HOCHSCHULE
HANNOVER
UNIVERSITY OF
APPLIED SCIENCES
AND ARTS
–
*Fakultät IV
Wirtschaft und
Informatik*

Performance Evaluation: Simulative Analysis

Lecture 11: Fahrzeugvernetzung – V2X

Hugues Tchouankem, 14.12.2022

Lecture 11
Previous Lecture

- ► Evaluation Objectives
- ► Evaluation Methodologies
- ► V2V Performance Evaluation in urban Environments
- ► Impact of Vegetation on V2V Performance
- ► Co-Channel Interference on V2V Performance
- ► Demonstrations

Lecture 11
Outline

- ► Vehicular Mobility
- ► Network Simulation
- ► Road Traffic Simulation
- ► Bidirectional Vehicular Simulation
- ► Scenarios Modeling
- ► Some Simulation Results

Lecture 11
Motivation

- ► In previous lecture it has been show that the **efficiency of V2V** depends mainly on the **inevitable interference** generated
  - ► Due to the **broadcast** nature of the vehicular network

- ► To accurately investigate the **scalability of V2X networks** in a realistic environment
  - ► Simulative evaluation allowing to **emulate large-scale scenarios** which involves a **high number of vehicles** is indispensable
  - ► Level of **realism is increased** as this reflects real traffic behavior

- ► Simulation of V2X networks is **special** as **vehicle’s motion** has to be reproduced in a **realistic way**
  - ► **Car following**, **lane change**, **intersection modeling** and other factors have to be taken into account

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Vehicular Mobility Modeling

- V2X networks are **distributed** und **self-organizing** communication networks built up by moving vehicles
  - Very high mobility of nodes and **limited degrees of freedom** in nodes movement patterns
- An accurate performance evaluation of V2X requires a mobility model which reflects, as close as possible, **the real behavior of vehicular traffic**

- Both following descriptions have to be jointly considered in modeling vehicular movements
  - **Macro-mobility**
    - Road topology, street characterization, car class dependent constraints, traffic signs
  - **Micro-mobility**
    - Vehicle-to-vehicle interactions, vehicle-to-road interactions, acceleration and deceleration, overtaking

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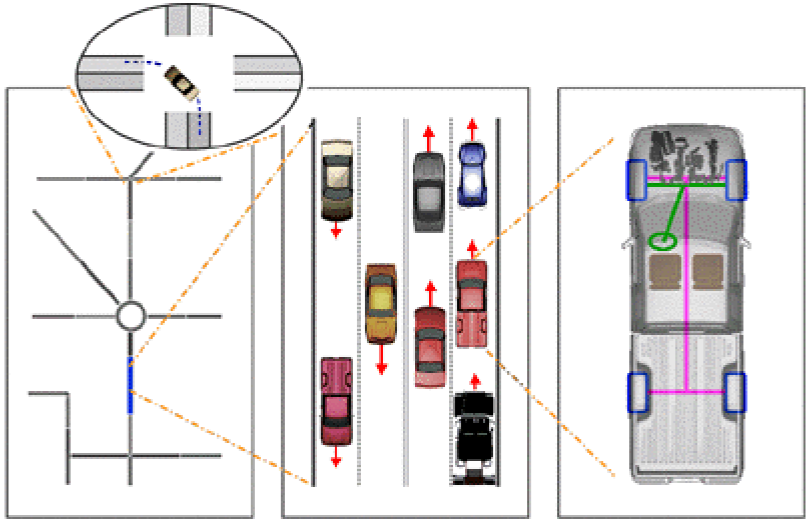
Vehicular Mobility Models

- **Macroscopic**:
  - Used for large scale simulation focusing not on individual vehicles but on a entire flows of traffic
  - e.g. congestion estimation on an area

- **Microscopic**:
  - Model the behavior of each vehicle individually



- **Mesoscopic**:
  - Serve as an intersection between the Micro- and the Macro- levels of vehicular and traffic description

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Mobility Models – Random Node Movement

- Unconstrained node movement in a **completely random manner**
  - Every node picks up **a random destination** and a **random velocity** at certain points called waypoints
- Vehicle's movement is restricted by **road** and **environment** in V2X networks
- Traditional random mobility model and way-point mobility model
  - Cannot **reflect vehicular mobility** in a realistic way

- These **aspects of vehicular traffic** are ignored:
  - Cars acceleration and deceleration in presence of nearby vehicles
  - Queuing at roads intersections
  - Traffic bursts caused by traffic lights
  - Traffic congestion or traffic jams

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Mobility Models – Real-World Mobility Traces

- ► Modeling of node mobility on the basis of sets of **pre-recorded real-world mobility traces**
- ► Continuously log GPS information while the vehicles being driven
- ► Trace-based model results in most realistic vehicle movement in network simulation
- ► (-) Use is limited as only a **few traces** are available and do not reflect **all of the vehicles** on the road
- ► (-) Changing just the **vehicle density** and keeping all other parameters **unchanged** is infeasible in large scenarios
- ► (-) Adapt the vehicle's behavior according to communication requirement is not possible
  - ► E.g. trigger a vehicle re-routing in case of increasing traffic congestion

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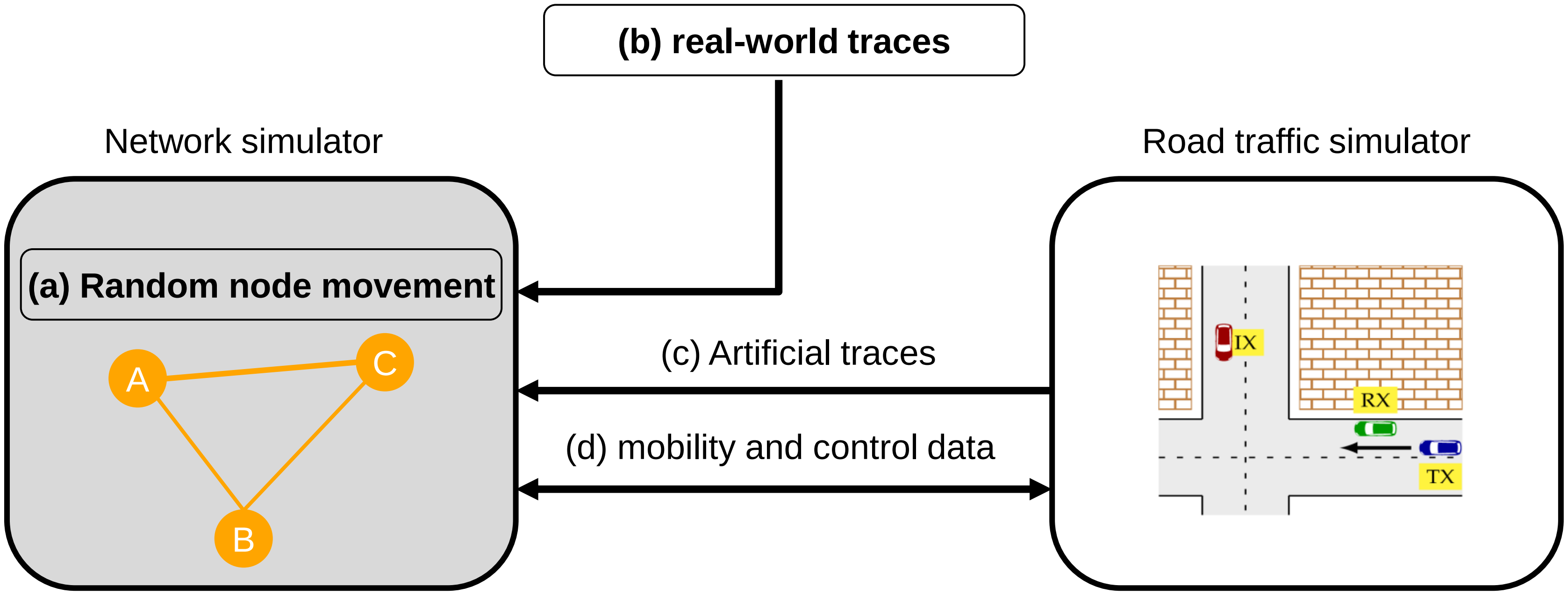
Mobility Modeling Technique

- ► (a) Create a random node movement directly in the network simulation
- ► (b) Use re-recorded real-world mobility traces as input for the network simulation
- ► (c) Exploit artificial mobility traces pre-generated by road traffic simulation
- ► (d) Road traffic simulation shares data like position and speed of the simulated vehicles so that the network simulator could influence the node mobility on the fly



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Network Simulation

- ► Field operational tests (FOTs) or small scale testing fail in achieving a large-scale deployment necessary to study the **scalability** of **network protocols** and **services**
- ► Network simulation becomes the **primary approach** of network testing
  - ► Provide time-saving, low cost and efficiency

- ► Objectives of simulation in communication
  - ► Determination of the **system-wide impact** of making local to the network
  - ► Improved **system performance**: packet delivery ratio, delays, throughput
  - ► Insurance that **performance objectives** are met before
  - ► Identification of **bottlenecks** before **implementation**
  - ► Reduced system **development time**

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Network Simulation

- The major task in building a simulation model of a communications network is that of converting a system description into a computer program
- An analyst may use either a general-purpose **programming language** (e.g. C or JAVA) or **simulation software** for this purpose
  - Simulation software provides
    - More **natural framework** for system modeling
    - Most of the **features needed** in programming a simulation model

      → Significant decrease in **programming time**

- A model is developed in a simulation language by writing a program using the language's modeling constructs including
  - Messages, attributes (message type or destination), resources (nodes or links) and queues (buffers)

