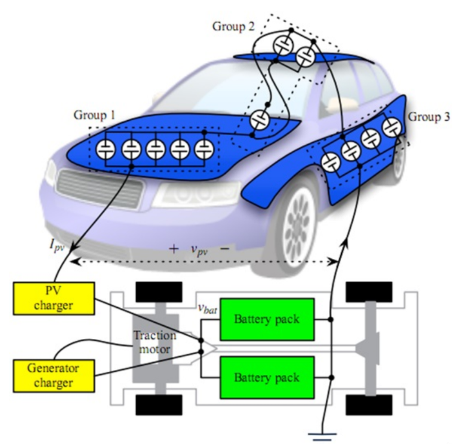


Electric Vehicle Energy Management

- 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



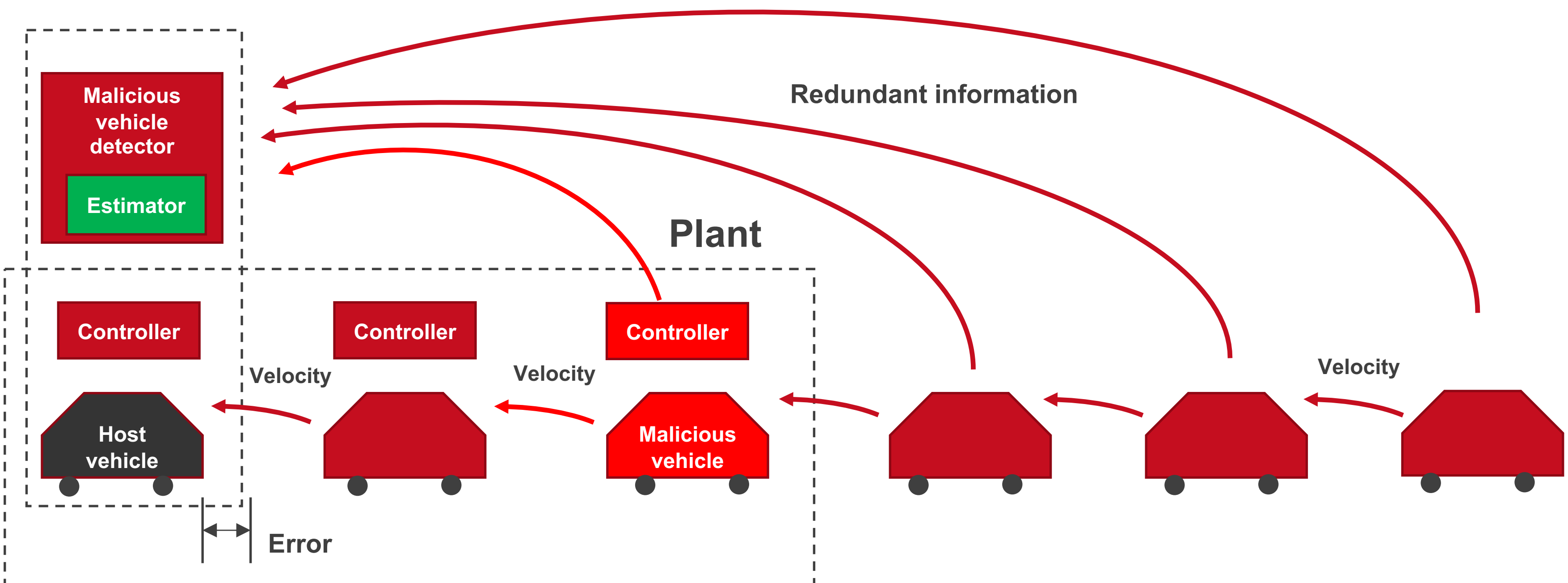
Renewable/EV integration

Chair of Smart Mobility Systems

- The Chair of Smart Mobility Systems (SMS) aims at developing designs and operation methodologies for future vehicles
- Team
  - Prof. Dr. Sangyoung Park
  - M.Eng. Philipp Kremer
- Now I want to add „smartness“ to the research topic
- „Communication“ and „computation“

Research Interests

- Ensuring safety vehicle fleets using Vehicle-2-X communication
  - Vehicles may share velocity and acceleration information
  - This can, of course, be used for better vehicle control
  - But also, be used to cross-verify vehicle safety states to detect malicious/unsafey activities/maneuvers



Research Interests

- eHighway: heavy-duty electric vehicles on highways (with Siemens Mobility)
  - Long-haul heavy-duty electric vehicles are hard to electrify
  - Various concepts are being considered
    - Hybrid drivetrain
    - Battery swapping stations
    - **Overhead power lines**
  - How do we ensure reliability of the overhead power lines?
    - Limitations in current
    - Reliability during traffic jams?
    - Monitoring/control using V2X

eHighway (Siemens Mobility)

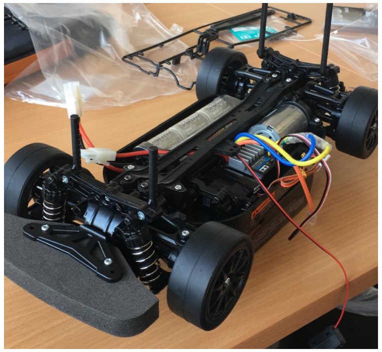
Research Interests

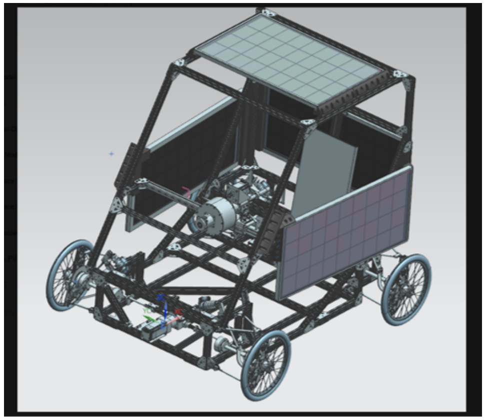
- Automatic battery swapping stations for logistics applications (FVB@TU Berlin, Dachser, etc.)
  - Replaceable batteries should be charged at the swapping stations
  - How should they be charged?
  - Can they be used for vehicle-to-grid purposes?
    - Grid frequency stabilization, etc.

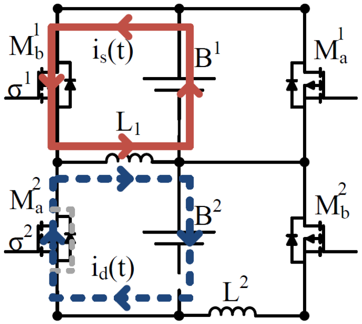
Source: https://www.youtube.com/watch?v=FQVx167iYS4

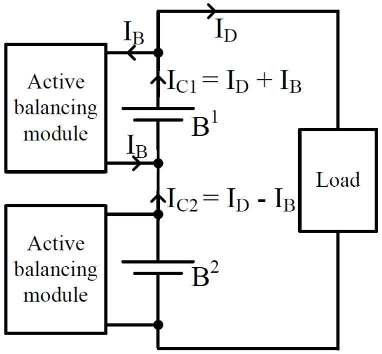
Master Thesis Topics @ SMS

- List of topics available from
  - https://www.sms.tu-berlin.de/menue/teaching/thesis_topics/
- Vehicle platooning
  - Lateral control of RC cars for platooning
- Photovoltaic arrays for one-man electric vehicle
  - Let’s put a PV array on an actual EV!
- Battery cell balancing strategies for electric vehicles









