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

Performance Evaluation – Methods and Measurement-based Analysis

Lecture 10: Fahrzeugvernetzung – V2X

Hugues Tchouankem, 01.12.2021

Lecture 10
Previous Lecture

- ► 5G Communication Basics
- ► 5G Communication Usage Scenarios
- ► 5G New Radio (NR)
- ► 5G-V2X Features
- ► 5G-V2X Sidelink Modes
- ► Coexistence of C-V2X and 5G-V2X
- ► V2X Applications supported by 5G-V2X

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Outline

► Evaluation Objectives

► Evaluation Methodologies

► V2V Performance Evaluation in urban Environments

► Impact of Vegetation on V2V Performance

► Co-Channel Interference on V2V Performance

► Demonstrations

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Performance Evaluation Objectives

- ► Determine certain **performance measures** for existing systems or for models of systems
- ► Assessment of **system's capability/capacity**
  - ► Determine **bounds** or limitations of a system
- ► Develop new **analytical** and **methodological foundations**, e.g. in queuing theory, simulation
- ► Validate **theoretical approaches** in creating and evaluating performance models

- ► Typical specific goals
  - ► **Bottleneck** analysis and **optimization**
  - ► **Comparison** of alternative systems / protocols / algorithms
  - ► Pure (academic) **interest**
  - ► Also: performance analysis is often a tool in **investment decisions**

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Performance Evaluation Methodologies

- ► Three mains **methodologies** to assess the performance of a system
  - ► **Mathematical analysis**
    - ► Use mathematical notions and models describing aspects of a system
  - ► **Experiments**
    - ► Provide a concrete behavior of a system without simplification
  - ► **Simulation**
    - ► Allow for a greater level of detail than analytical modeling
    - ► Topic of next lecture
- ► Hard to provide a **general recommendation** of the **choice** of the methodology
- ► BUT the selection of the method could be proposed on the basis of **empirical evidence** or **lessons learned**
  - ► Depending of the evaluation **objective** all **three** methodologies could be applied for **V2X-networks**

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Choice of Methodology

- ► **Choice** of a **technique** depends on:
  - ► Type of **system** to be investigated
  - ► Its **availability**
  - ► **Familiarity** of the modeler with the **techniques**
  - ► **Time** and **resource** constraints
  - ► Desired **accuracy** of results

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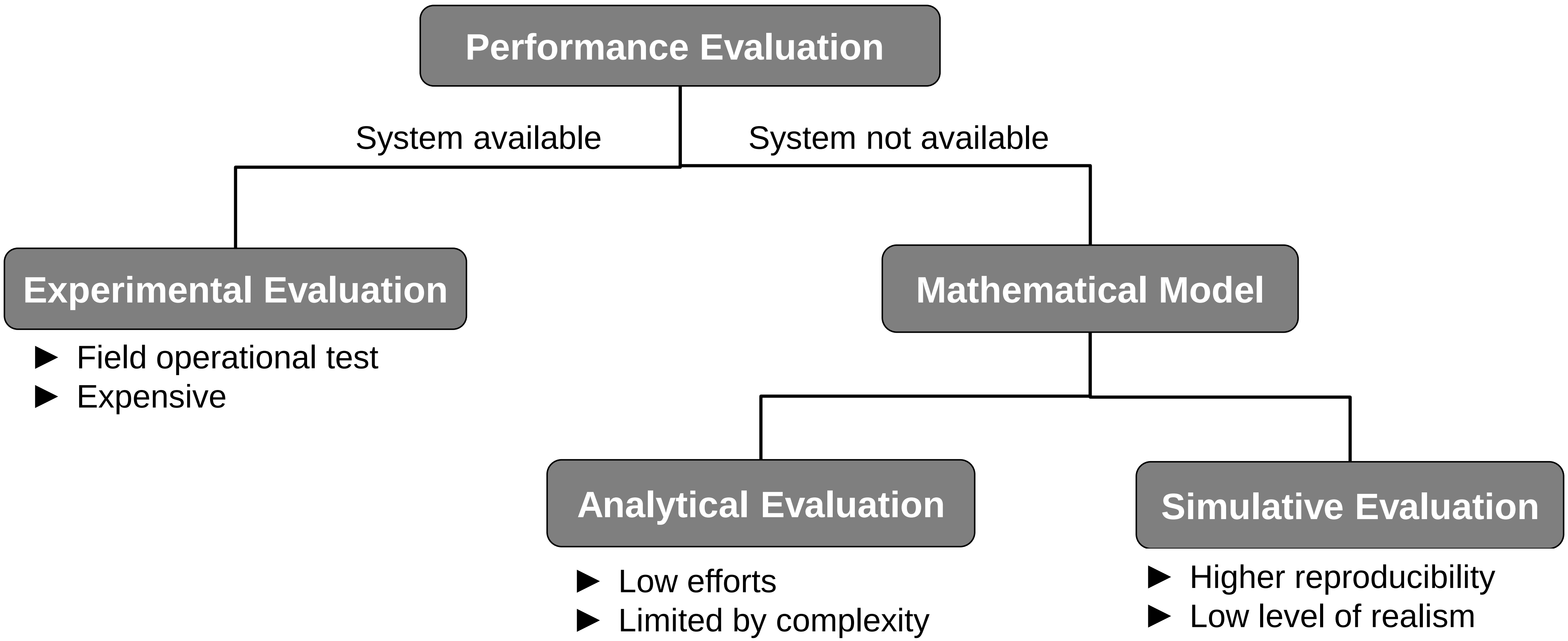
Selection Strategy of Evaluation Methodologies



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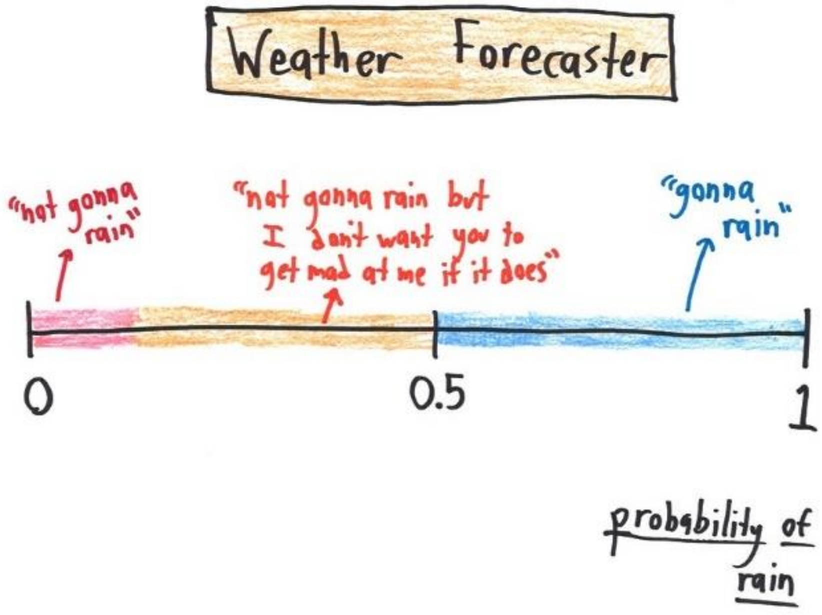
Mathematical Analysis (1/2)

- ► Uses **mathematical notions** and models describing certain aspects of a system
- ► Provide **borderline behavior** (upper and lower bounds) of a system characteristics
- ► For modeling of **communication networks** often **probabilistic** models are used
  - ► Packet generation times are **random**
  - ► Packet arrival times to a network are **random**
  - ► Errors on communication links are **random**



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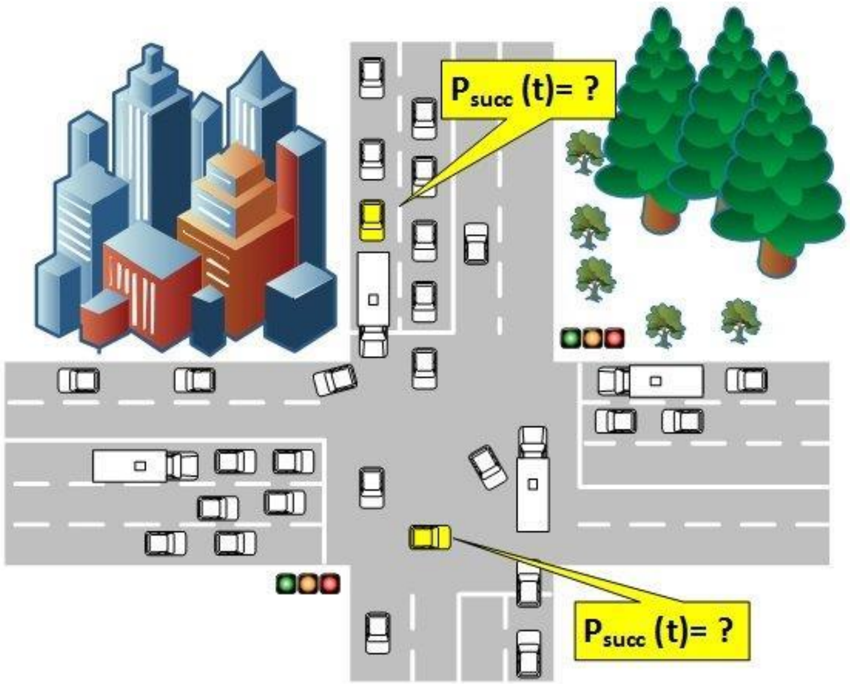
Mathematical Analysis (2/2)



- ► Many assumptions have to made
  - ► 1-D linear road topology
  - ► Uniformly placement of nodes
  - ► **No fading** and shadowing effect considered
  - ► Number of nodes not **easily tractable**
    - ► Depends on **traffic density**, **velocity**, **communication range**, **fading** component, etc.

