Visible Light Communication Technology – Challenges and Potentials for Connected and Autonomous Mobility Systems

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https://tu-dresden.de/bu/verkehr/vis/itvs?set_language=en

Agenda

1. **CV, Chair and Topics of University Research**
2. ICT-Systems - Information technology basics
3. Visible Light Communication (VLC) – Theoretical and Practical Foundation
4. Challenges and Potentials for VLC-based Mobility Systems
5. Conclusion and future outlook

1. CV Oliver Michler, University Full Professor

Scientific and Professional Positions (since 1993)

1993 - 1997	Scientific Staff and PhD-Research of TU Dresden, Faculty of Electrical and Computer Engineering
1997 – 2000	Scientific Project manager at Video-Audio-Design GmbH as a Telkom-Partner
2000 – 2005	Scientific Staff at Fraunhofer Institute for Transportation and Infrastructure Systems Dresden (FhG-IVI)
2005 – 2008	Professor at University of Applied Sciences Dresden in Signal Processing and Electronic Measurement Techniques
2010 – 2017	Head of department of TUD-Researchgroup at FhG-IVI
2008 –	Full Professor at TU Dresden in Systems Information Technology, Faculty of Transportation and Traffic Sciences
2019 -	Director of TU Dresden of Institute of Traffic Telematics
2017 -	Scientific advisory board member of MRK AG, Metirionic and ISCons and aeroLifi as a knowledge and research transfer role

Research topics

data-driven and model-based approaches, wireless mobility systems over all traffic carriers and services, autonomous driving, intelligent vehicle, next generation technologies based of communication/localization/sensing, software defined radio

1 University of Technology in Dresden (TUD)
The “Friedrich List” Faculty of Transport and Traffic Sciences

A unique, interdisciplinary competence center for transportation sciences

Dresden Institute of Automobile Engineering

Institute of Railway Vehicles and Railway Technology

Institute of Railway Systems and Public Transport

Institute of Logistics and Aviation

Institute of Transport Planning and Road Traffic

Institute of Traffic Telematics

Institute of Transport and Economics

iTVS
Informationstechnik für Verkehrssysteme

Technological and Market Progress in Transportation & Mobility

Changed Education in Transportation Engineering (Diploma, Bachelor, Master / international)

1 Fields of competence (ITVS)

Communication networks
Pico cell
(ZigBee, BLE, UWB, Lifi, …)

Communication networks
Micro cell
(Mobil radio, WLANp, …

Communication networks
Macro cell
(DAB+, …)

Multi Modal Traffic Carriers
Digital Synergies

Environmental perception via LIDAR / Camera

Multi-GNSS-tracking
(GPS, GALILEO, …)

Environmental perception via Radar

Multi-sensor data fusion (Integrity)

Precise georeferencing

Source: TTI-Education-Script, 2020, TU Dresden, Faculty Transportation+TrafficScience

1 Traffic ICT and Research fields of Chair competence

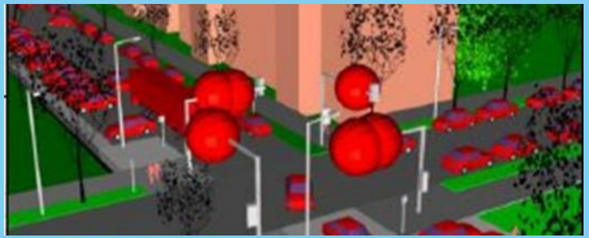
- **Overview:**

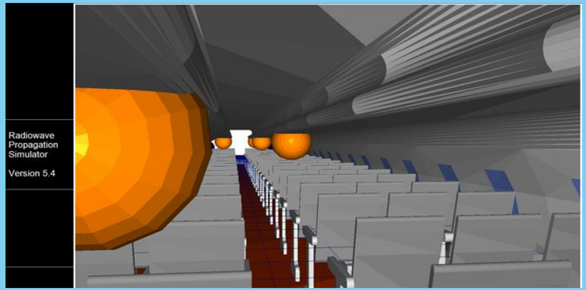
Simulation
Emulation
Radio planning

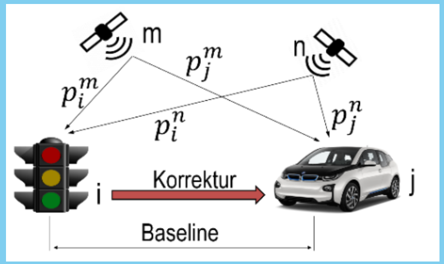
Networking
Localisation
Sensing

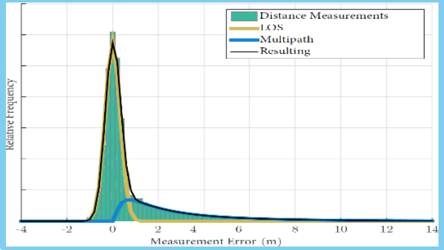
Lab Environment
Experimental -
Vehicles
Test fields