Administrative Information

- Vehicle-2-X: Communications and Control
  - Some mathematical background
  - Minimum programming skills required, but assistance will be provided
- Time & location
  - Will take place online SS20
  - I will upload videos on Wednesday
- Credits
  - 6 ECTS
- Each lecture consists of 2 hours of lecture and 2 hours of tutorial every week
- You really need to keep up with the tutorial part!
- Language: English

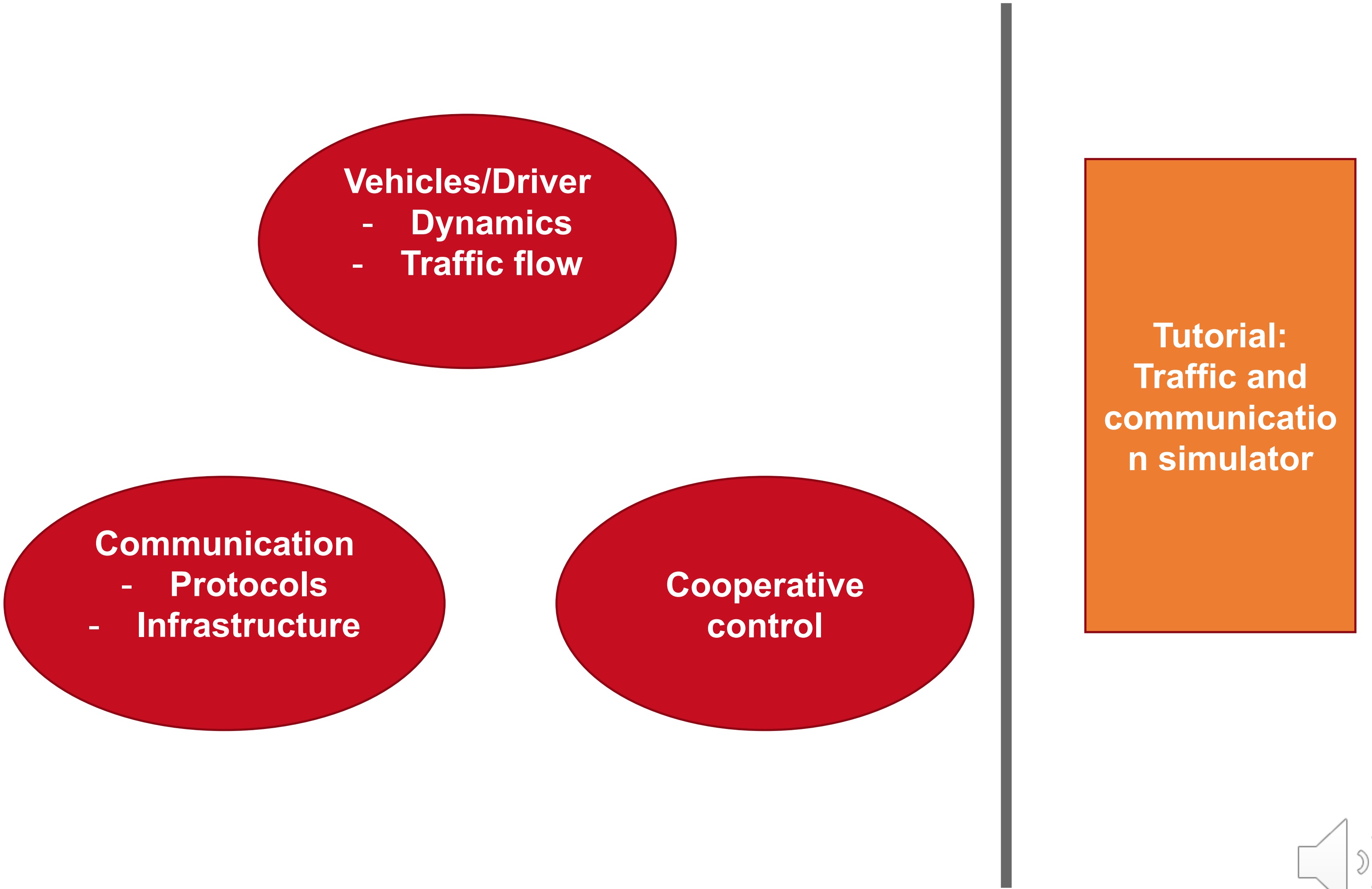
Evaluation

- Evaluation will consist of three parts
  - Oral exam (50%)
  - Exercise on selected topic
    - Presentation (20%)
    - Written report (30%)
  - The written report will not be extensive, it is a means to document what you have investigated
  - Topics will be assigned or negotiated in the middle of semester

Need Help?

- If you have questions, just email me
  - sangyoung.park@tu-berlin.de
  - Appointment by e-mail: sangyoung.park@tu-berlin.de
    - ~~But just knocking on the door also often works (depends on the size of the class)~~
  - Room: H4133 (in the main building)
  - Let’s meet on Zoom

Course Overview (Goal?)



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

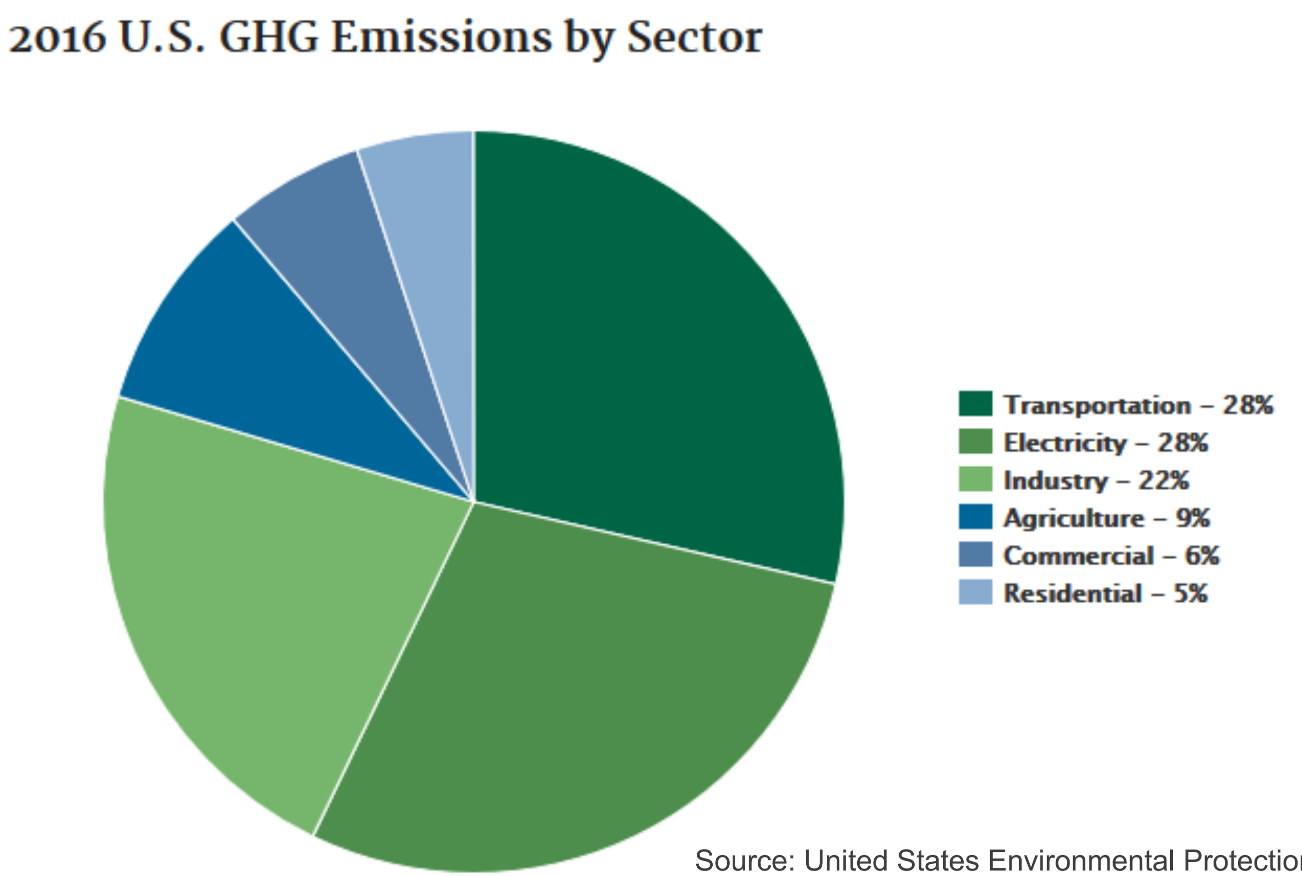
- The full potential of connected, intelligent vehicles are yet to be realized
- Implications in traffic safety
  - Traffic accidents caused 33,808 fatalities and 2.2 million injuries in the USA (2009)
  - Estimated economic loss of 230.6 billion USD
- However, it has been improving
  - Fatalities per 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?