- ► In reality
  - ► **2D** intersection topology
  - ► **Shadowing** through buildings, vegetation and vehicles
  - ► **Heterogeneous** traffic pattern (Signal change at traffic light)

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Simulative Evaluation

- ► Performance evaluation using simulation models
  - ► **Models** have to created **in advance**
- ► A simulation model
  - ► is a **computer program**, written in a general-purpose or specific simulation language
  - ► implements the **most important aspects** of the system under study, often in a simplified manner
  - ► allows for a **greater level of detail** than analytical modeling

- ► **Scalability**: Large scale scenarios involving a **high number** of vehicles in a controlled platform (+)
- ► **Repeatability:** Different experiments can be evaluated under **exactly the same environment** parameters (+)
- ► **Accuracy:** Low level of **realism** (-)

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Experimental Evaluation

- Use **experiments** with **real systems**
- Assessment of a system behavior **without** making **unrealistic** assumptions
  - Without simplification leading to **incomplete** analysis
- Provide **high level** of accuracy
- Allow a deduction of measurement-based **path loss models** used for simulation

- **Challenges**
  - **Expensive** and time consuming
    - Huge logistic to control the measurement required
    - Several **devices** and **vehicles** required
  - Fail in **reproducibility** of experiments
    - Inevitable presence of mobile and static obstacles (buildings and vegetation)
    - Shadowing effects and multipath fading

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Field Operational Tests (FOTs)

- Aim to **reproduce** a scenario that is at least similar to the typical use of V2X networks on a **large scale**
  - Several **hundred of vehicles** are needed even for smaller experiments
- Extremely **expensive** and require a **huge logistic** to manage and analyze the measurement results

- Current largest FOT in Europe
  - **C-Roads:** platform of harmonized C-ITS in Europe
    - Cross country **seamless traffic information system**
    - **8 cooperative countries** (GB,F,B,NL,D,CZ,A,SLO)
    - Use **wireless** communication (C-ITS G5, Mobile 3G/4G/LTE Wi-Fi and Bluetooth technology)

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Small-Scale Testing

- Help to acquire a **better** understanding of **certain functionalities** of a system
- **Few** system component and communication system needed
  - Not too expensive and required few human resource
- Often used for **validation** of **simulation models**
- Ease the **development** of **new models** based on empirical data

- Provide important **insights** into the **behavior** of selected parts of the system
  - BUT **not the performance of the application** as FOTs is needed for this
  - E.g. shadowing by buildings, vegetation or impact of co-channel interference

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Measurement Equipment

- ► Standard WiFi chipset
  - ► **Modified driver** to meet IEEE 802.11p
  - ► Cheap hardware solution fully compliant to ITS-G5/DSRC
  - ► **Suitable** for small scale testing

- ► Several **ready-to-market V2X systems** already available
  - ► V2X-based Roadside Unit (RSU) for FOTs and commercial applications
  - ► V2X-based Onboard Unit (OBU) for FOTs and commercial applications
  - ► **V2X Protocol stack** for rapid development and deployment of ITS applications

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Performance Measures

- **Lower layer metrics**
  - **Received power level**: for propagation channel modeling
  - **Channel busy ratio**
  - **Power delay profile**: intensity of a signal received through a multipath channel as a function of time delay (delay spread)

- **Application-centric metrics**
  - **Packet delivery ratio**: ratio between the numbers of successfully received and transmitted frames
  - **Latency**
    - End-to-end latency
    - Inter-packet gap
    - Round-trip-time

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Measurement Campaigns – some Impressions

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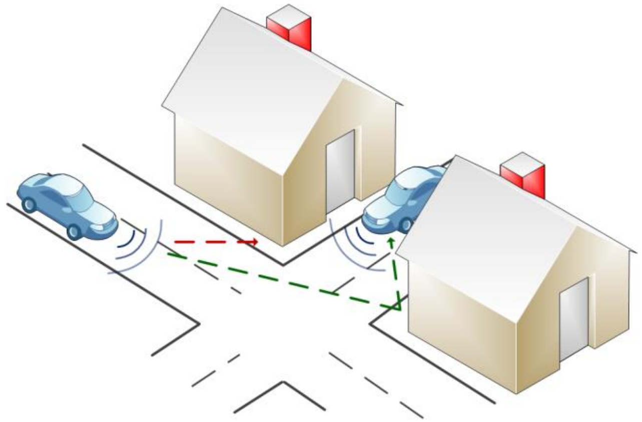
Evaluation of V2V Performance in urban Environments



- ► Most critical scenarios are considered to be in **non-line-of-sight (NLOS)** situations
  - ► Typical for **urban scenarios**
  - ► Radio channel is susceptible to multipath propagation and **shadowing**
  - ► Resulting packet losses may significantly **impair application reliability**
- ► Adequate quality of the communication link is a main prerequisite for reliable operation of V2V applications
  - ► Intersection collision warning

- ► **Measurement campaign** at four different urban intersections under non-line-of-sight (NLOS) conditions

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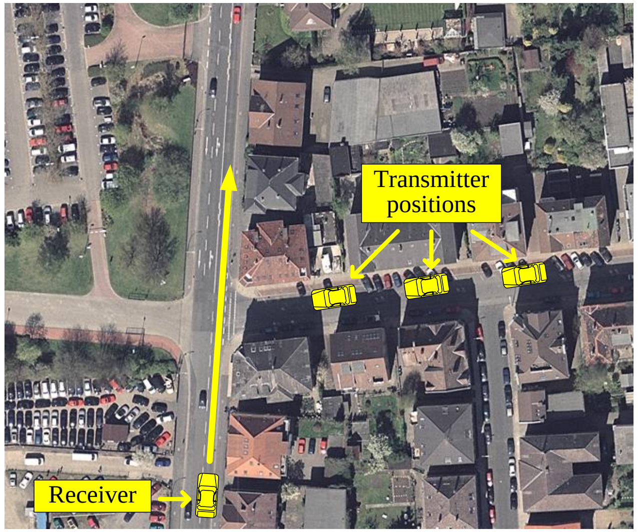
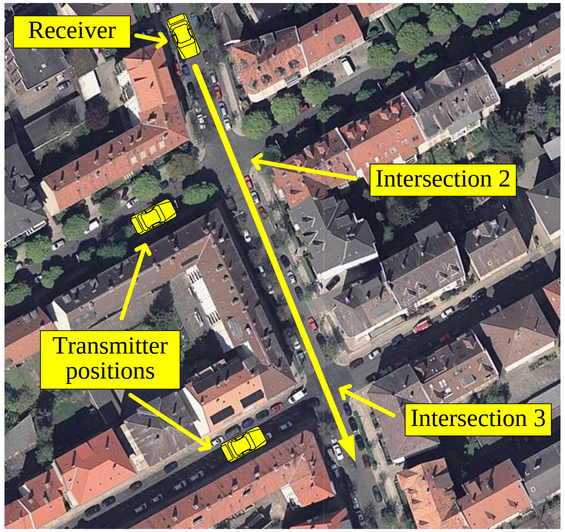
Evaluation of V2V in urban Environments – Scenarios and Goals

Intersection 1



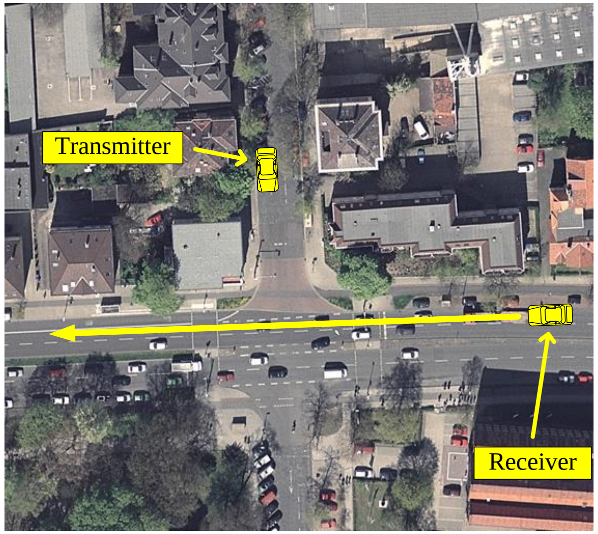
Quantify impact of transmitter‘s distance to intersection