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Network Simulation – Network Simulator 3 (ns-3)

- ns-3 is a tool used for simulating local and wide area networks
  - Built as a **library** which may be statically or dynamically linked to a C++ main program that defines the simulation topology and starts the simulator
- ns-3 is a **discrete-event** network simulator
  - Keeps track of **a number of events** that are scheduled to execute at a specified simulation time. The job of the simulator is to execute the events in **sequential time order**
- ns-3 follows an **object-oriented approach**
  - Objects can be declared and instantiated as usual per C++ rules
  - Include classic object-oriented design with **separation** of **interface** and **implementation**
- (-) No **integrated development environment** (IDE) available

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Network Simulation – Network Simulator 3 (ns-3)

- ns-3 provides a rich **set of libraries** for modeling mobility, communication channel, and many other network components
- ns-3 is designed for **simulating Wi-Fi networks**
  - Some enhancements still required to make the simulations more realistic for vehicular networks
    - Physical (PHY) layer
    - Medium access control (MAC) layers
    - Support DSRC and ITS-G5

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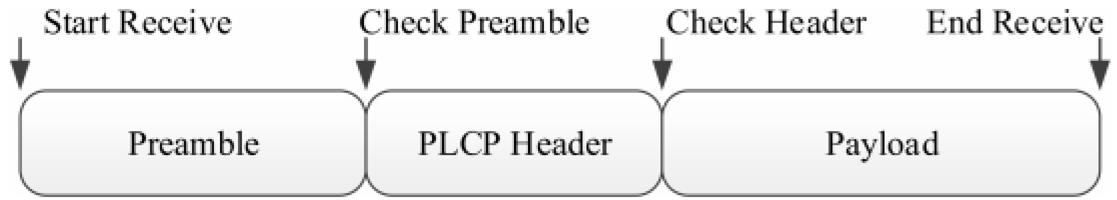
Network Simulation – Enhancements on PHY Layer ns-3

- **Preamble detection and PLCP header decoding**:
  - For each incoming packet with signal strength over a certain threshold, receiver schedules a *preamble check* event after the preamble duration
  - PLCP header decoding event checks if receiver has correctly decoded the PLCP header, which contains information about the frame length and bit rate



- **Capture Effect**
  - Allows a wireless receiver to lock to a **stronger signal** in the presence of other signals (interferences) regardless of its arrival time
  - Increase the **probability of packet reception** under high channel load

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Network Simulation – JiST/SWANS

- **Java in simulation time (JiST)** is a discrete event simulation engine that runs over a **Java virtual machine**
- Scalable Wireless Ad hoc Network Simulator (SWANS)
  - Built atop the JiST platform
  - Organized as independent software components that can be composed to form **complete wireless network** or **sensor network** configurations
  - Provide a simulation **debugger** and interactive simulators
  - Enable **parallel** and **distributed** execution
- Features and applications supported
  - Networking
  - Radio transmission and signal propagation and fading models
  - Routing and media access protocols
  - Reception and noise models

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Network Simulation – OMNeT++ (1/2)

- Extensible, modular, **component-based simulation** library and **framework** primarily for building network simulator and is written in C++
  - Its primary application area was not only the **simulation of communication** networks but can be also utilized in other areas such as **queuing networks**, **communication systems**, and **hardware emulation**
  - Not designed as a **network simulator** but to be as general as possible to serve as the basis for the development of **future model frameworks** as independent projects
- Provides a comfortable **graphical user interface** that can be used to trace and debug simulations
  - Acquisition of results statistic
  - Data collection
  - Graphical representation of simulation results

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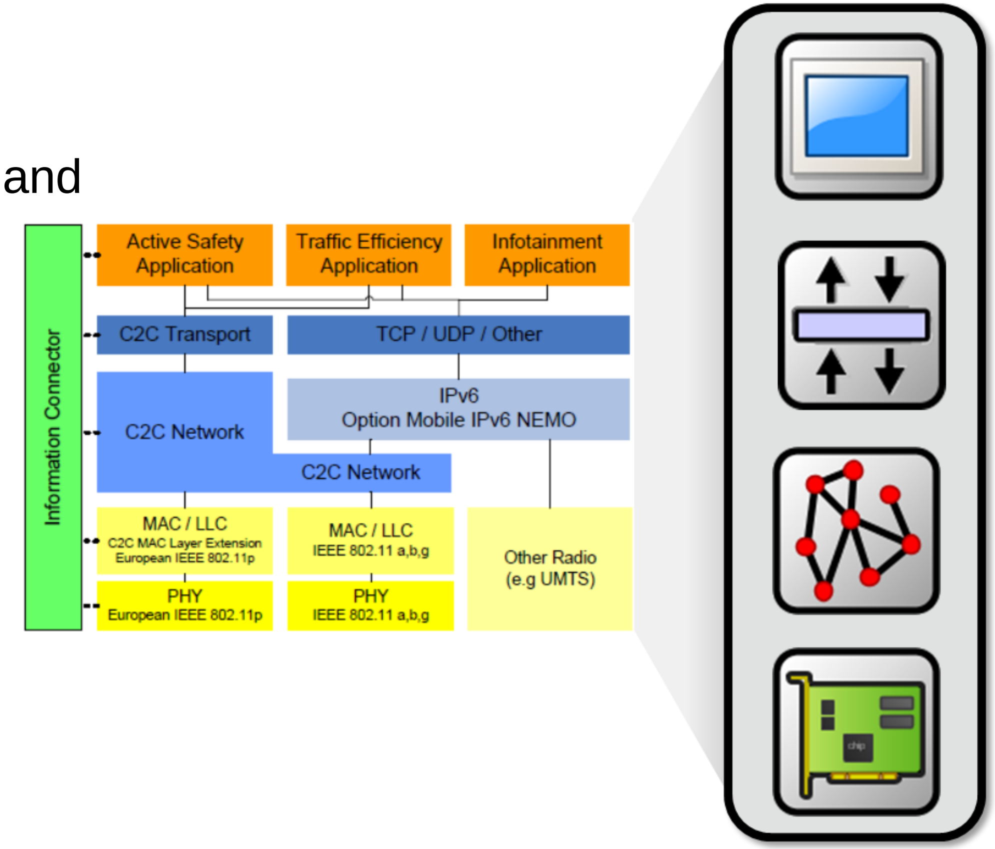
Network Simulation – OMNeT++ (2/2)

- Some model frameworks conceived especially for computer networks:
  - INETMANET, MiXiM, OverSim and Castalia
- **INETMANET** supports **mobile ad-hoc networks** and is an extension of the INET framework which contains models for several **Internet protocols**:
  - TCP, UDP IPv4, IPv6, Ethernet, IEEE 802.11, routing protocols and many other protocols
- V2X communication models (protocol stack)
  - Application layer
  - Physical layer model
  - Wireless protocols
  - Channel model



Vehicle

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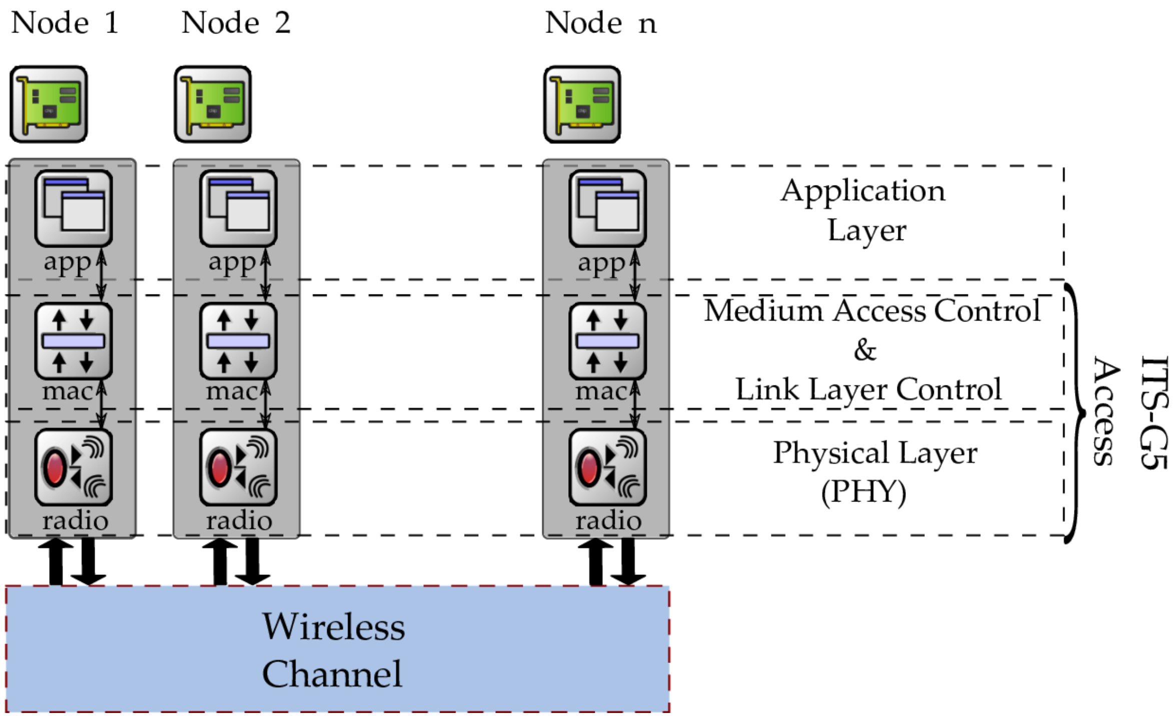
Network Simulation – Extension for ITS-G5