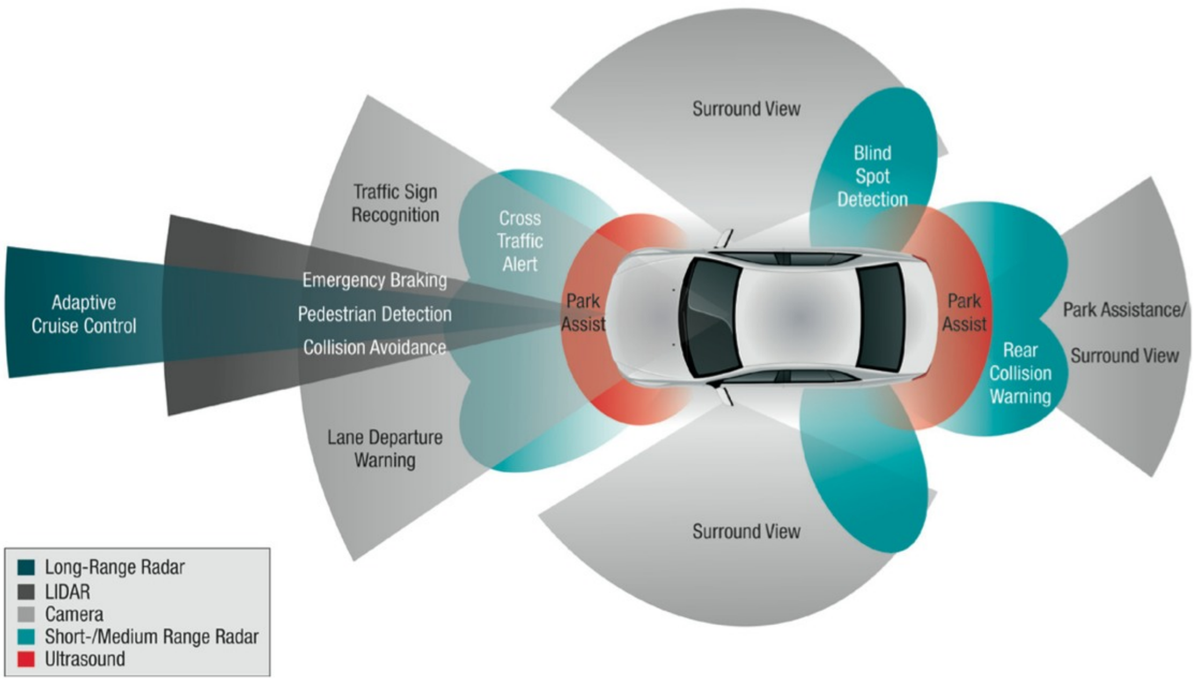
- Vehicular communication systems
  - Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications
- Advanced driver-assistance systems (ADAS)
  - Depend on sensory inputs from a vehicle has limitations in range and line of sight (also expensive)
    - Radar
    - LIDAR: can cost up to 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