Intersection 2 and 3



Quantify impact of street width

Intersection 4



Quantify influence of traffic density (and street width)

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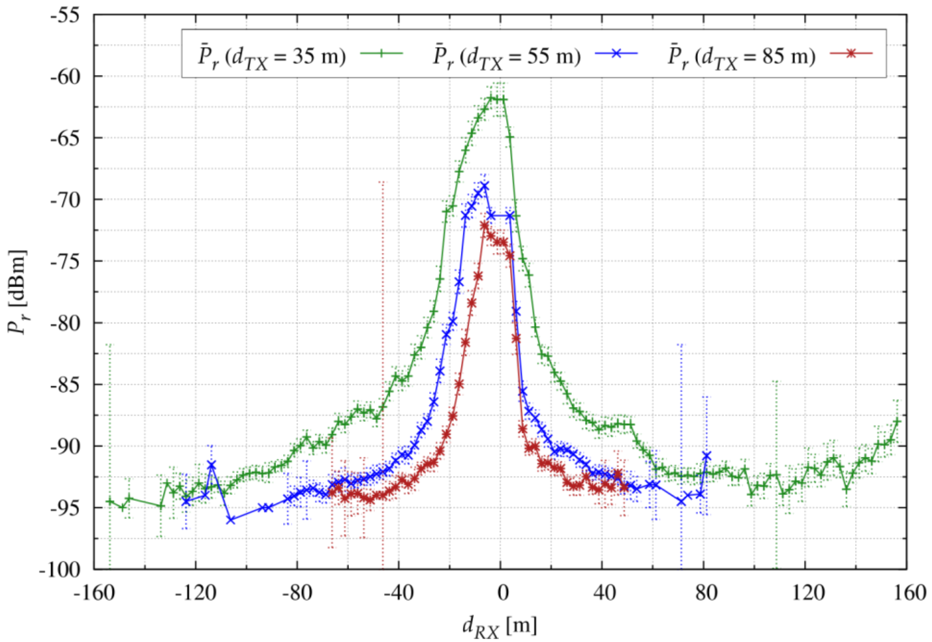
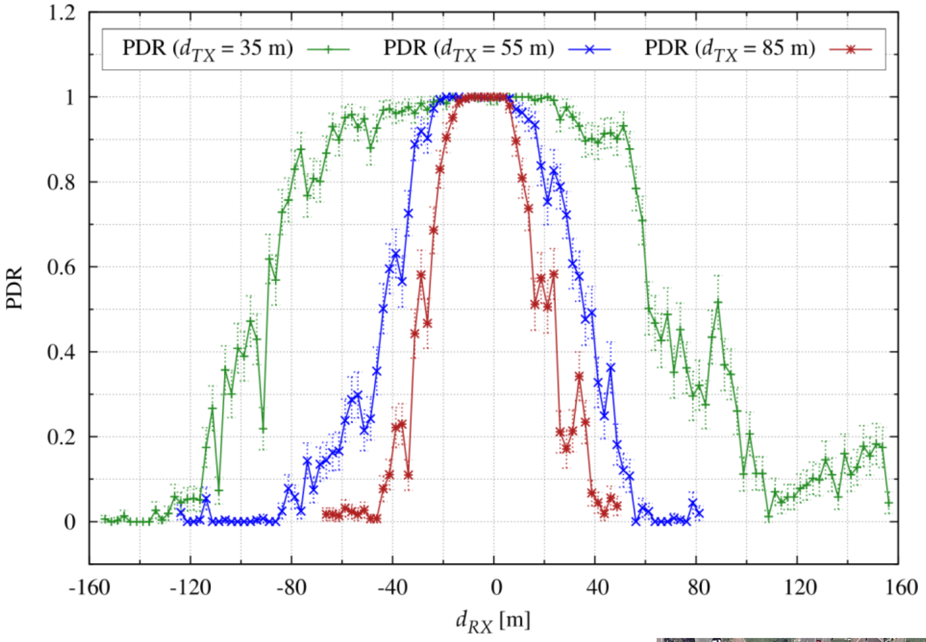
Evaluation of V2V in urban Environments – Results of Intersection 1

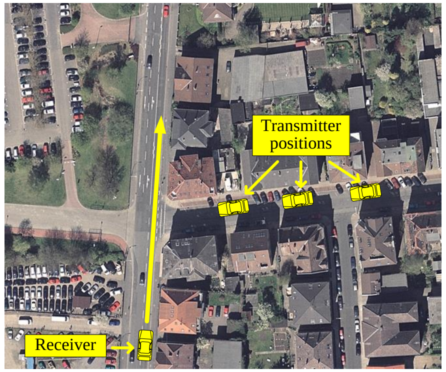
Received power



Packet delivery ratio



d_{TX}, d_{RX}: distance of transmitter and receiver to intersection center



- Quick transition from unreliable to reliable communication and vice versa
- Approaching phase: $\mathrm{PDR} \geq 0.9$ for $d_{RX} = \{65, 30, 20\}\, m$

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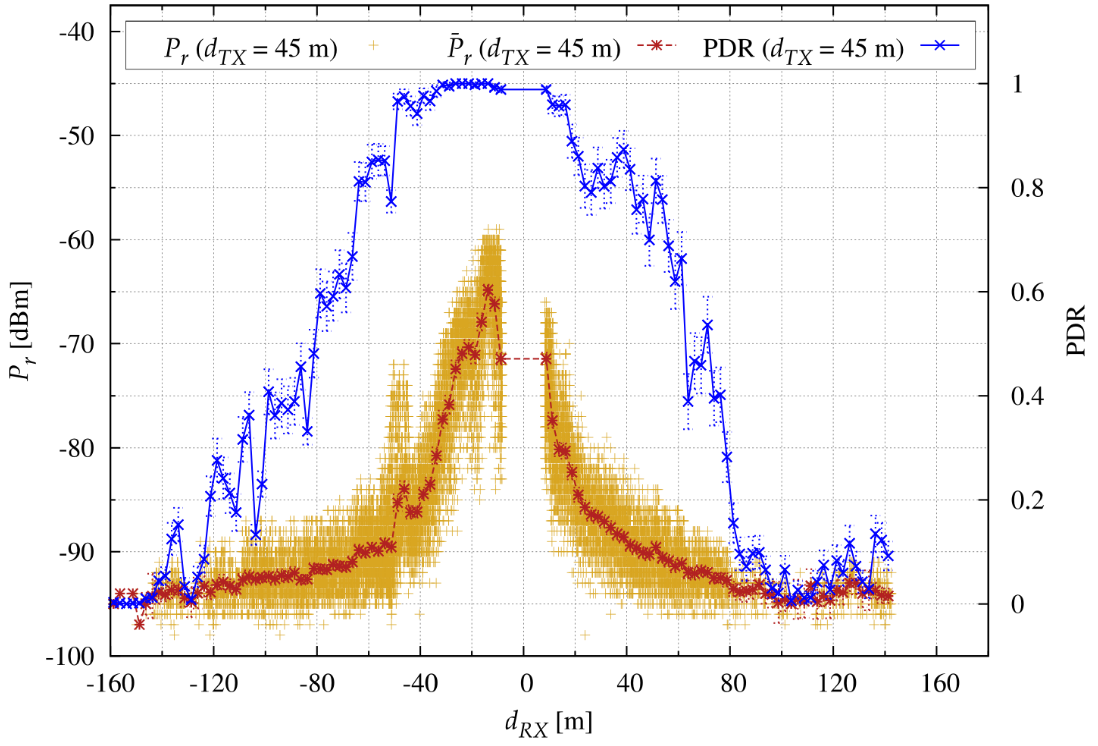
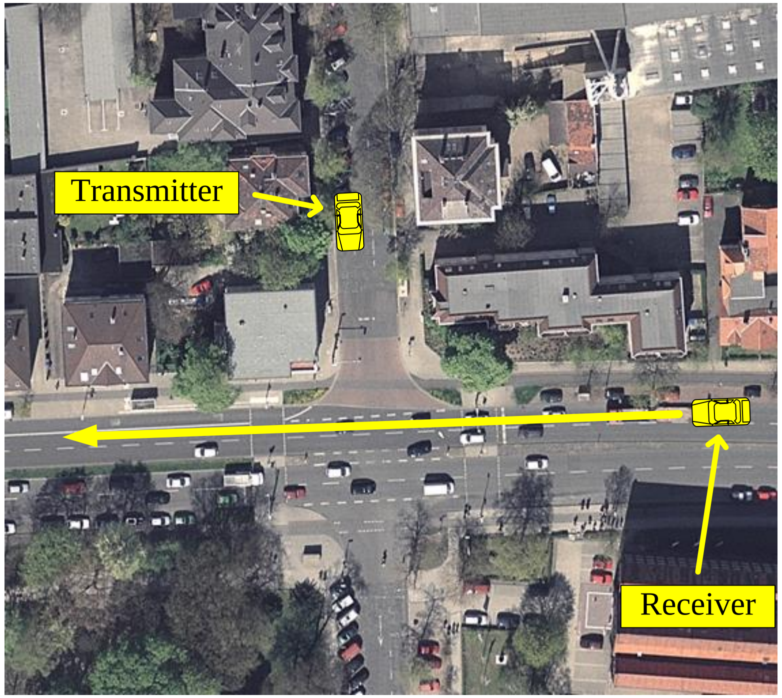
Evaluation of V2V in urban Environments – Results of Intersection 4





d_{TX}, d_{RX}: distance of transmitter and receiver to intersection center

- Effective reliable communication range ($\mathrm{PDR} \geq 0.9$) :
- Surrounding cars and especially buses cause probabilistic shadowing