- ► Extension of **INETMANET** framework for OMNeT by adding a model of the **ITS protocol stack**, particularly focusing on ITS-G5 and its medium access control
- ► Each simulation module corresponds to the ITS-station reference architecture



- ► **CA basic service** and **DEN basic service** modules are implemented within the application layer
- ► **MAC** and **PHY layer** modules belong to the ITS-G5 access layer

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Road Traffic Simulation - SUMO

- Simulation Urban Mobility (SUMO) is a C++-based microscopic, inter- and multimodal, and time-discrete **traffic flow simulation** platform designed to handle large road networks
- Provide graphical user interface and several utility tools
  - **Road network importer** capable of supporting several source formats
  - **Traffic demand generation** and routing utilities which use a high variety of input sources such as origin-destination matrices and traffic statistics
  - **Traffic Control Interface** (TRaCI) to interlink road traffic and network simulators together
    - TRaCI adapts and controls the simulation run online

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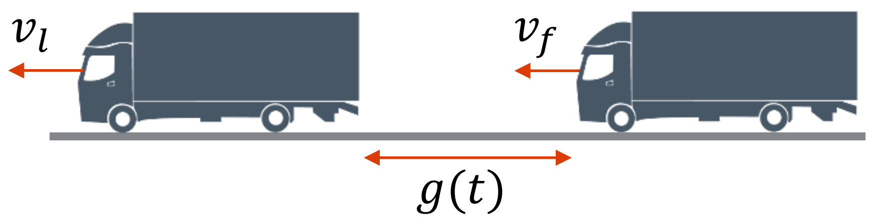
SUMO Car Following Models

► Microscopic traffic simulation

- ► Each vehicle and its dynamics are **modeled individually**
- ► Each vehicle has an **own route** and **move individually**
- ► Vehicle interaction based on **car following** and **lane change** models



$$v_{safe} = v_l(t) + \frac{g(t) - v_l(t)t_r}{\frac{v_l(t) + v_f(t)}{2b} + t_r}$$

$$v_{des} = \min[v_{max}, v + at, v_{safe}]$$

► Car following and lane-changing models

- ► Describe how one vehicle follows another vehicle in an uninterrupted flow
- ► Maintain a **distance headway** and **gap**
- ► Speed of the vehicle in relation to the vehicle ahead
- ► **Adapt** of the **deceleration behavior** of the leading vehicle

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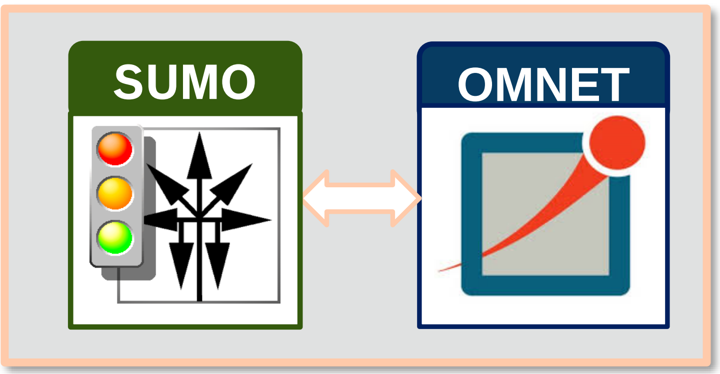
Coupled Simulation Platform

- ► **Close-loop** between road traffic simulation and network simulation
- ► Two-inter-dependent **processes** running concurrently
- ► Both simulators share data like **vehicle position** and **control information**
  - ► Properties of the radio signals **are local** to the network simulator
  - ► State of the **vehicle controller** and **car following data** in the road traffic simulator
- ► Simulation time could be managed by the network simulation side



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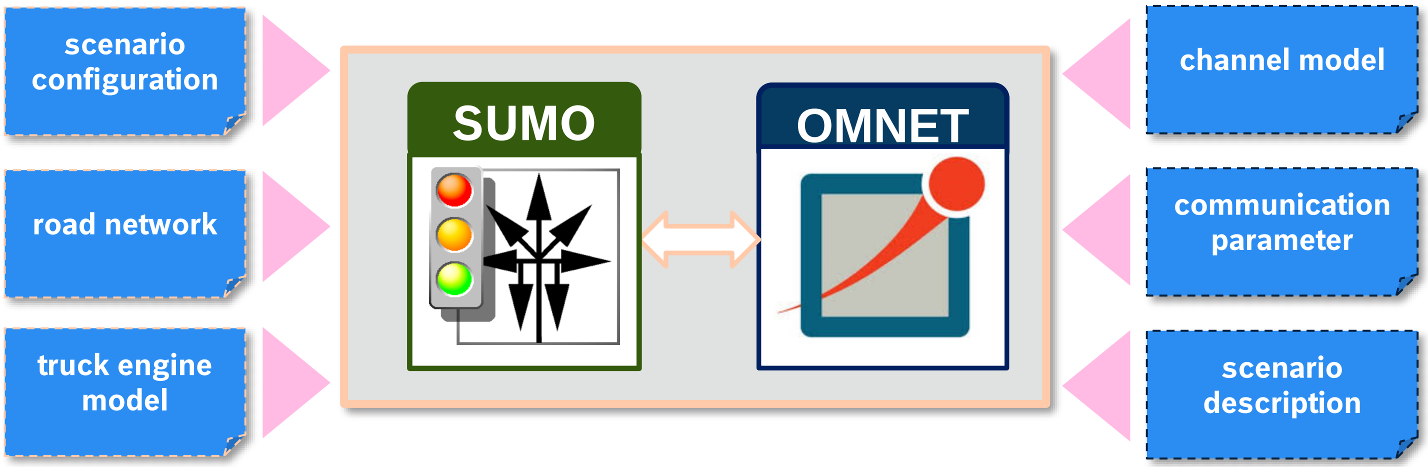
Bidirectional Coupled Simulation

- Simulation of V2X networks consists of **two main phases**:
  - The road traffic simulator performs **traffic computations** and sends vehicle movement **updates** to the network simulation
  - **Network simulator** sends parameter changes to the road traffic simulation altering **driver behavior** and influences vehicle's routing decision
- **Real** vehicle dynamics (e.g. truck engine model) and road network **data**
- **Validated** communication and propagation channel **models**



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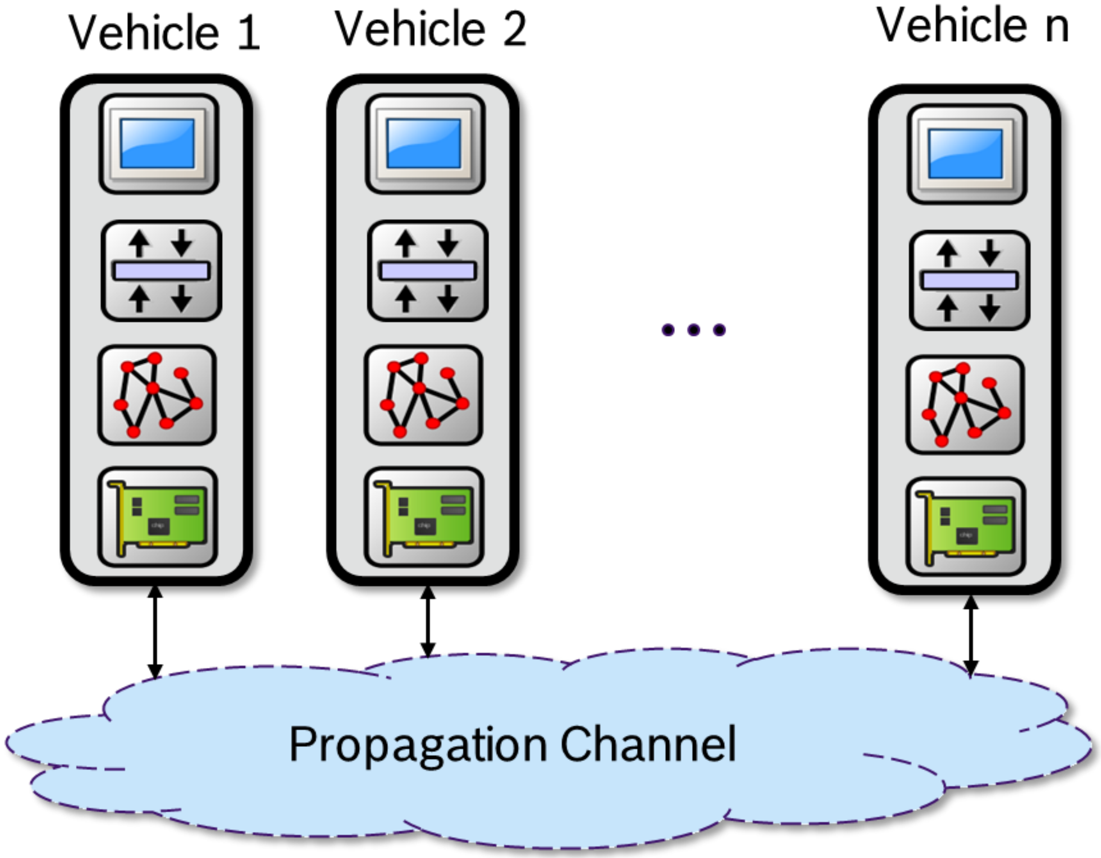
Propagation Channel

- ► Integration of the propagation channel model in the **simulation platform**

- ► Specific considerations
  - ► Antenna position and type
  - ► Vehicle type (height, length)
  - ► Propagation environments (rural, highway, urban)