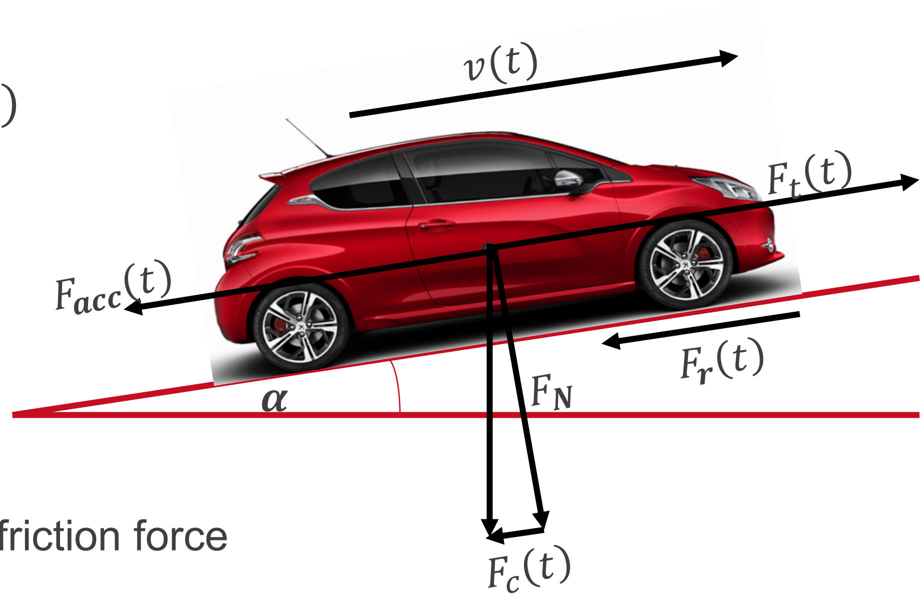
Vehicle Modeling

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

Vehicle Modelinig: Driving resistance equation

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

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

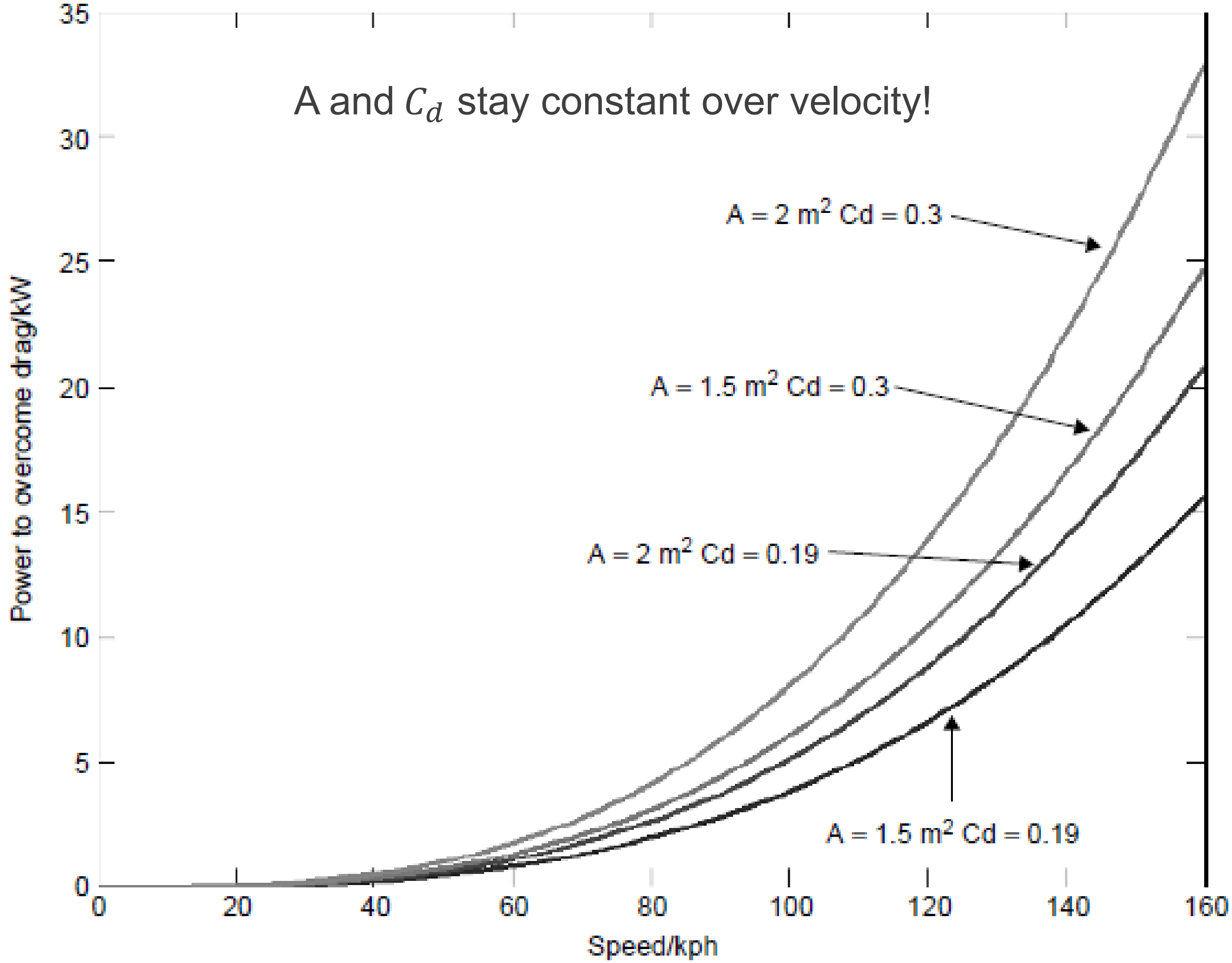


- $F_t(t)$ Traction Force
- $F_{air}(t)$ Aerodynamic drag, aerodynamic friction force
- $F_c(t)$ Climbing Force
- $F_r(t)$ Rolling resistance, rolling friction force
- $F_{acc}(t)$ Acceleration Force
- $P_t(t)$ Traction Power
- $v(t)$ Vehicle Velocity

Attention:

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

Aerodynamic Drag



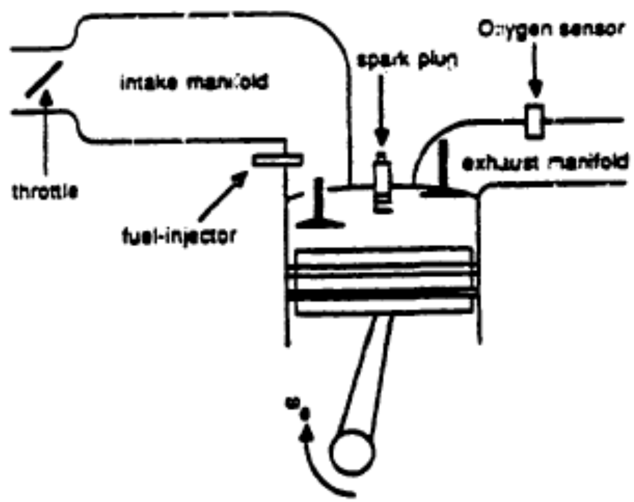
Larminie (2003), Electric Vehcile Technology Explained

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

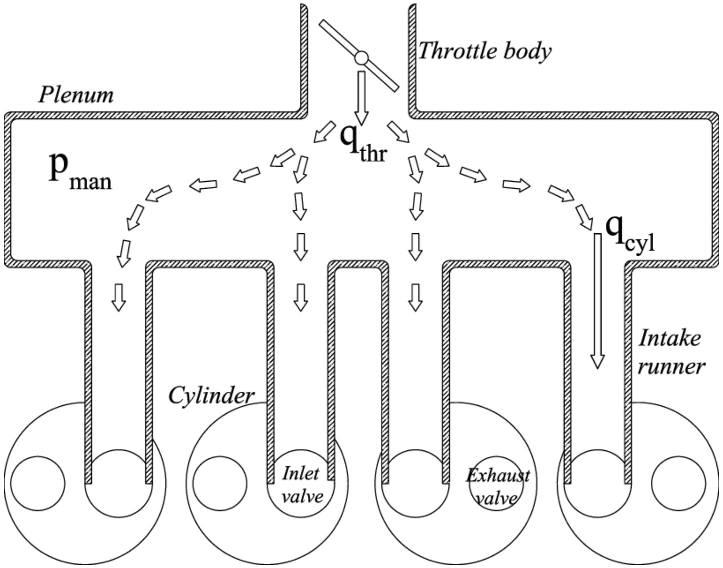
Simplified Models for Longitudinal Control Design

- Further simplified model (four state)

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

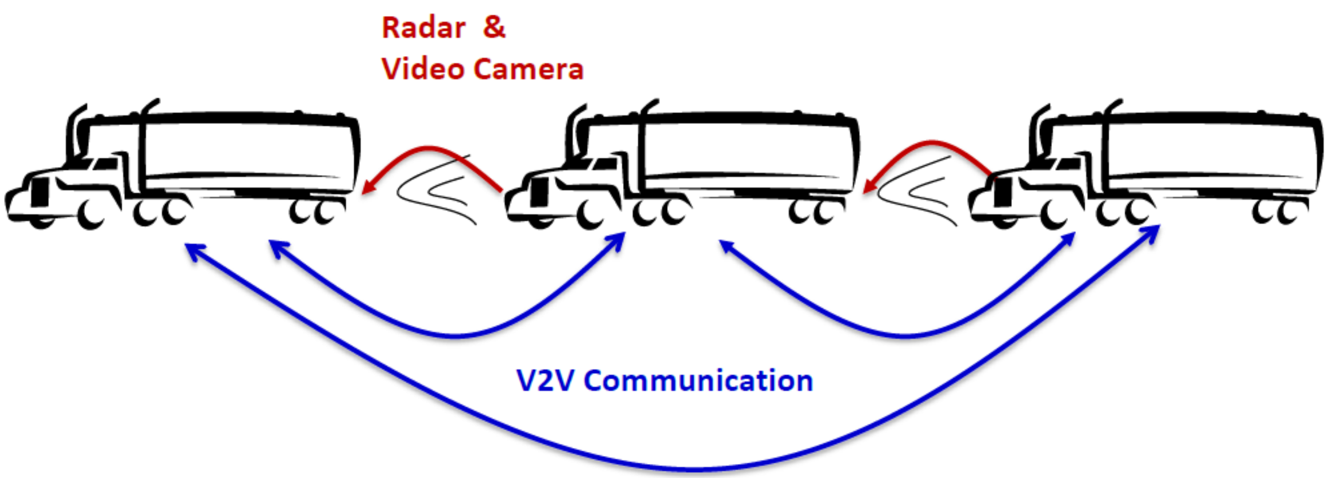
  where $\dot{m}_{ai}$ and $\dot{m}_{ao}$ are the flow rate into the intake manifold, and out from the manifold