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Evaluation of Vegetation Effect

- Influence of **vegetation** on the performance of V2V communication based on a **measurement campaign**
  - Urban and rural intersections
  - **Different types of vegetation** under non-line-of- sight (NLOS) conditions
  - **Seasonal effect**

- Analysis of radio shadowing obstructions caused by **clusters of trees** and **high bushes**
- **Vegetation-based path model** for estimation of the additional path loss caused by vegetation in V2V scenarios

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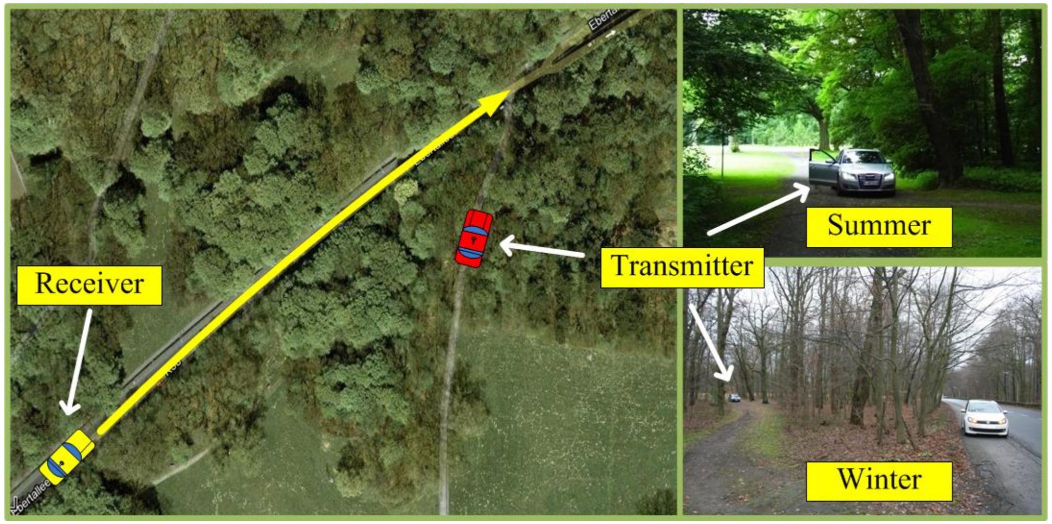
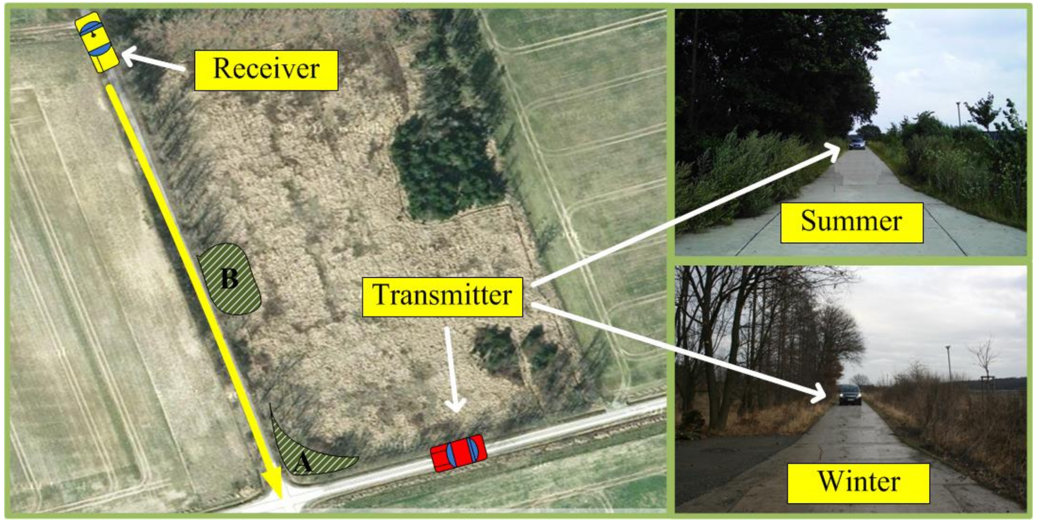
Evaluation of Vegetation Effect - Scenarios

Intersection 1



Intersection 2



- City park - vegetation dominated by trees and bushes of unequal height with different foliage densities, types of wood and leaf sizes
- LOS between transmitter and receiver partially obstructed

- Very-dense vegetation (large trees, grass and bushes) along the roads, but sparser (small young trees, a lot of high grass, less bushes)
- LOS between transmitter and receiver completely obstructed

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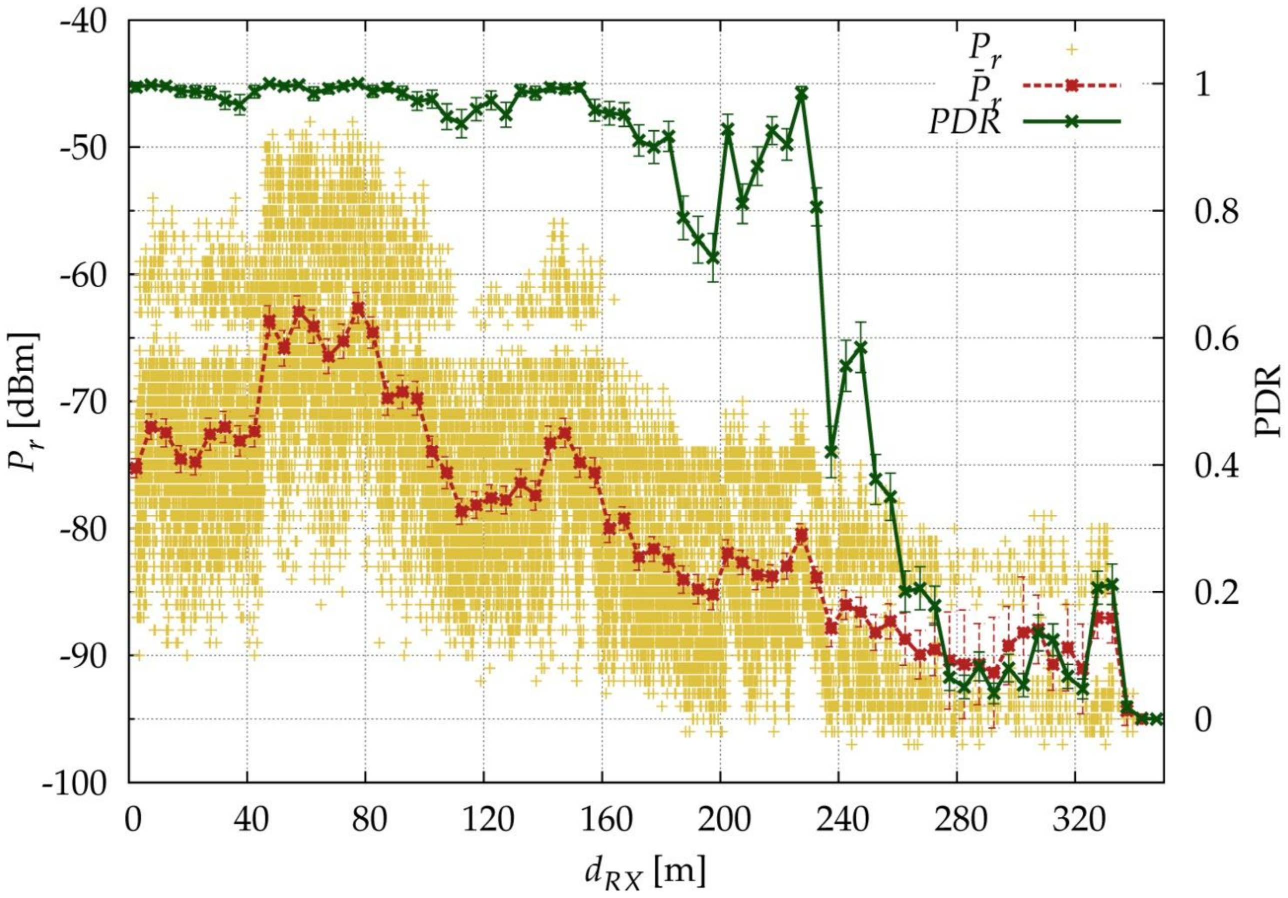
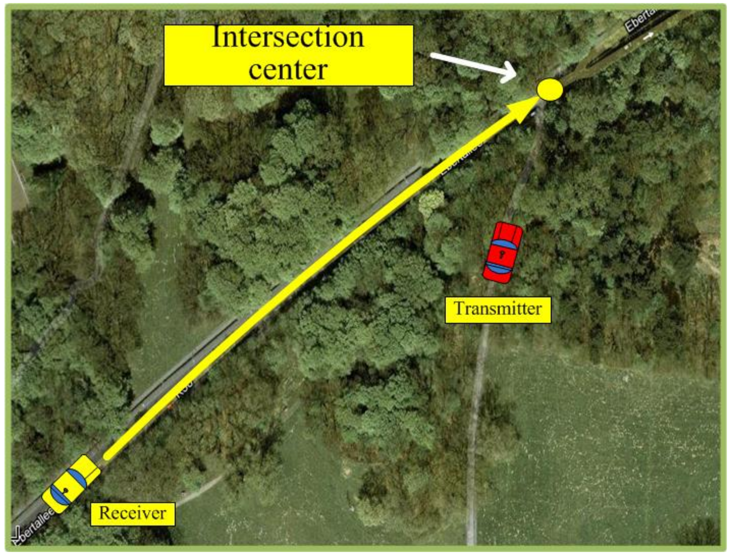
Evaluation of Vegetation Effect – Results Intersection 1