- ► Radio propagation characteristics
  - ► Small-scale fading
  - ► Large-scale fading



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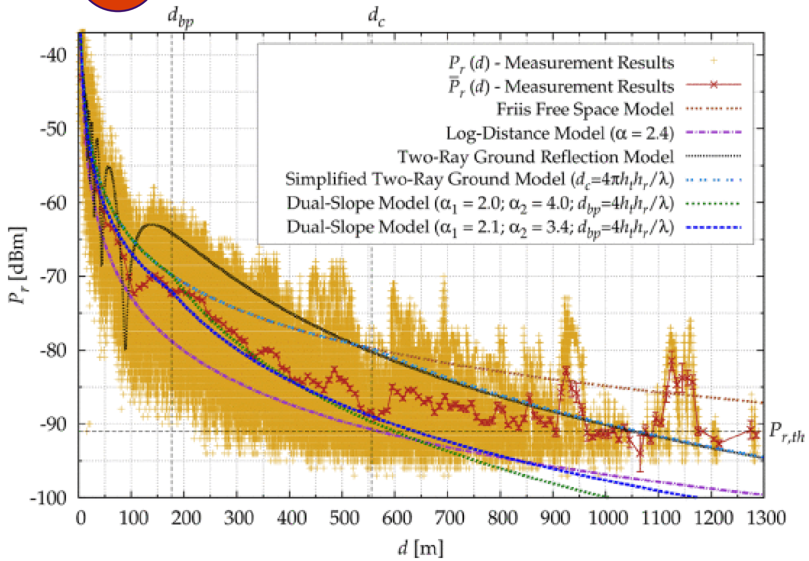
Propagation Channel Modeling

1 Measurements

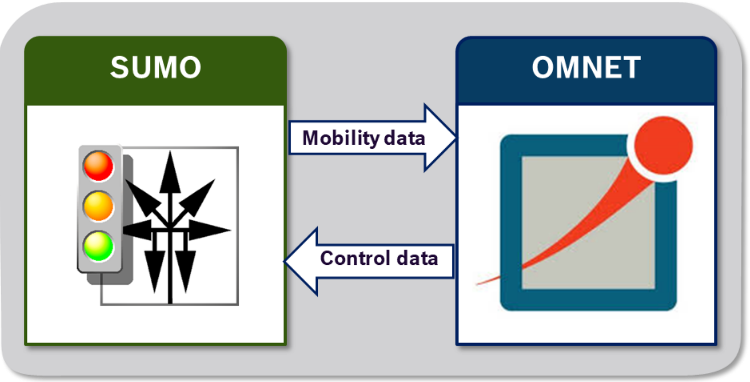
2 Linear Regression



$$\mathrm{PL}(d) = \begin{cases} 10\log\left(\dfrac{16\pi^2 d^2}{G_t G_r \lambda^2}\right), & d < d_c \\ 10\log\left(\dfrac{d^4}{G_t G_r h_t^2 h_r^2}\right), & d \geq d_c \end{cases}$$

3 Modell

4 Simulation



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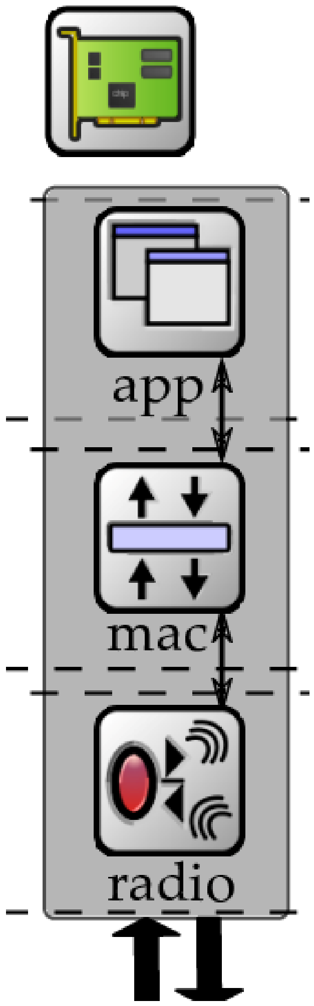
Physical Layer Modeling

- PHY layer modeling is done at **packet domain**
  - Statement can only be derived if a packet is successfully received but **not which bits** were corrupted in case of erroneous packet reception
  - Reduce the **demanding computational complexity** introduced by a physical layer simulation at bit level
- Radio module at the PHY layer is responsible for the **sending** and **receiving** of packets or frames
- Before the sending procedure, the node shall be in **transmission state** and **no other frames** should be currently being received at this time
- Packets in OMNeT are encapsulated into a so-called **air frame** which contains the physical properties of the radio transmission



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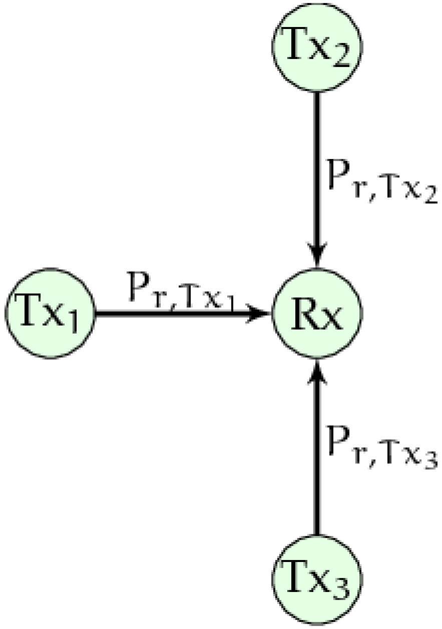
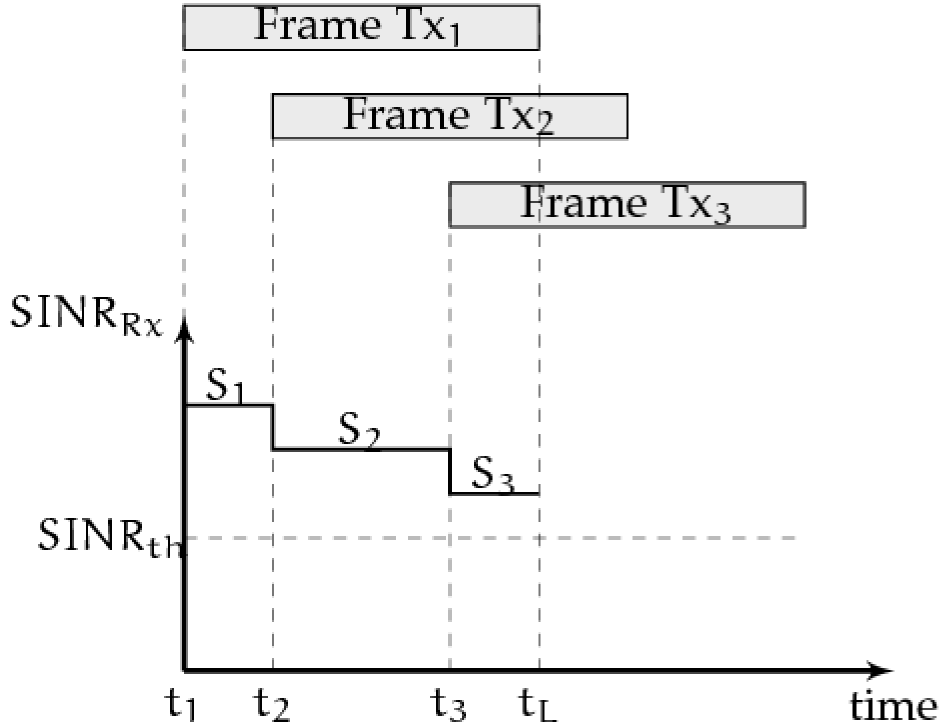
PHY Modeling – Packet Reception Procedure



- When receiving an air frame, a detailed representation of **co-channel interference** and resulting **frame collisions** are applied
- A frame can be **successfully** decoded if and only if the SINR during the complete frame reception is **greater or equal** a given **threshold** $SINR_{th}$

$$\text{for all } S_i, \quad S_i \geqslant SINR_{th}$$

$$SINR_{RX} = \begin{cases} S_1 = \frac{P_{r,Tx_1}}{N} & \text{for } t_1 \leqslant t < t_2 \\ S_2 = \frac{P_{r,Tx_1}}{N + P_{r,Tx_2}} & \text{for } t_2 \leqslant t < t_3\,, \\ S_3 = \frac{P_{r,Tx_1}}{N + P_{r,Tx_2} + P_{r,Tx_3}} & \text{for } t_3 \leqslant t < t_L \end{cases}$$



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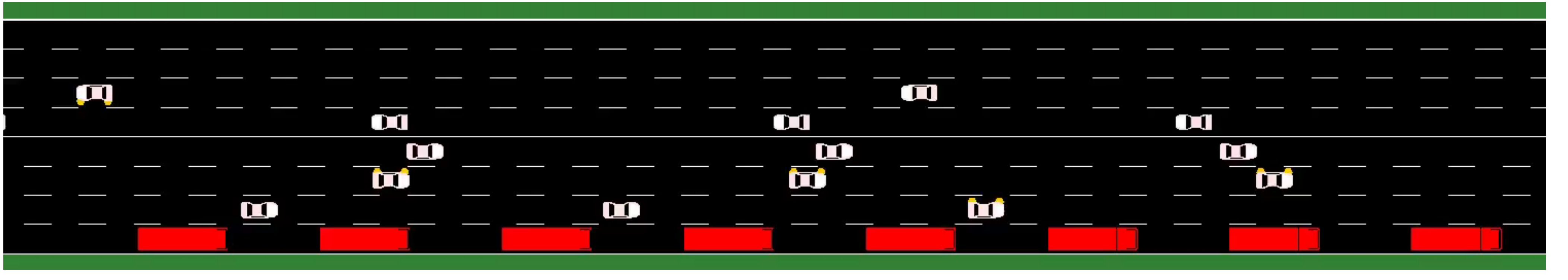
Scenario Modeling – Single Street Freeway