- 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

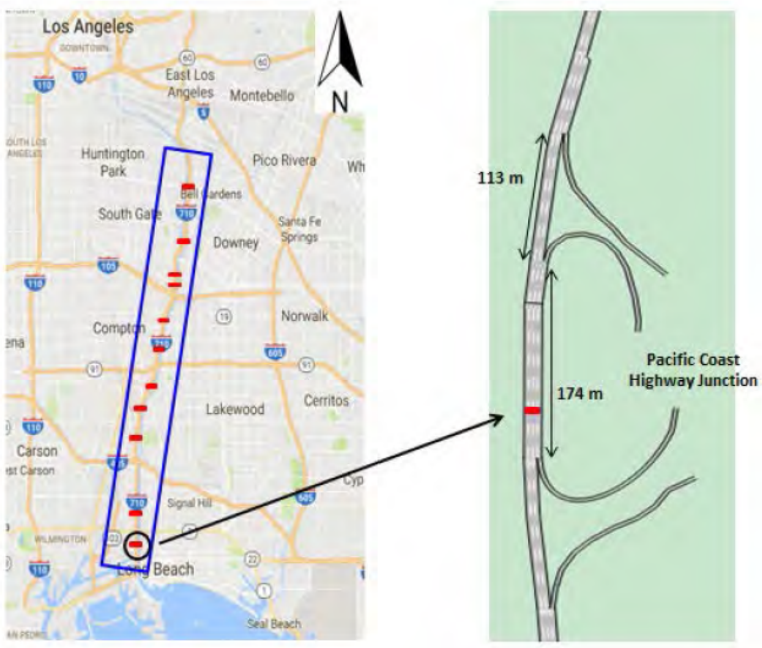
- California PATH program example
  - Truck platooning project
    - Coordinatinig driving of clusters of heavy trucks using automatic control of their speed and separation
    - Wireless vehicle-2-vehicle communication to enable close coordination
    - Loose coupling by cooperative ACC or tighter coupling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



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

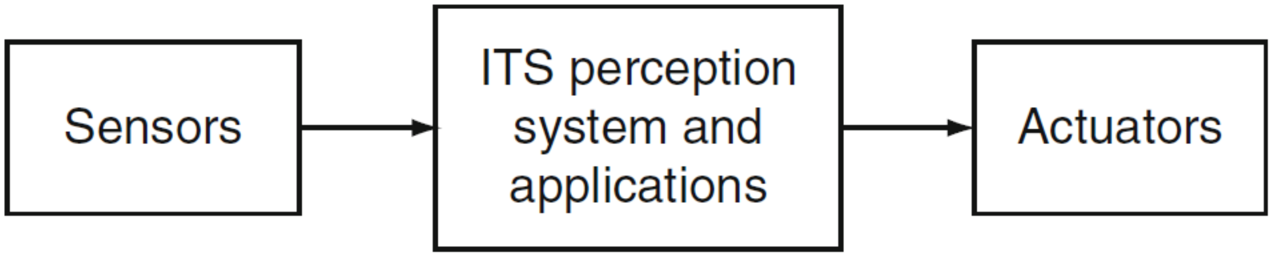
Longitudinal Control System Design

- 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



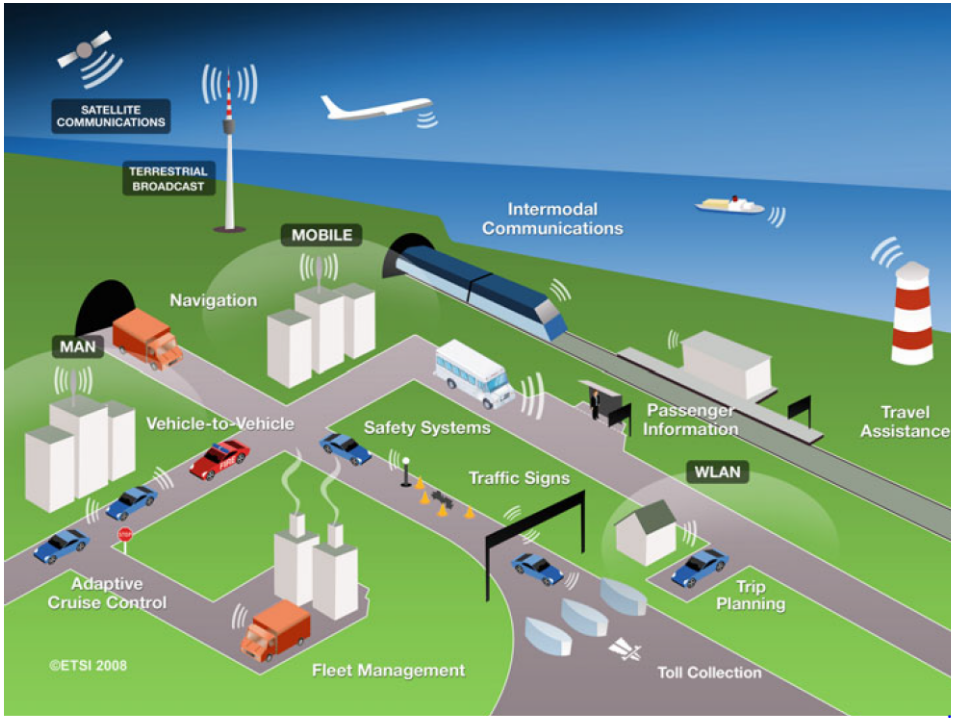
Source :Hand book of Intelligent Vehicles