d_{RX} : distance of receiver to intersection center

► Strong fluctuations of the received power

► Rapid decrease of the PDR

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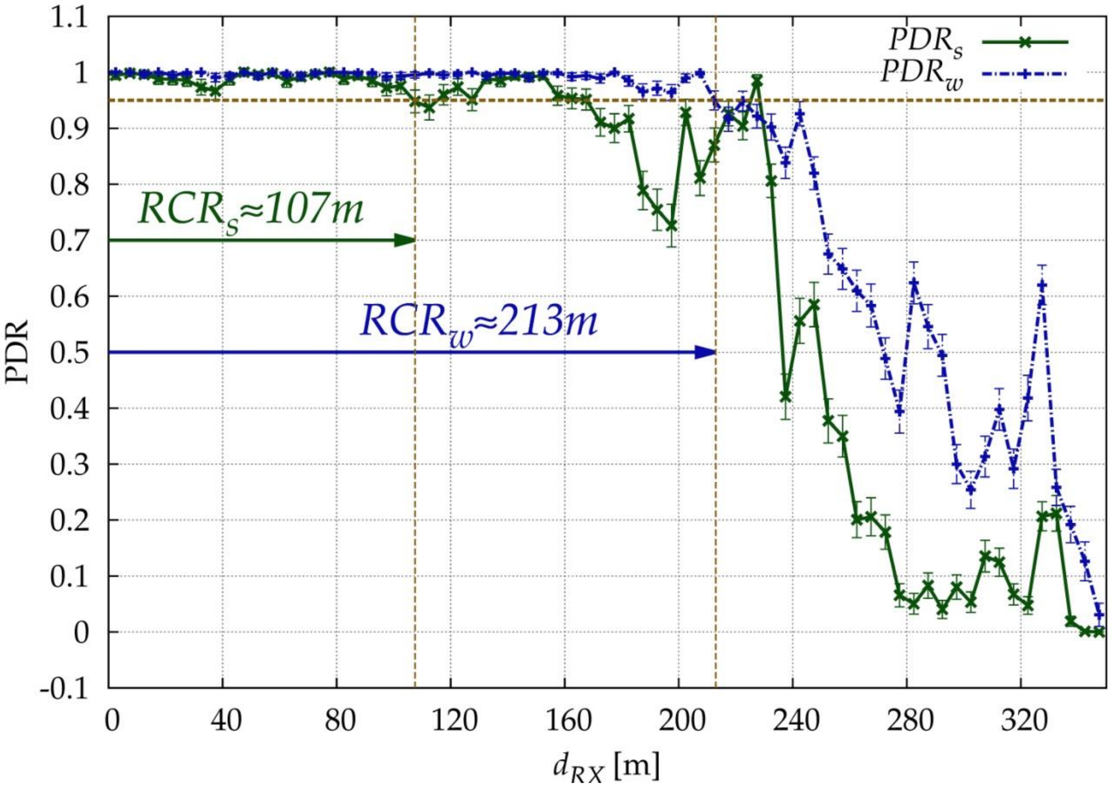
Evaluation of Vegetation Effect – Seasonal Influence



► Absence of foliage improves communication reliability

► RCR is approximately doubled from 107m to 213m

$PDR \geq 0.95$

PDR: Packet Delivery Ratio

d_{RX} : distance of receiver to intersection center

RCR: Reliable communication range

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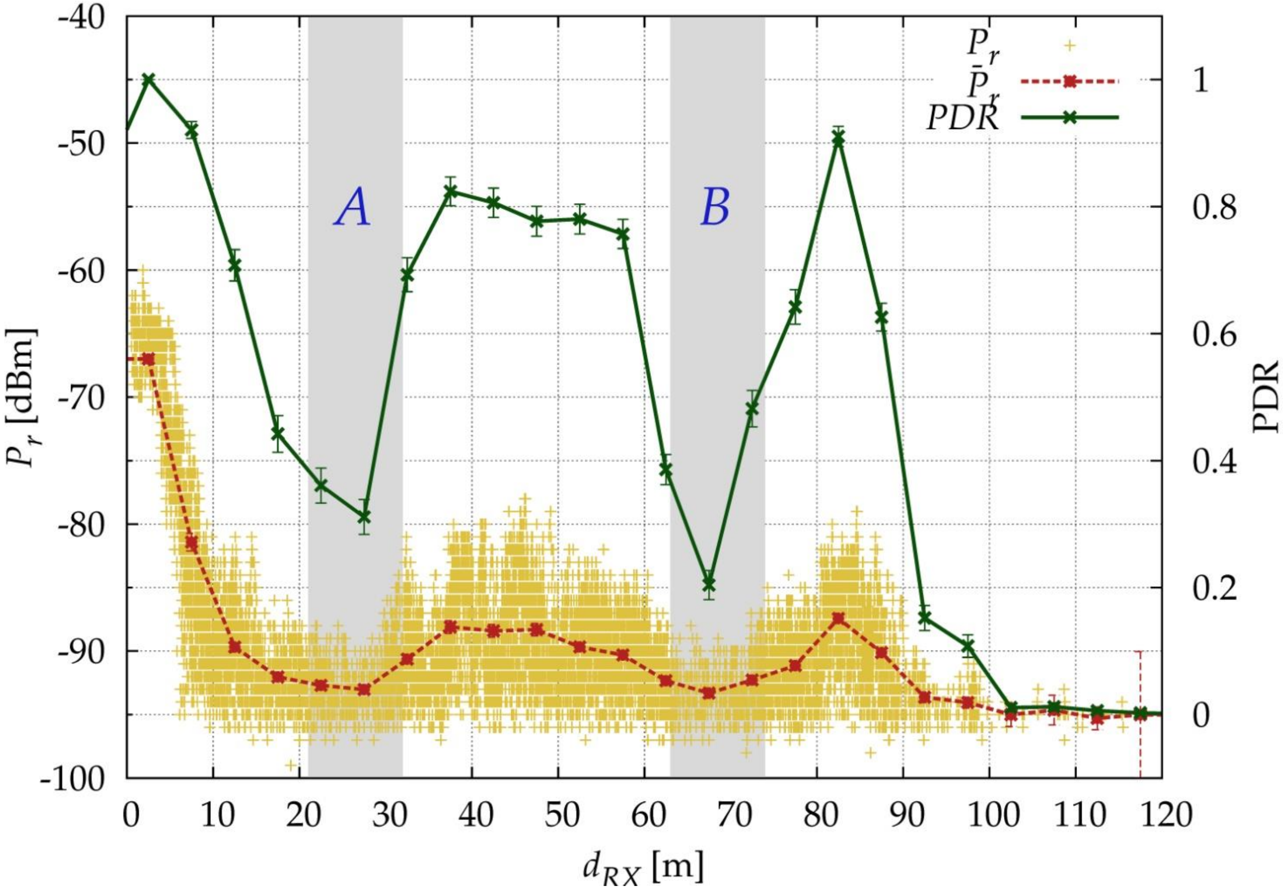
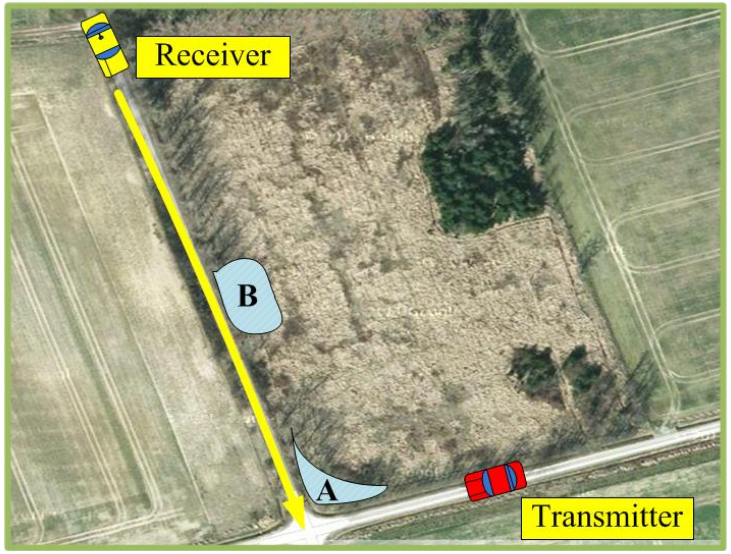
Evaluation of Vegetation Effect – Results Intersection 2





d_{RX} : distance of receiver to intersection center

► Significant Influence of vegetation structure on received power levels

► Two significant drops where the vegetation structure is extremely dense and impenetrable