- Scenario used may have a **strong influence** on the resulting **performance** of the application being studied
  - A new protocol for information dissemination in emergency situations will be unlikely to represent the **most critical cases** if the protocol is tested in a **sparse setup** with only few number of **vehicles in communication range**
- Simplest scenario as a single street or freeway
  - Vehicles can drive in an both directions on one or multiple lanes
  - Realistic car following models need to be applied
  - Use to investigate **platooning use case**



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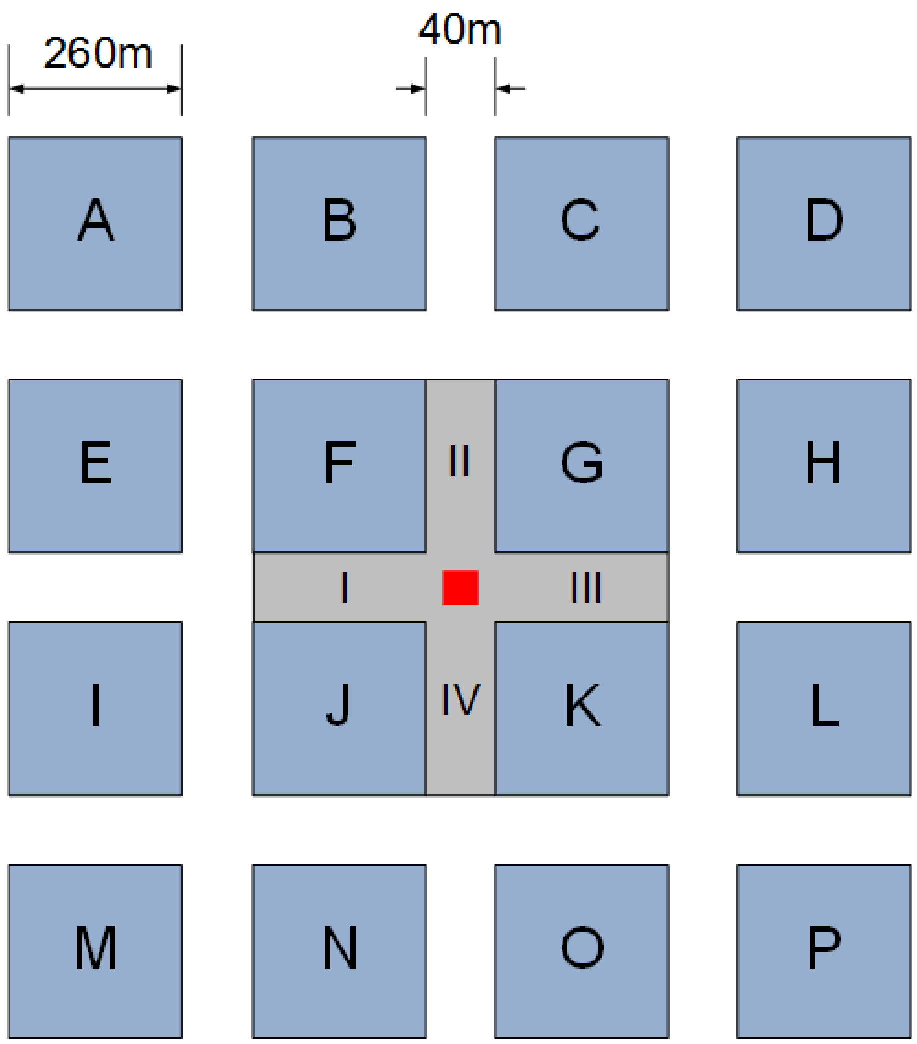
Scenario Modeling – Manhattan Grid

- Provide a **rough approximation** of an urban road network
- Simulation area is represented by a **map** containing **vertical** and **horizontal roads** made up of two lanes
- **Traffic lights** might completely change the behavior of vehicles and the communication network topology
- Incorporate the **effect of building** shadowing typical for urban environments
- Used to simulate use case such as **intersection crossing assistant** as well as **vehicle re-routing** applications



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Scenario Modeling – Realistic Maps for urban Scenarios

► Use real map information to generate the road network

► Street layout, buildings, traffic rules are more realistic

OpenStreetMap (OSM)

SUMO

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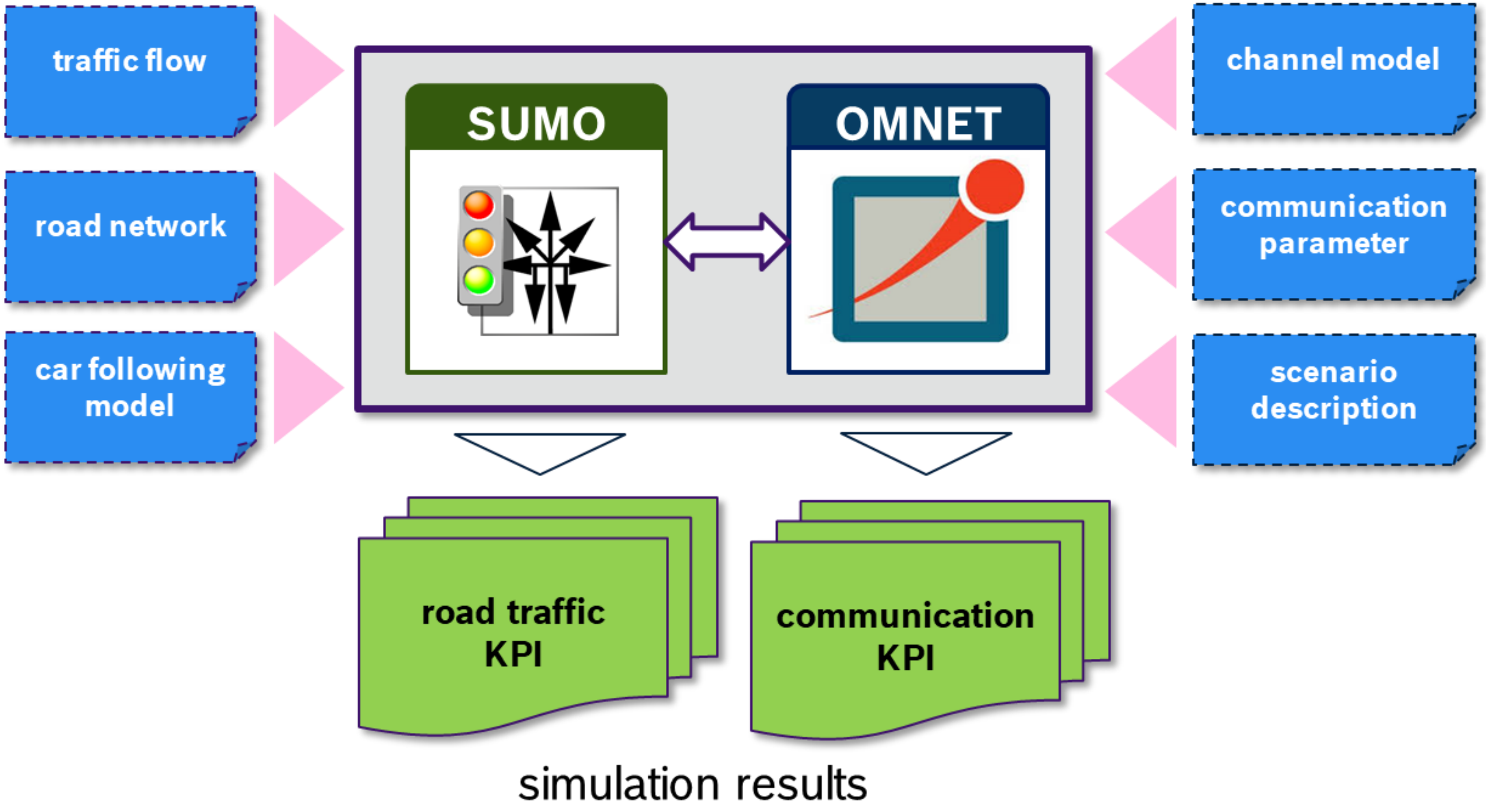
Hybrid Simulation Platform

► Bidirectional coupling of road traffic simulation and network simulation



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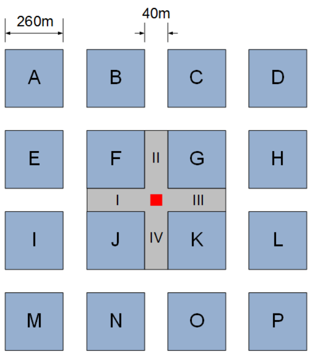
Impact of Building – Scenarios

► Variation of intersection topology/layout

► Each intersection is controlled by **traffic lights** following a realistic traffic control plan → **High density** of vehicles expected around **intersections** where queuing and clustering phenomena occur