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



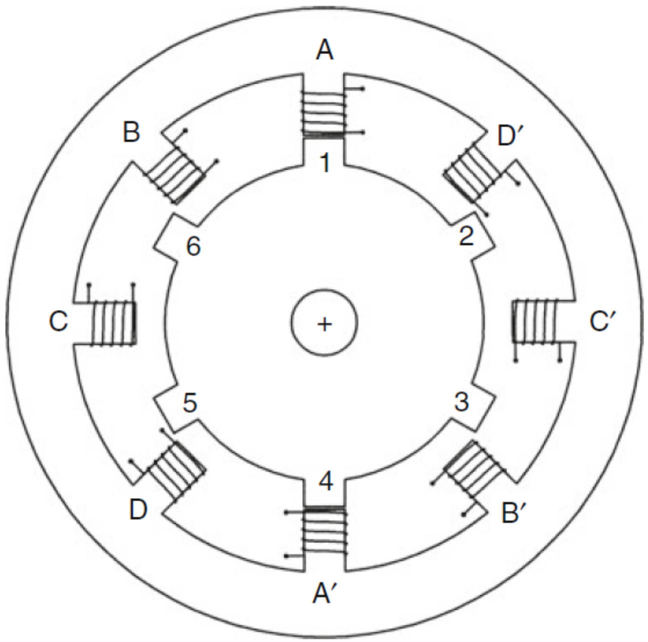
Types of Sensors

- 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

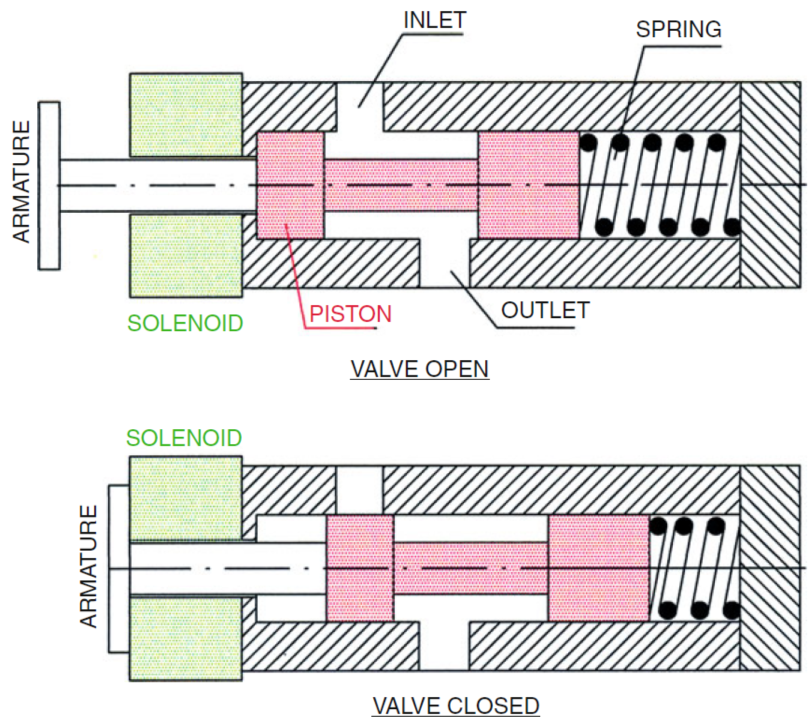
Smart coolant pump by Continental using a DC motor



Stepper motor

Types of Actuators

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



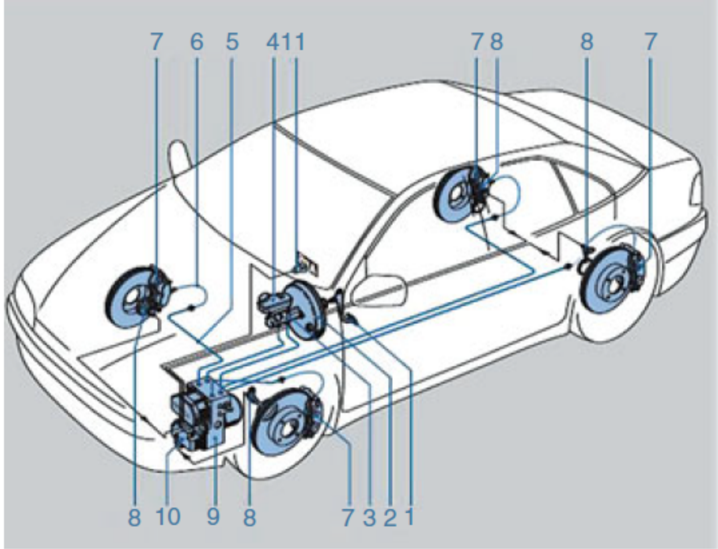
Solenoid valve example

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



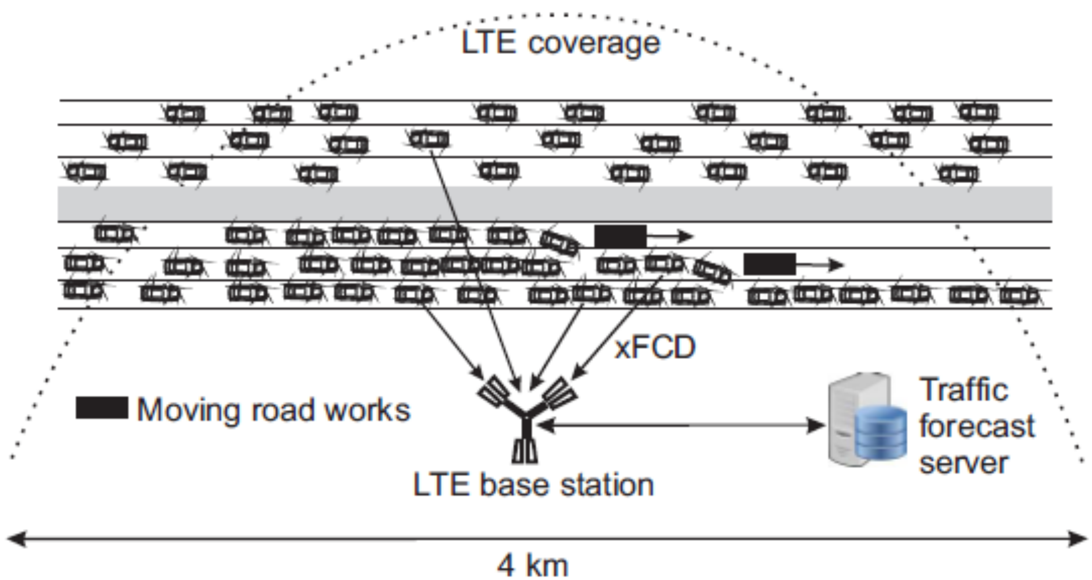
1	Brake pedal
2	Brake servo unit
3	Master cylinder
4	Brake fluid reservoir
5	Brake pipe
6	Brake hose
7	Disc brake with wheel cylinder
8	Wheel speed sensor
9	Hydraulic modulator
10	ABS control unit
11	ABS warning lamp

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?



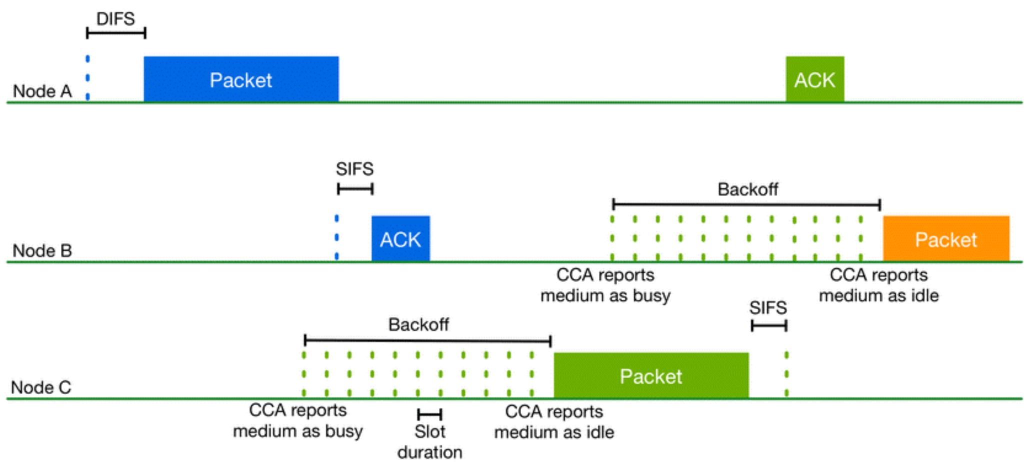
Source: C. Ide, et al., „Interaction between Machine-Type Communcation and H2H LTE Traffic in Vehicular Environments, IEEE VTC19