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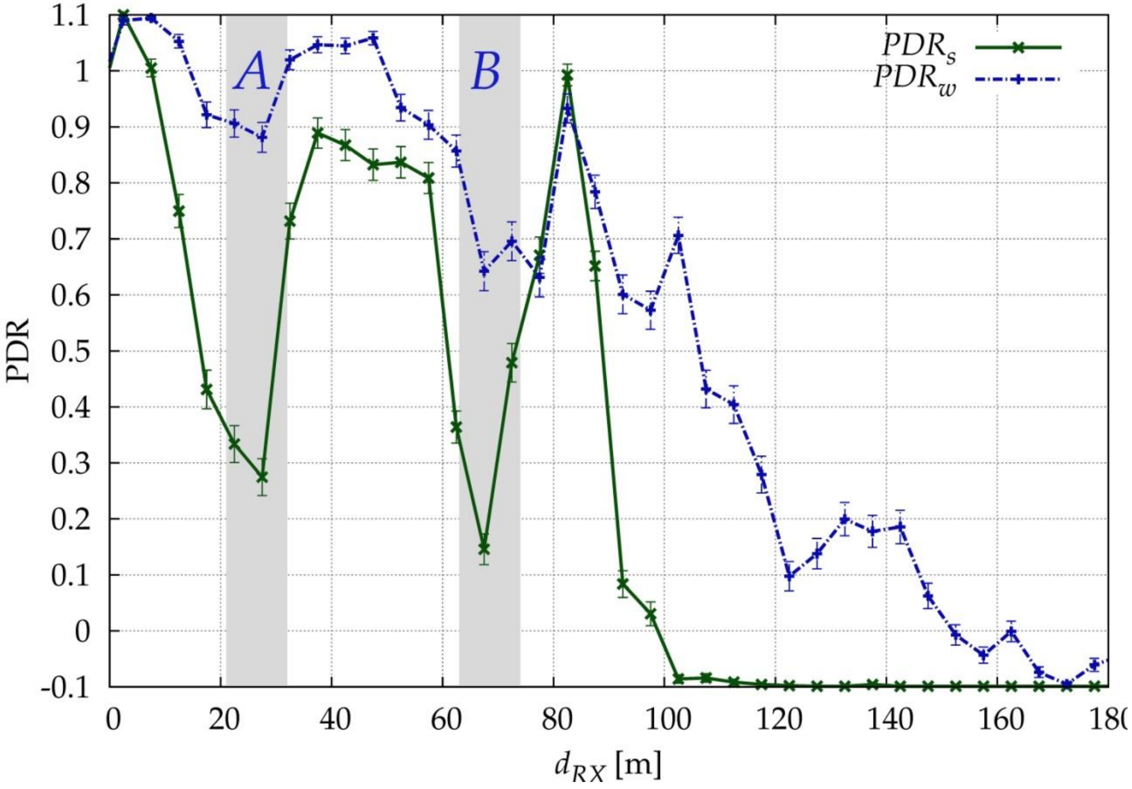
Evaluation of Vegetation Effect – Seasonal Influence



PDR: Packet Delivery Ratio

d_{RX} : distance of receiver to intersection center

- ► Inevitable presence of branches and tree trunks
- ► Drops are considerably less pronounced in winter

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Evaluation of Co-Channel Interference

► Co-channel Interference

► causes by stations transmitting in the **same channel**

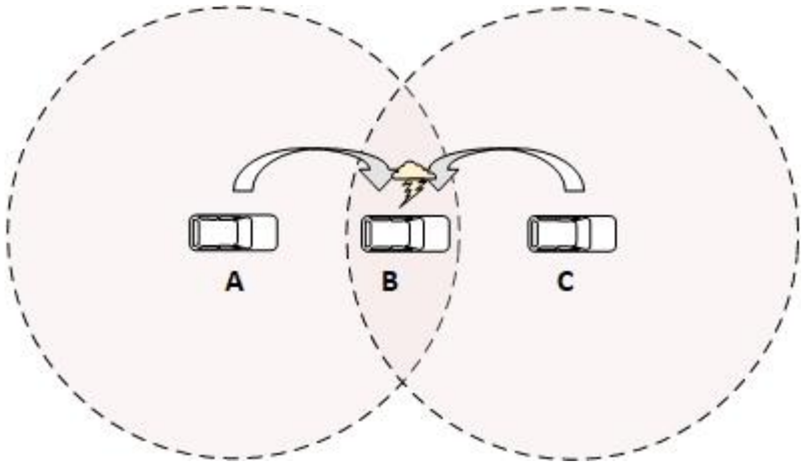
► **Single-Hop Broadcast** (no error-handling, no ACKs and no RTS/CTS)

► Distributed coordination Function with **CSMA/CA**

► Co-channel interference can not be fully prevented by the DCF approach

► **Two (or more) stations** select the **same backoff** counter

► **Hidden node problem**



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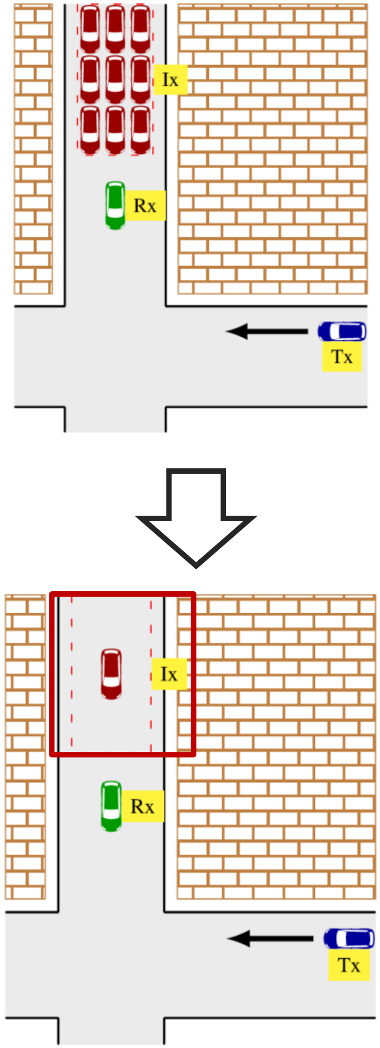
Evaluation of co-Channel Interference - Approach



- Conditions of a **successful packet transmission**
  - Based on receiver sensitivity in interference-free conditions
  - **Minimum signal-to-interference-noise ratio (SINR)** for the whole transmission duration

$$SINR = \frac{P_r}{N + I} = \frac{P_r}{N + P_1 + P_2 + \cdots}$$

  - P_r is the received power of the strongest signal, N the thermal noise and I the sum of interference produced by other vehicles

- **SINR** is used to understand the source of packet loss, since the **stronger the interference** level, the **lower the probability of packet reception**

- Configuration of **a single node** as a **set of interferers** by sending at a **higher transmit rate**

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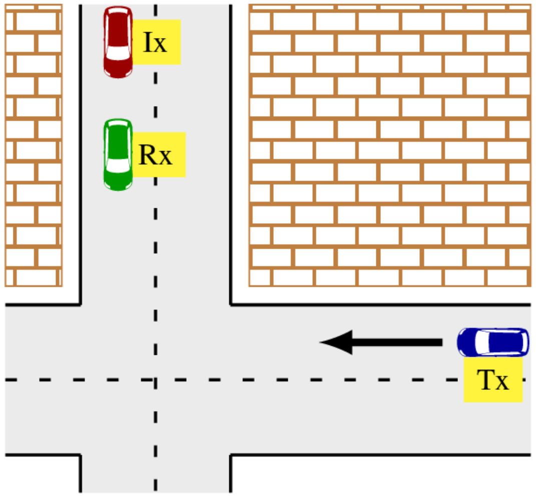
Evaluation of co-Channel Interference - Scenarios