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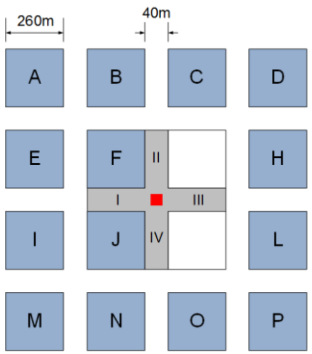
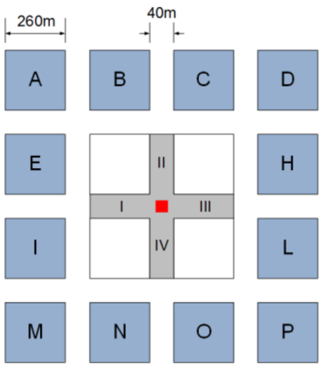


Half-Open



Open

► Fixed traffic density of 83 veh/km/lane, which quantifies the aggregated **number of vehicles** on a roadway segment per km per lane

► Intersection in the middle chosen as **target intersection** to eliminate boundary effects

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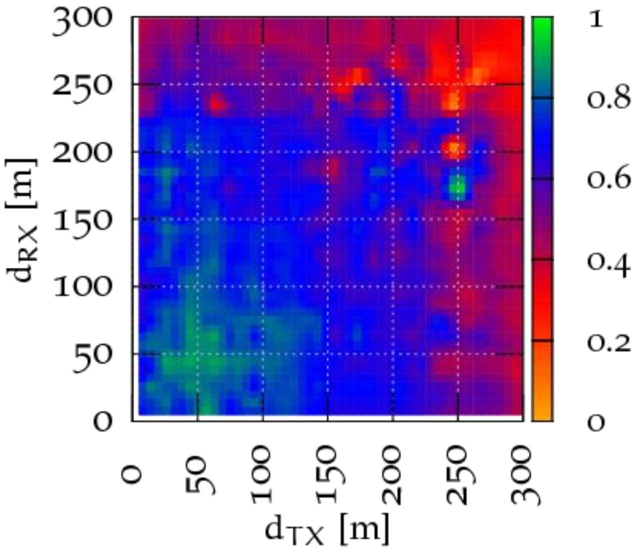
Impact of Intersection Type – Packet Delivery Ratio

► Average **PDR** as function of d_{RX} and d_{TX} distances recorded with different intersection types

► Open intersection type provides the best performance compared to the Half-open and Close type



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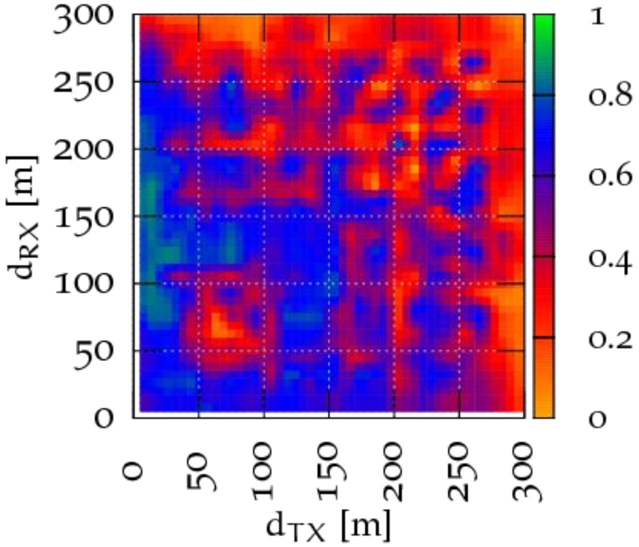

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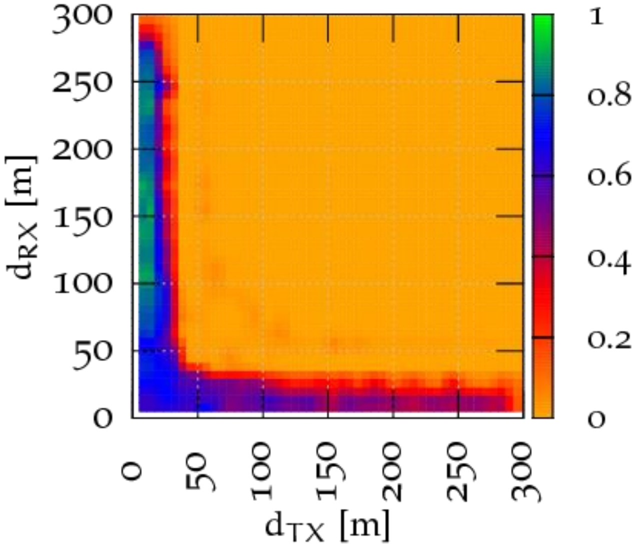

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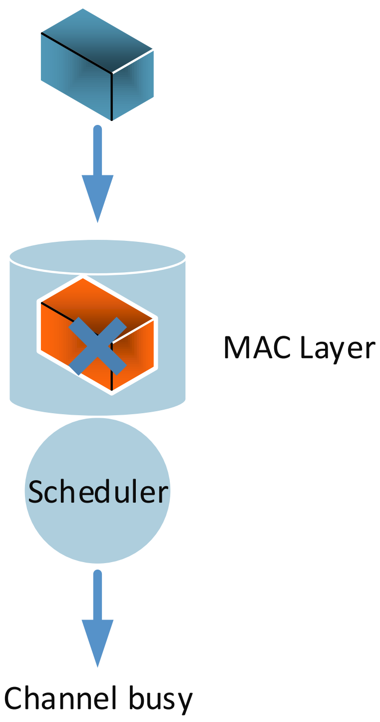
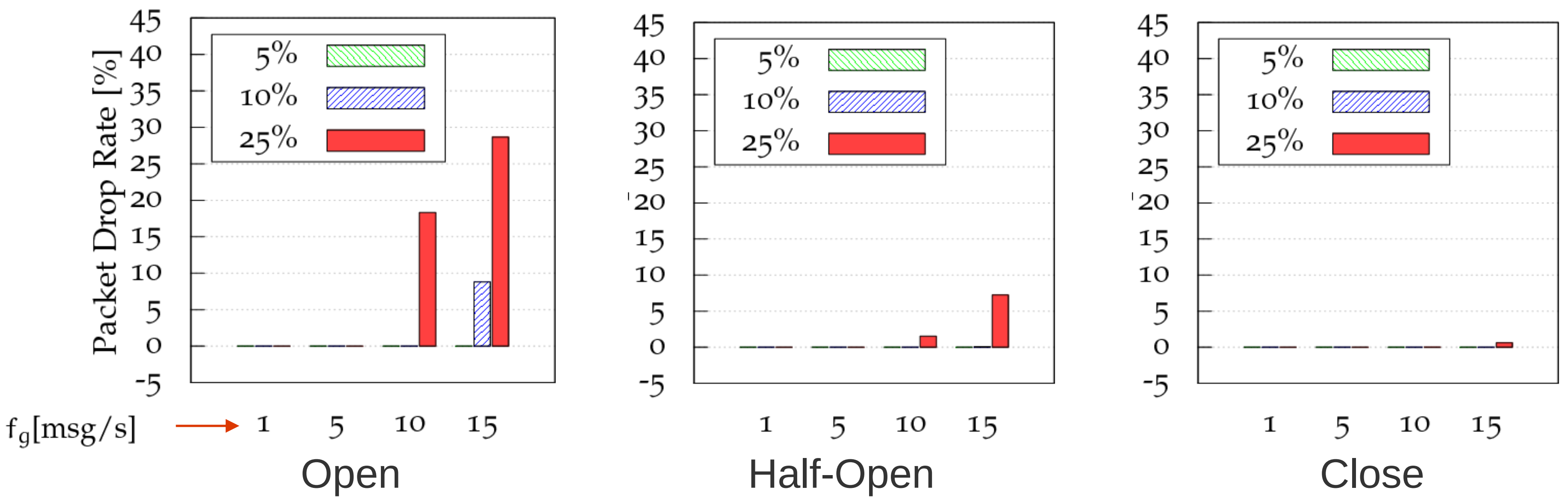
Impact of Packet Generation Rate – Packet Drop Rate



- Number of packets **discarded** due to **expiry time** among the number of packets **generated** by the application layer
- Lifetime of a packet in the MAC queue is **bounded** by the message **generation interval** so that a **newly** generated packet would **replace** the **old** one
- **Positive** effect of surrounding buildings which **limits interference** power and thus relaxes the channel load