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

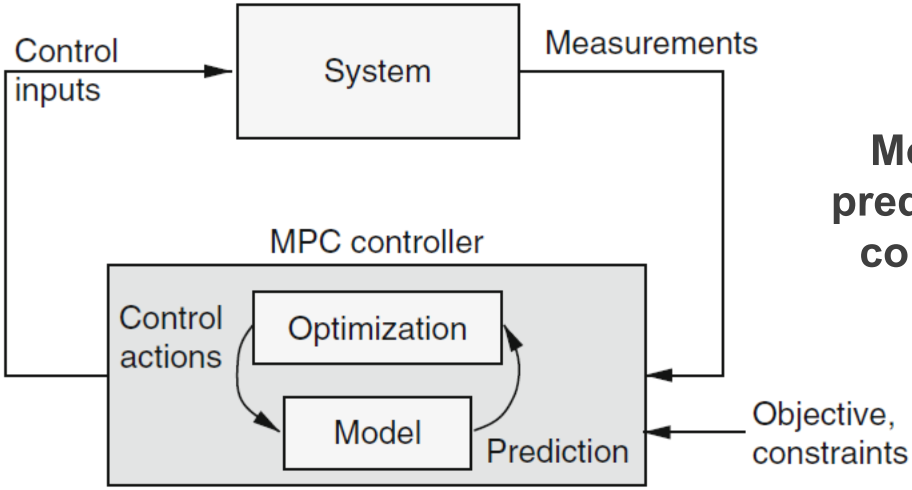
Architectures for Communication Systems

- 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



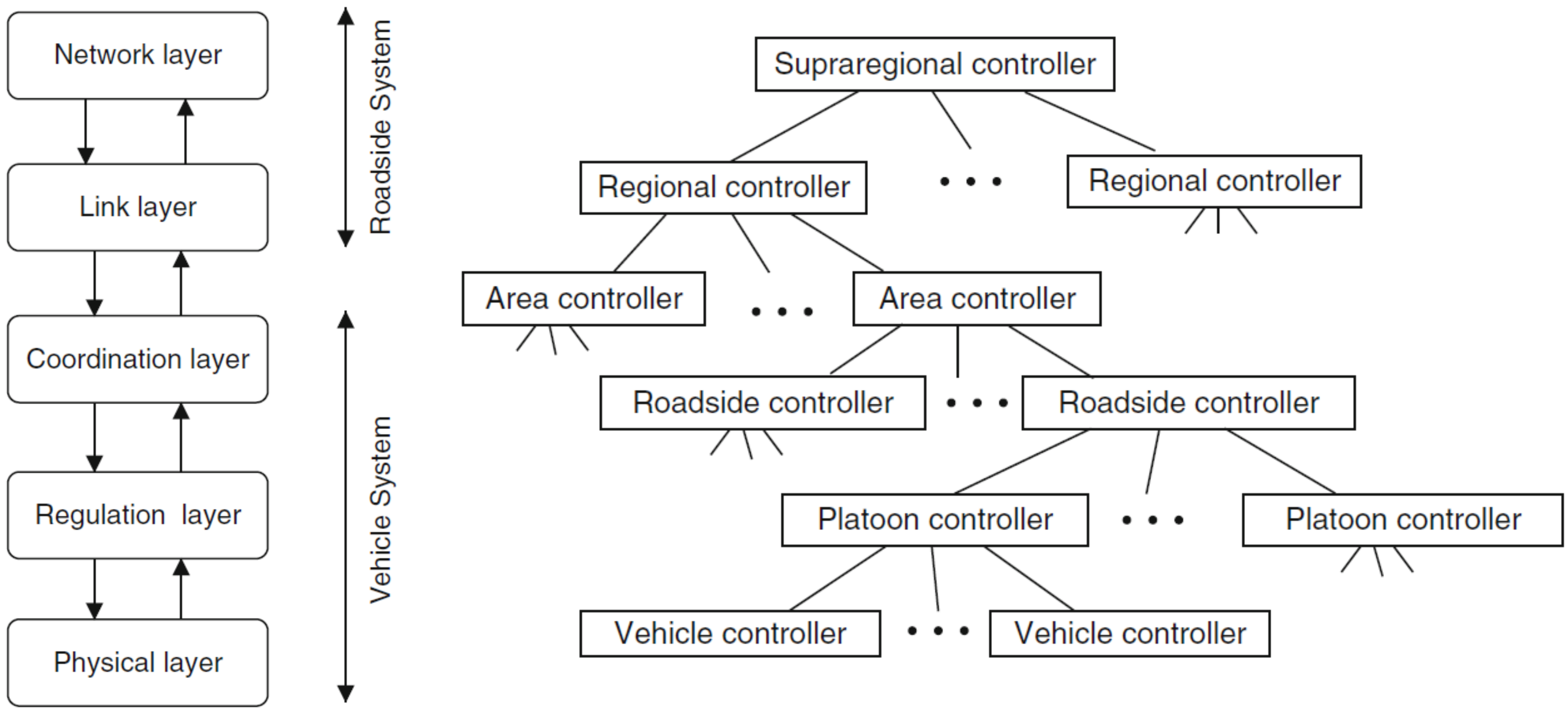
Model predictive control

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

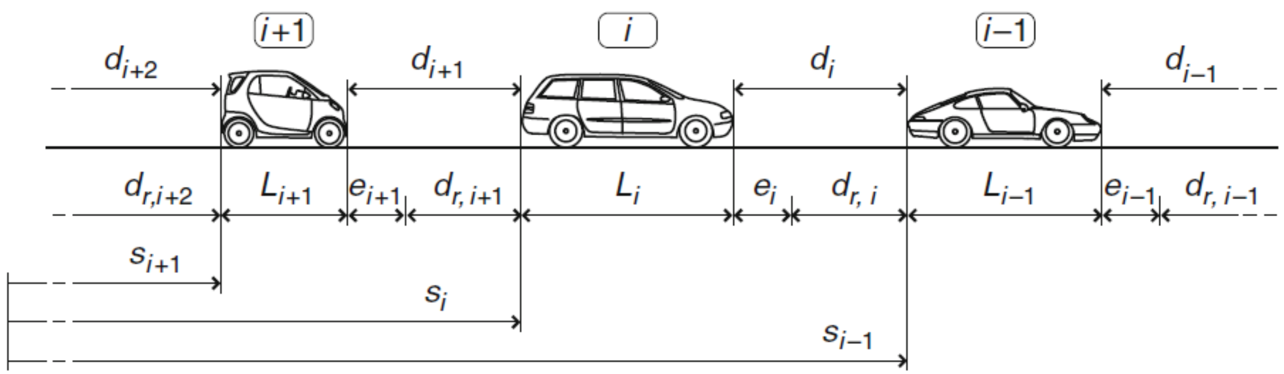
- PATH example



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.