- Real world experiments at **two** intersections
- Careful selection of **three** representative test **scenarios**

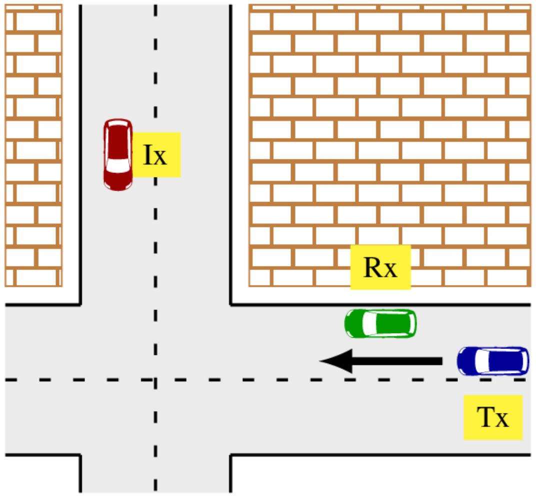
Scenario A



Hidden node effect

Emergency vehicle (Tx) traverses the traffic light (Emergency Vehicle Warning)

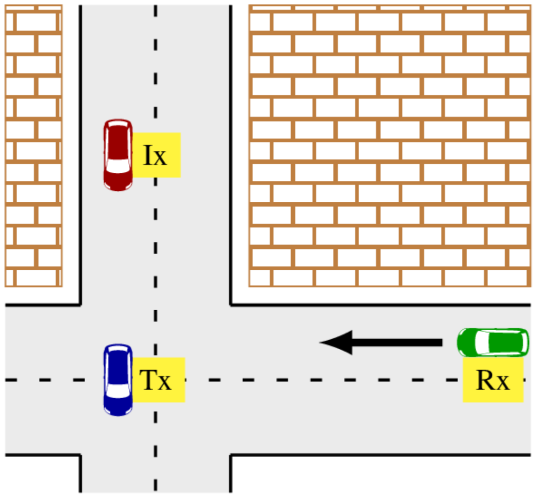
Scenario B



Impact of building shadowing

Building may block or limit the interference level from Ix

Scenario C



Impact of mobility

Near-Far Effect on the interference level from Ix

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Evaluation of co-Channel Interference - Intersections

Rural Intersection

Open area in the outskirts of Hannover (near IKEA)

Inner city Intersection

Urban intersection in Hannover (Linden, Elisen-Leinausstraße)

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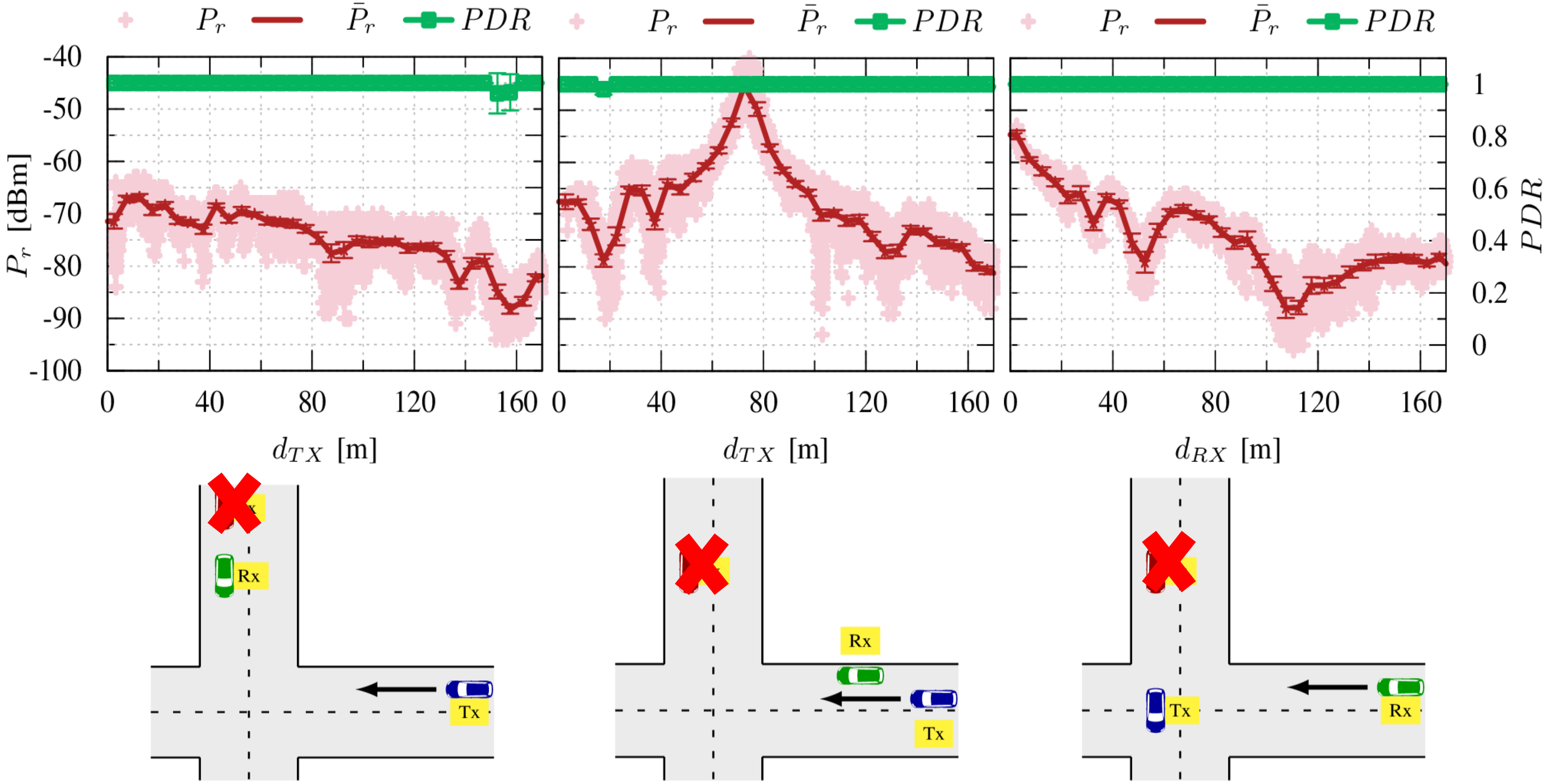
Rural City Intersection (without Interferer)

PDR: Packet Delivery Ratio



► High PDR due to constant availability of LOS leading to a low probability of multi-path components on the received signal

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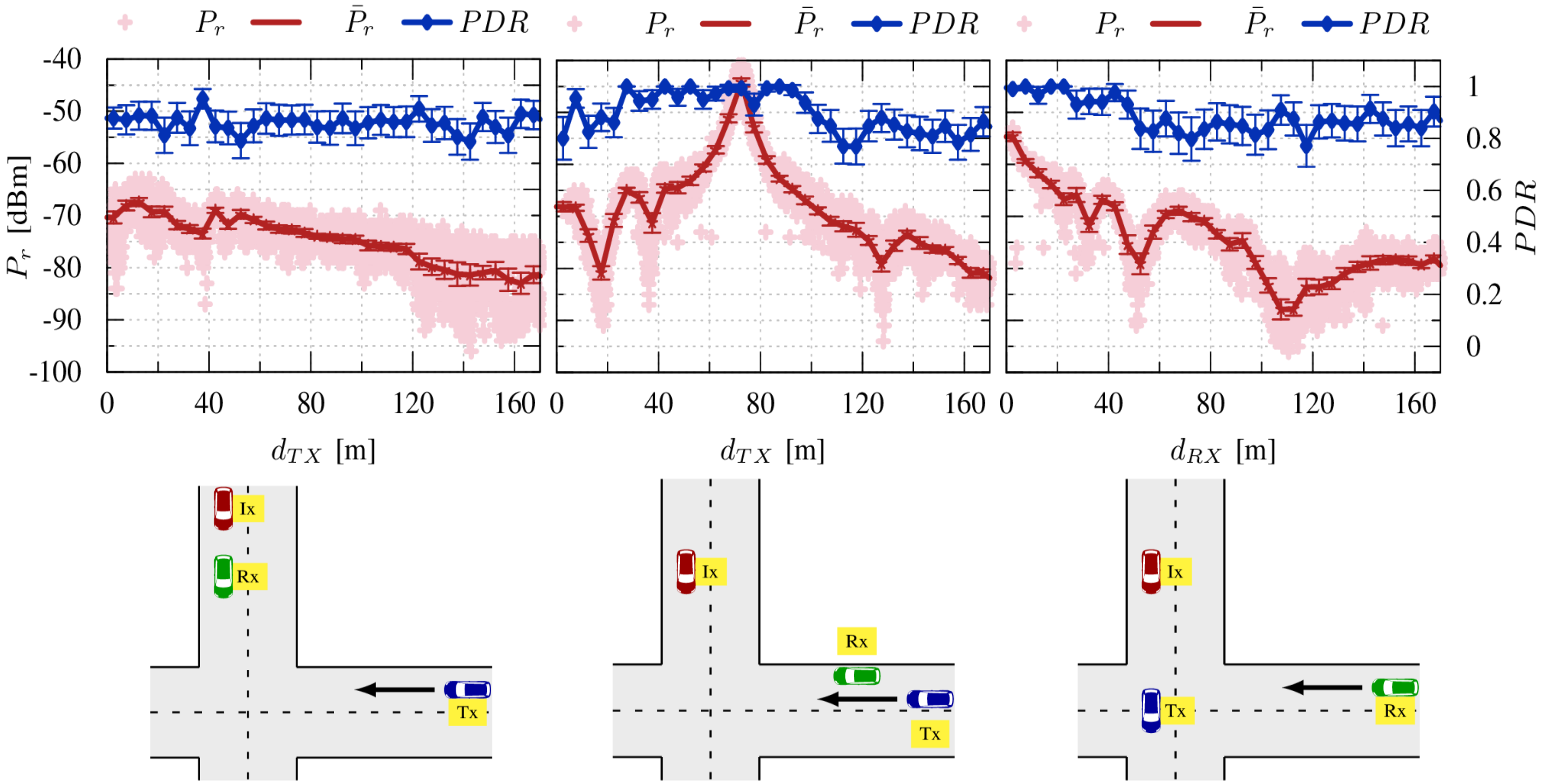
Rural City Intersection (with Interferer)