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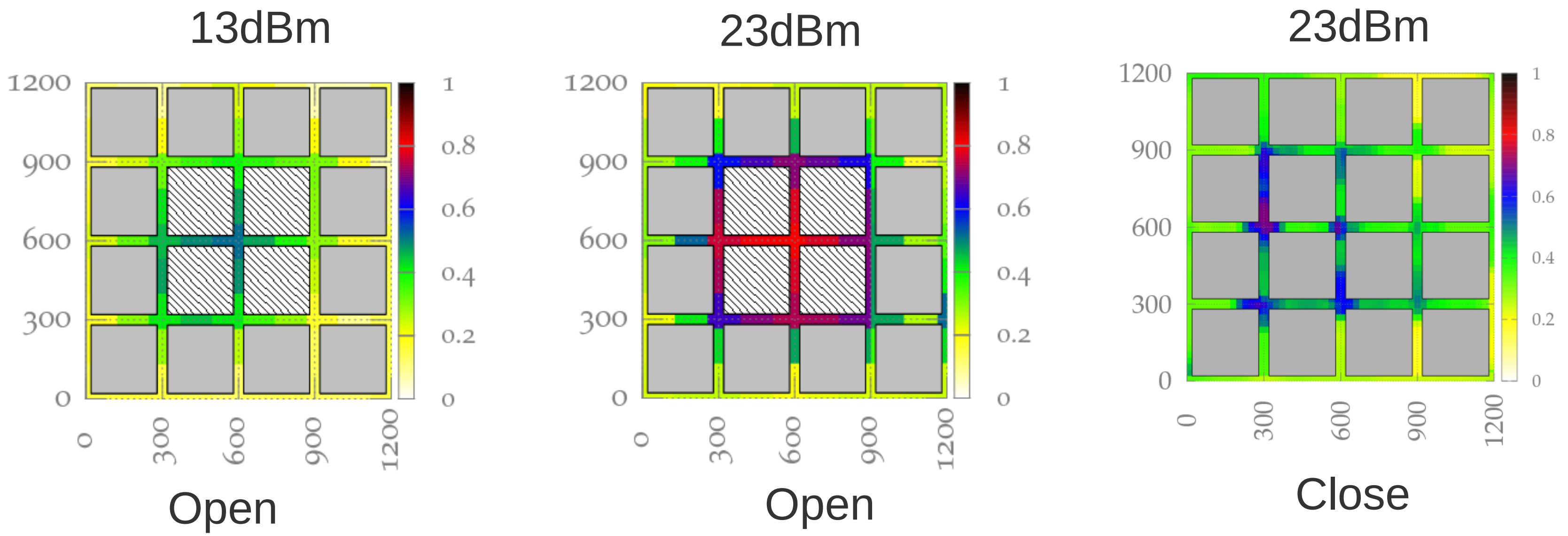
Impact of Transmission Power – Channel Busy Ratio (CBR)

- CBR is the fraction of a set period of time that a **channel is busy**
  - Channel reported as busy if the **measured signal power** is above the carrier sense **threshold** even if no packet is currently received
- The higher the **communication range**, the higher the **signal strength** measured at a given node
- Presence of buildings around the intersection provides again a positive impact by halving the CBR from 80% to 40 %



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Simulation Platooning Use Case

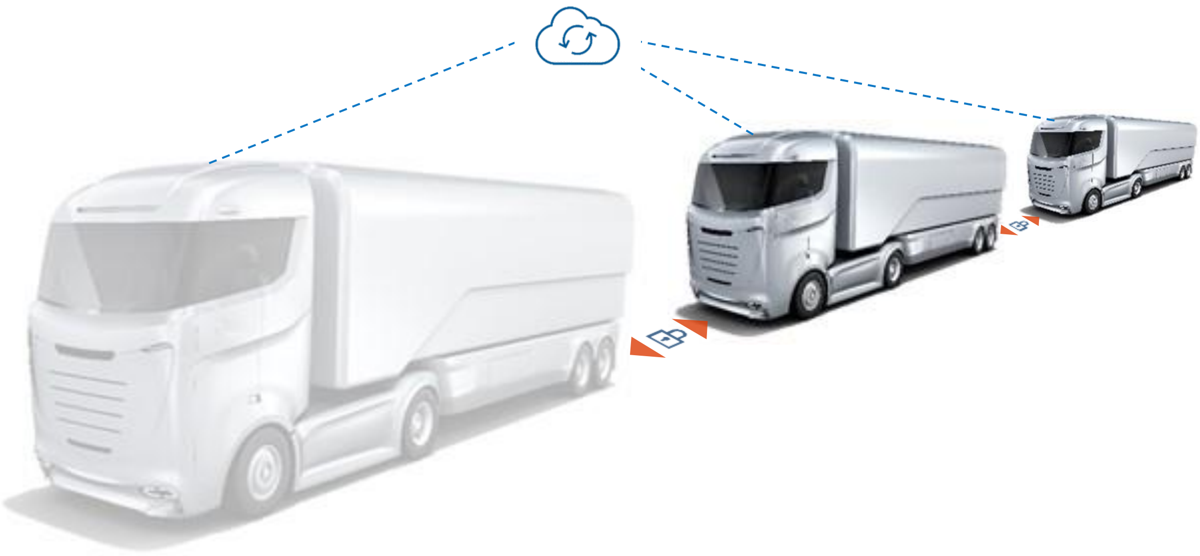
► Platoon is formed by electronic **coupling** of two or **more trucks**

► Distance between trucks **~7 to 8m** at 80km/h

► Synchronized surround **sensing** and **connected** vehicle communication

► Reduced **driver costs** and **fuel consumption**

► Increased **safety** and **efficiency**



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V2V Communication Challenges for Platooning

- **Harsh** communication performance required by **platoon controller**
  - High communication reliability, low end-to-end latency

- Communication performance may influence
  - Platoon **controller stability**
  - Platoon **safety** and **efficiency**

- Platooning should **remains stable** irrespective of the V2V channel quality/load
  - Impact of **co-channel interference** on platoon controller
  - Channel load **increases** when **other vehicles transmit** on the same channel

Lecture 11

V2V Communication Challenges for Platooning

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Lecture 11
Road Modelling for Platooning

- **4-Lanes bidirectional** highway scenario
- Consideration of different **traffic conditions**
  - **Free flow** to traffic **jam**
- Traffic classification through Level of Service (LOS) approach
  - **Mapping LOS** to **traffic flow/density**
- Passenger cars as **interfering vehicles**

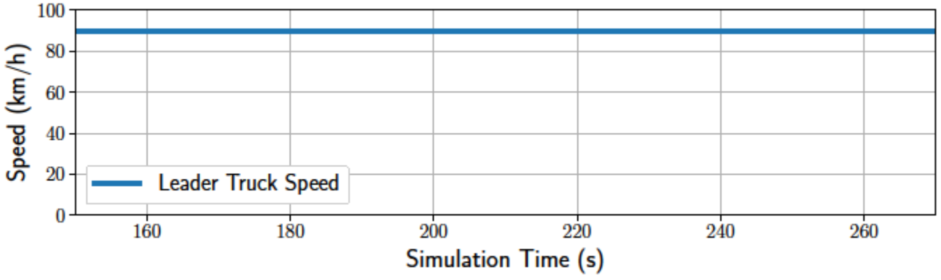
Source: Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS)

LOSTF	Utilization Rate x	Traffic Intensity Interval [veh/h]	Traffic Intensity [veh/h]	Traffic Density [veh/km]	Total Vehicle [#]
A	$\leqslant 0.30$	0-2190	2150	35	260
B	$\leqslant 0.55$	2190-4015	3950	65	460
C	$\leqslant 0.75$	4016-5475	5450	90	640
D	$\leqslant 0.90$	5475-6570	6500	105	765
E	$\leqslant 1.00$	6571-7300	7250	120	860
F	$\geqslant 1.00$	$\geqslant$ 7301	9000	150	1090

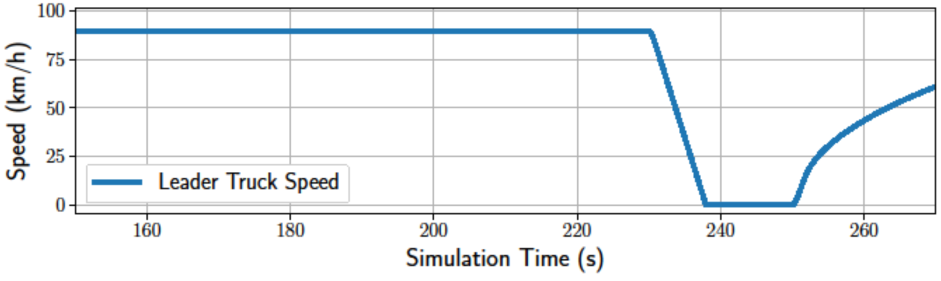
Lecture 11

Scenario Modelling for Platooning

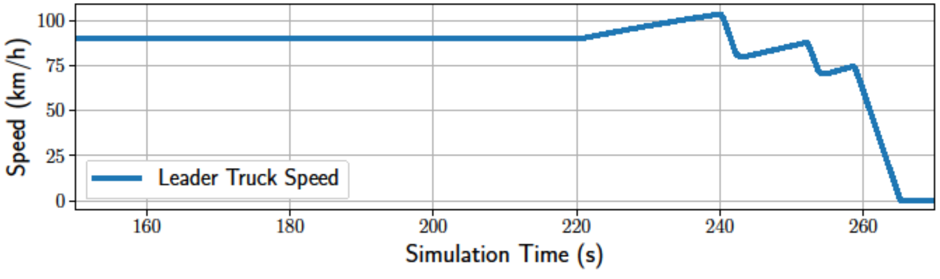
- **Constant cruising**
  - Platoon leader drives at a constant velocity
  - Without brake or acceleration periods



- **Emergency braking**
  - Platoon leader performs a hard braking
  - Single brake and acceleration periods