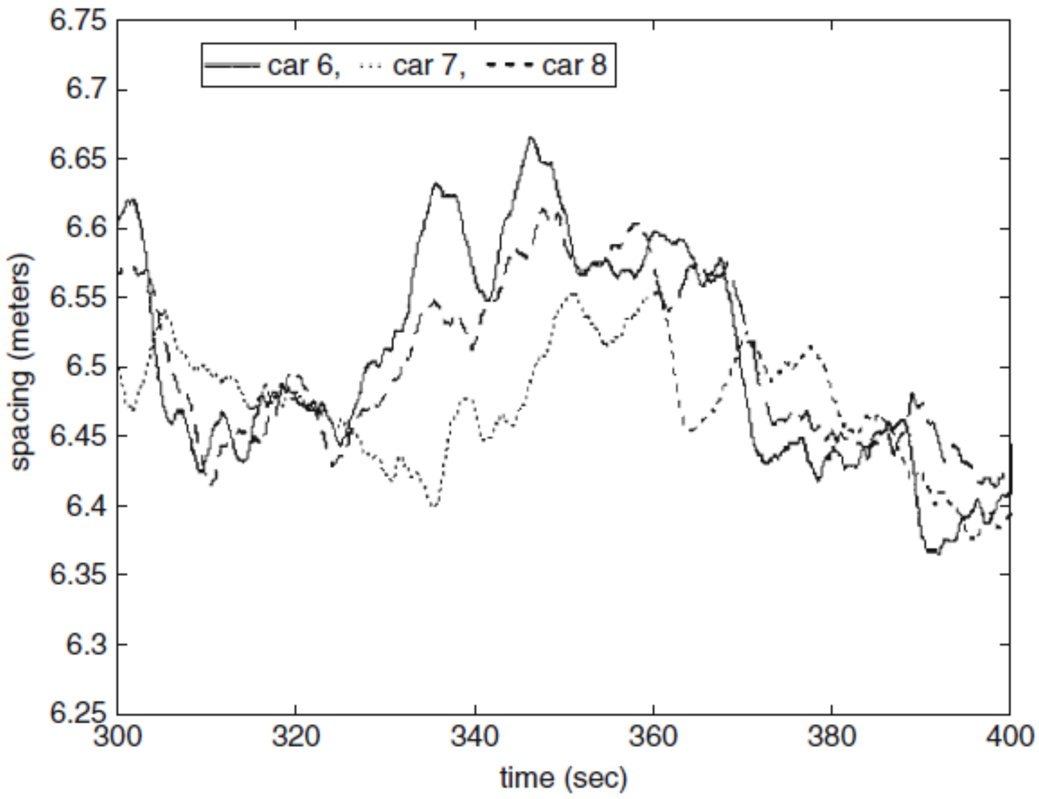


Longitudinal Control System Design

- 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

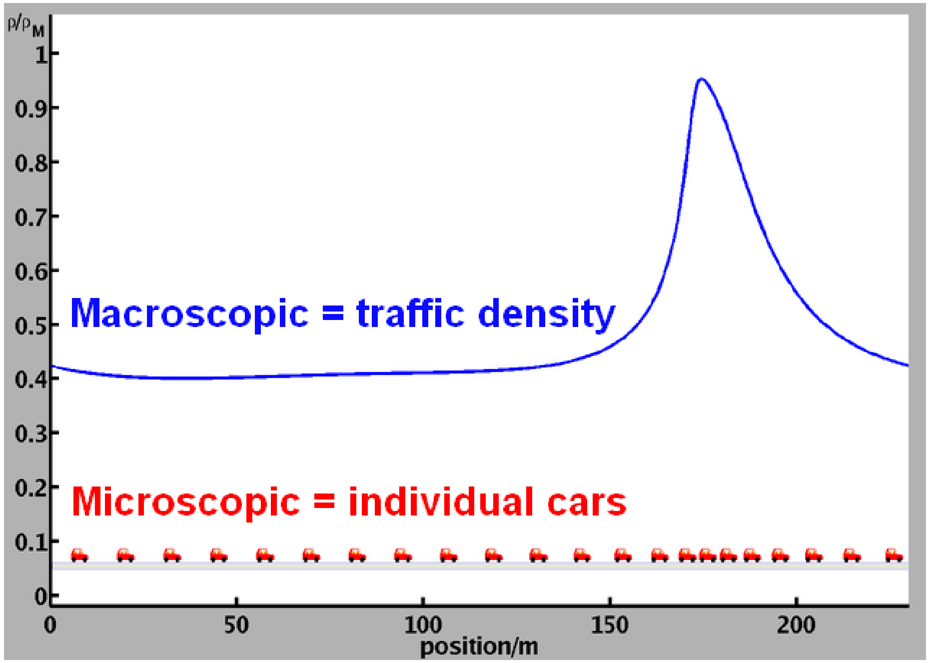
Source: B. Seibold, “A mathematical introduction to traffic flow theory”

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??

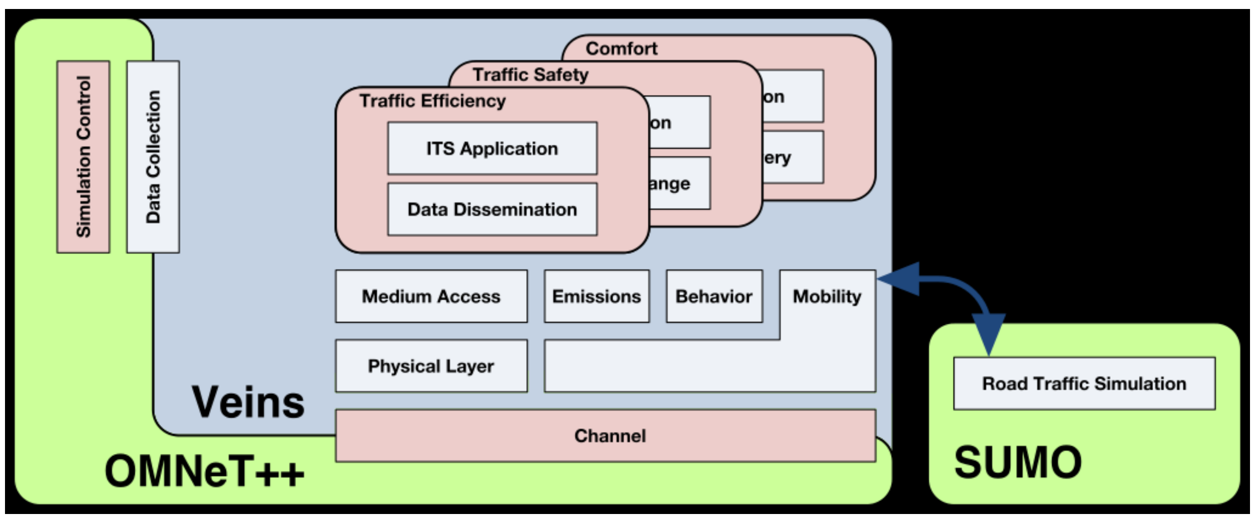
- Our goal of the course would be to investigate such effects

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	-
2	Vehicle dynamics and modeling	Introduction to simulation setup
3	Microscopic Traffic Modeling	C++ basics
4	Sensing and actuation in intelligent vehicles	Introduction to SUMO
5	Vehicular communication protocols (1)	OMNet++ tutorial: tic toc example
6	Vehicular communication protocols (2)	Veins simulator: Vehicle-2-Infrastructure example
7	Longitudinal control of vehicles (1)	V2V platooning example
8	Longitudinal control of vehicles (2)	V2V platooning example

Course Schedule

Weeks	Lecture	Tutorial
9	Issues with vehicle controller implementation	Traffic light control
10	Fuel-Economy and EV energy consumption	Time dedicated to term project
11	Final project	Time dedicated to term project
12	Final exam	Time dedicated to term project

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