PDR: Packet Delivery Ratio



- ► Decrease of PDR of approx. 20% due to high number of packet collisions at the receiver

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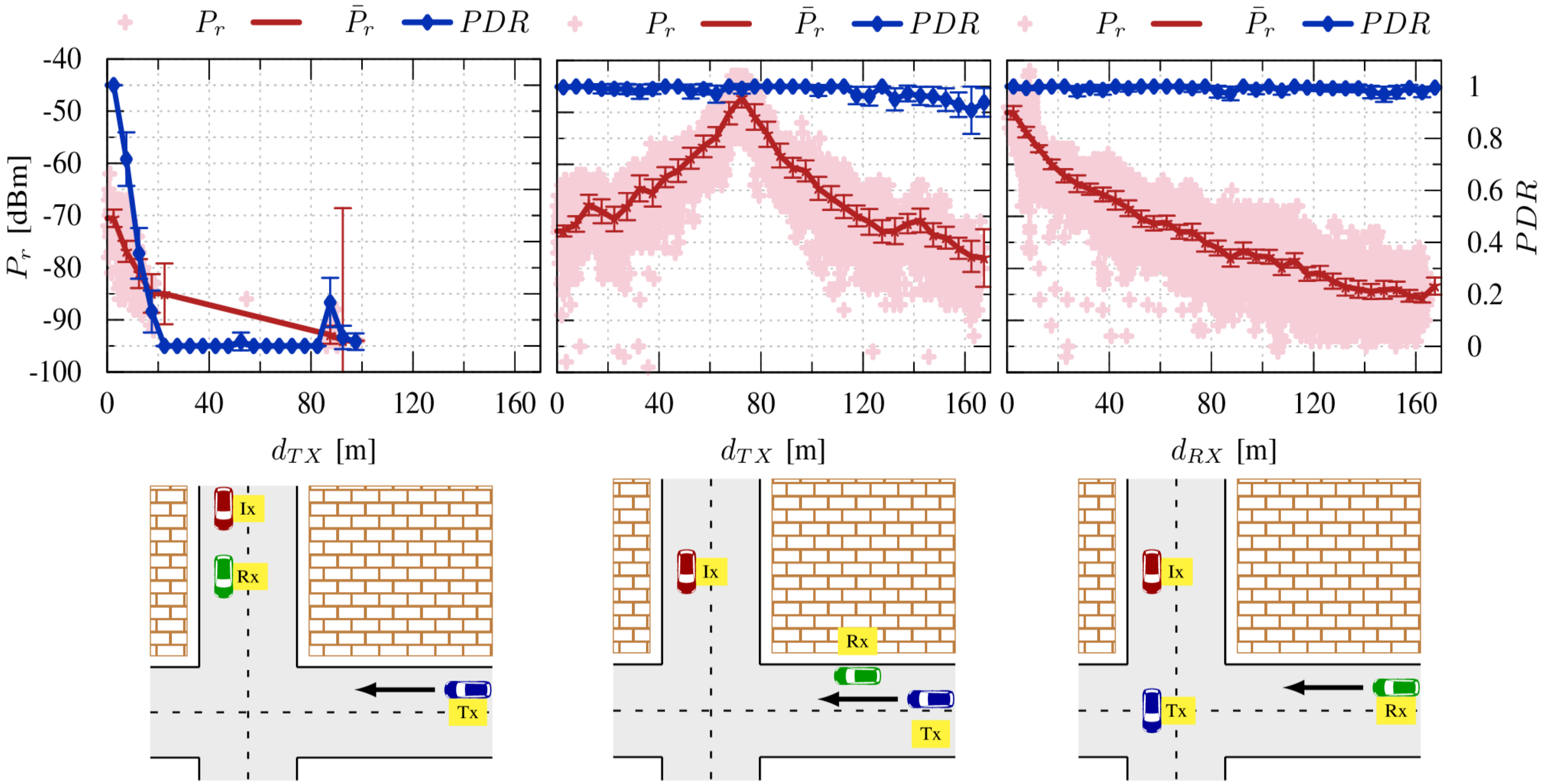
Inner City Intersection (with Interferer)

PDR: Packet Delivery Ratio



► Increase of PDR → Positive impact of buildings due to the attenuation of interfering signal by the building obstruction

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Demo – Emergency Electronic Brake Light

Electronic Brake Light

The Electronic Brake Light warns the driver early if a vehicle running ahead initiates an emergency brake.

The early warning prevents accidents and increases traffic safety particularly when the view on the braking vehicle is obstructed.

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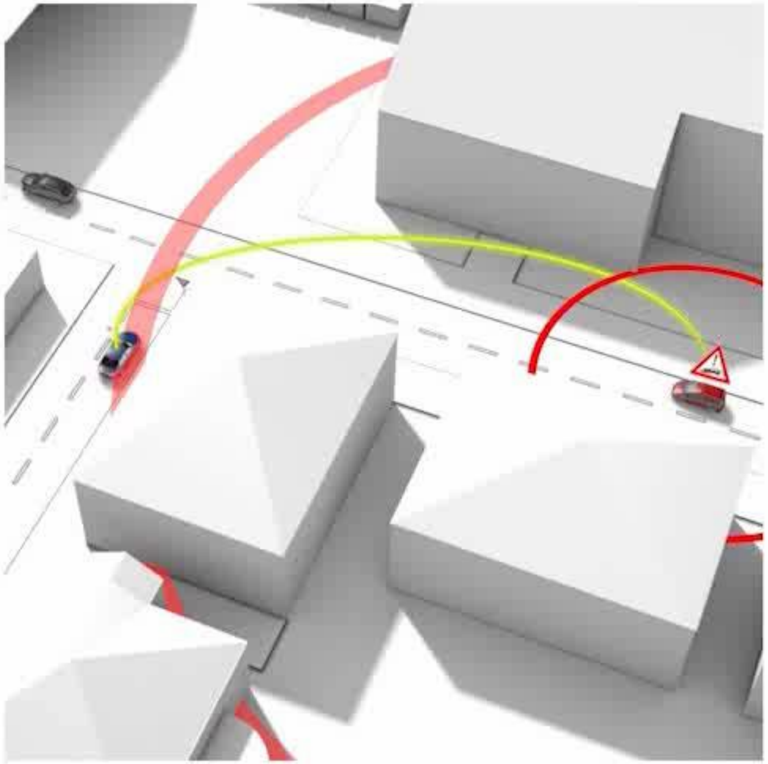
Demo – Intersection Traffic Assistant

Intersection and Cross Traffic Assistant

BOSCH
Invented for life



The Intersection and Cross Traffic Assistant informs the driver about crossing vehicles with right of way, especially when there is no line of sight between crossing vehicles.

This allows the simTD system to prevent accidents with cross-traffic in intersections.

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Demo – Platooning

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Demo – City Crossing

5G NetMobil:
City Crossing

BOSCH

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Vulnerable road user protection

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Literature

- ► H. Schumacher et al.: “Vehicle-to-Vehicle IEEE 802.11p performance measurements at urban intersections”, ICC 2012
- ► H. Tchouankem et al.: “Effects of vegetation on vehicle-to-vehicle communication performance at intersections”, VTC-Fall 2013
- ► H. Tchouankem and T. Lorenzen: “Measurement-based evaluation of interference in vehicular ad-hoc networks at urban intersections”, ICC 2015
- ► C. Sommer et al.: “Simulation Tools and Techniques for Vehicular Communications and Applications”, 2015