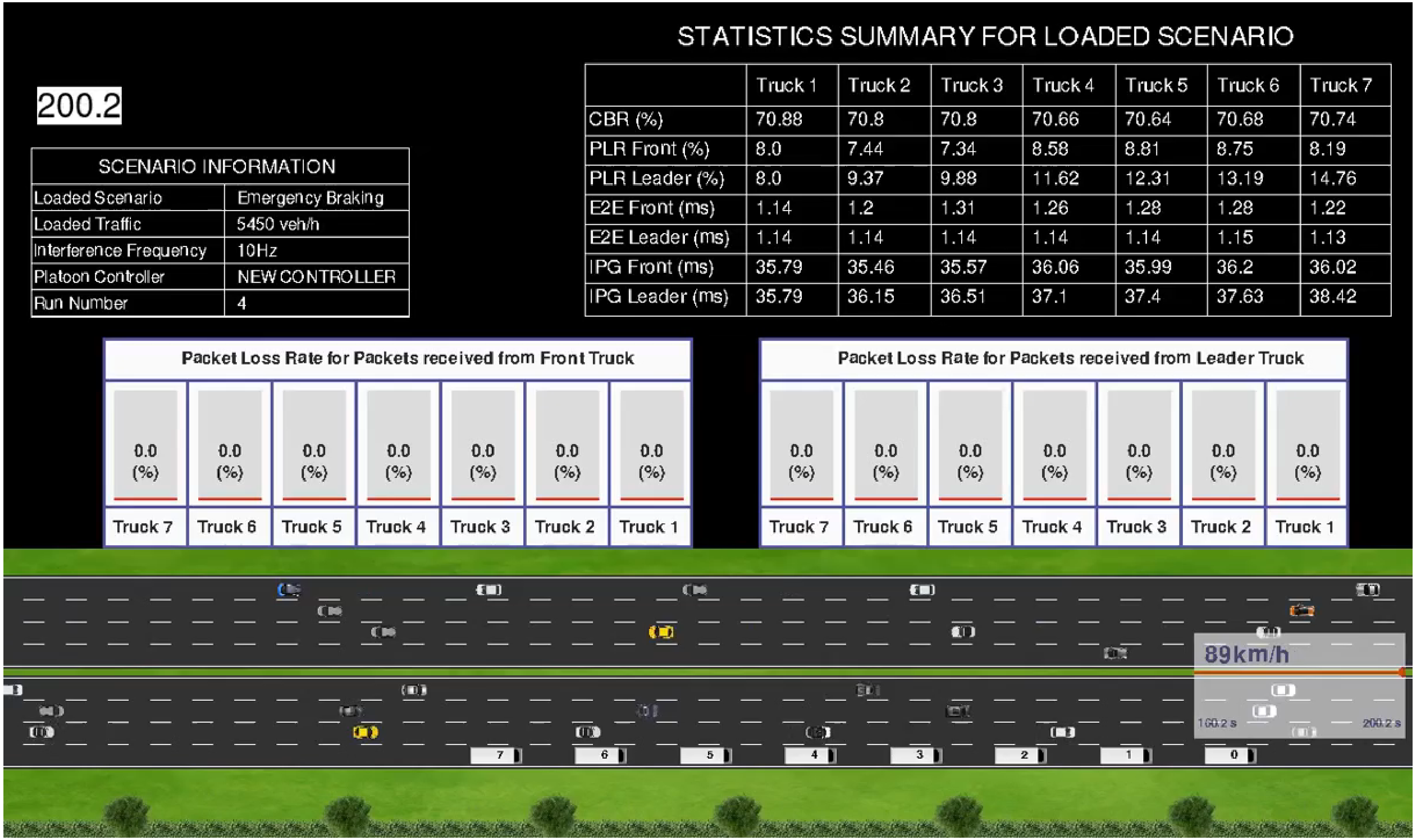


- **Mixed driving behavior**
  - Platoon leader performs a mixed driving maneuver
  - Several acceleration and brake periods within short periods



Lecture 11

V2V Co-Channel Interference – Emergency Braking Scenario



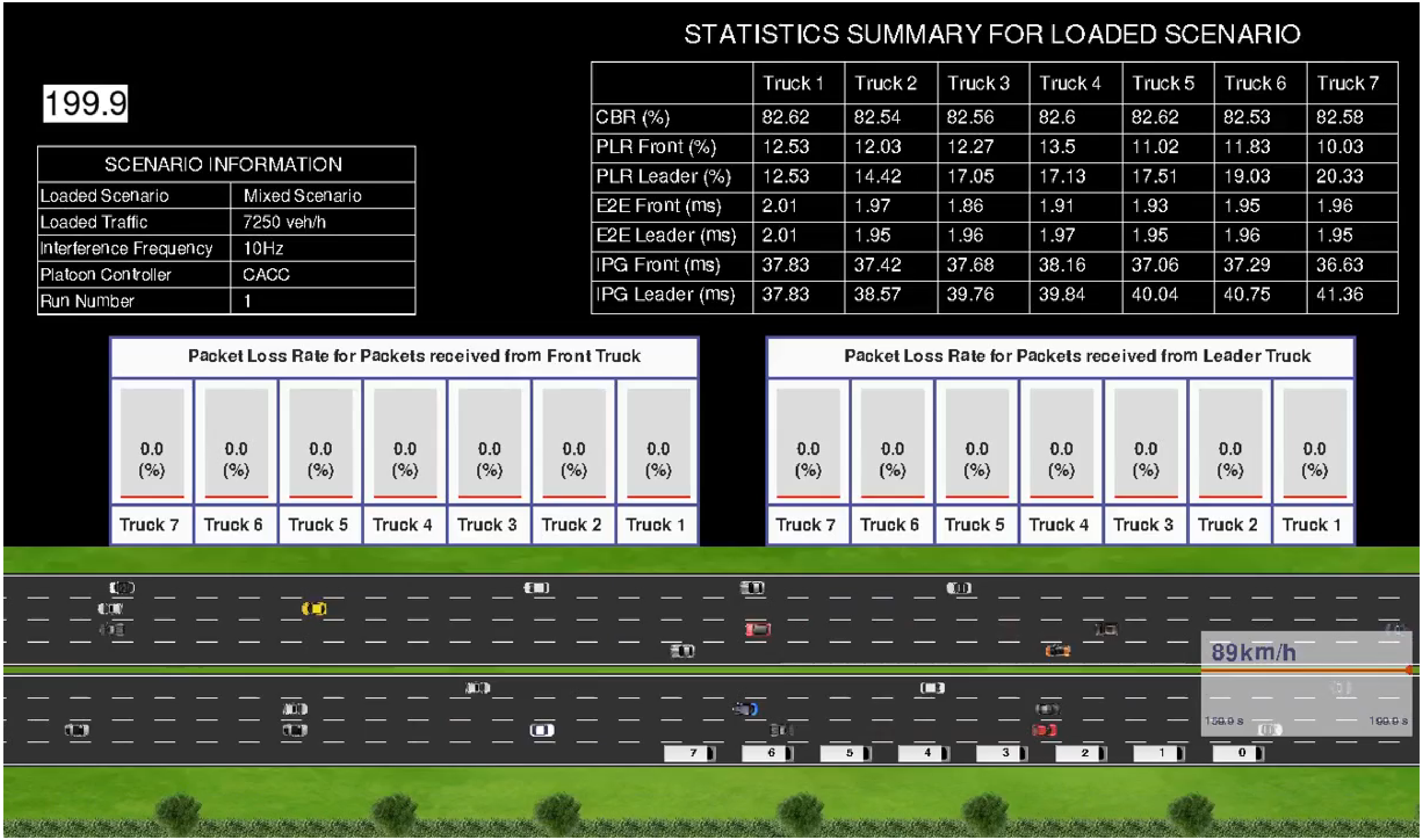
STATISTICS SUMMARY FOR LOADED SCENARIO

	Truck 1	Truck 2	Truck 3	Truck 4	Truck 5	Truck 6	Truck 7
CBR (%)	70.88	70.8	70.8	70.66	70.64	70.68	70.74
PLR Front (%)	8.0	7.44	7.34	8.58	8.81	8.75	8.19
PLR Leader (%)	8.0	9.37	9.88	11.62	12.31	13.19	14.76
E2E Front (ms)	1.14	1.2	1.31	1.26	1.28	1.28	1.22
E2E Leader (ms)	1.14	1.14	1.14	1.14	1.14	1.15	1.13
IPG Front (ms)	35.79	35.46	35.57	36.06	35.99	36.2	36.02
IPG Leader (ms)	35.79	36.15	36.51	37.1	37.4	37.63	38.42

SCENARIO INFORMATION	
Loaded Scenario	Emergency Braking
Loaded Traffic	5450 veh/h
Interference Frequency	10Hz
Platoon Controller	NEW CONTROLLER
Run Number	4

Lecture 11

V2V Co-Channel Interference – Mixed Driving Scenario



STATISTICS SUMMARY FOR LOADED SCENARIO

	Truck 1	Truck 2	Truck 3	Truck 4	Truck 5	Truck 6	Truck 7
CBR (%)	82.62	82.54	82.56	82.6	82.62	82.53	82.58
PLR Front (%)	12.53	12.03	12.27	13.5	11.02	11.83	10.03
PLR Leader (%)	12.53	14.42	17.05	17.13	17.51	19.03	20.33
E2E Front (ms)	2.01	1.97	1.86	1.91	1.93	1.95	1.96
E2E Leader (ms)	2.01	1.95	1.96	1.97	1.95	1.96	1.95
IPG Front (ms)	37.83	37.42	37.68	38.16	37.06	37.29	36.63
IPG Leader (ms)	37.83	38.57	39.76	39.84	40.04	40.75	41.36

SCENARIO INFORMATION	
Loaded Scenario	Mixed Scenario
Loaded Traffic	7250 veh/h
Interference Frequency	10Hz
Platoon Controller	CACC
Run Number	1

Lecture 11
Literature

- M. Fiore et al.: “Understanding Vehicular Mobility in Network Simulation”, 4th International Conference on Mobile adhoc and Sensor Systems, 2007
- H. Tchouankem: “Radio shadowing in Vehicle-to-vehicle Communication at urban intersections: A Measurement and Simulation-based Evaluation”, Dissertation, 2016
- C. Sommer et al.: “Simulation Tools and Techniques for Vehicular Communications and Applications”, 2015