Big data
Statistics
Methodology
Procedures
AI/ML









Source: TTI-Education-Script, 2020, TU Dresden, Faculty Transportation+TrafficScience

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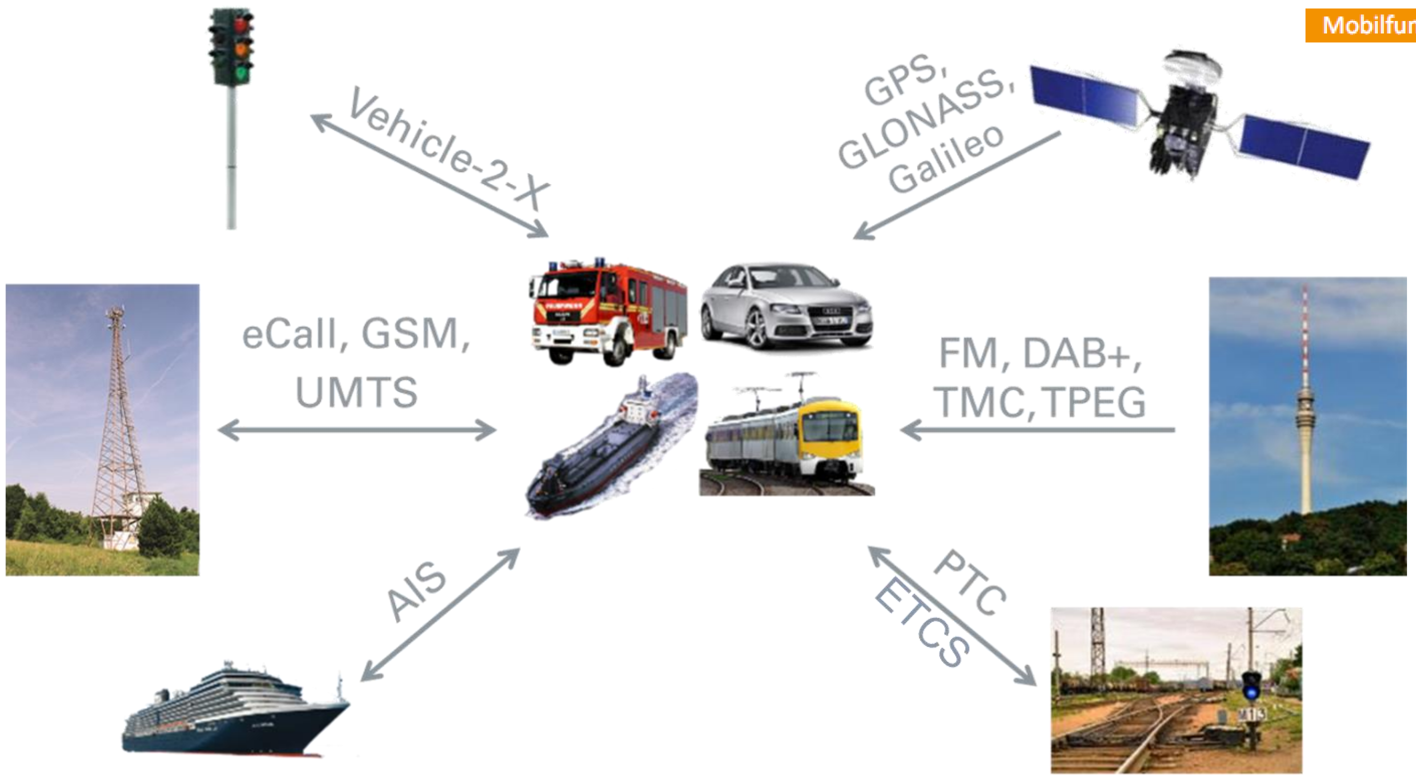
2 Introduction - Modern Systems and ICT-based Goal Formulation

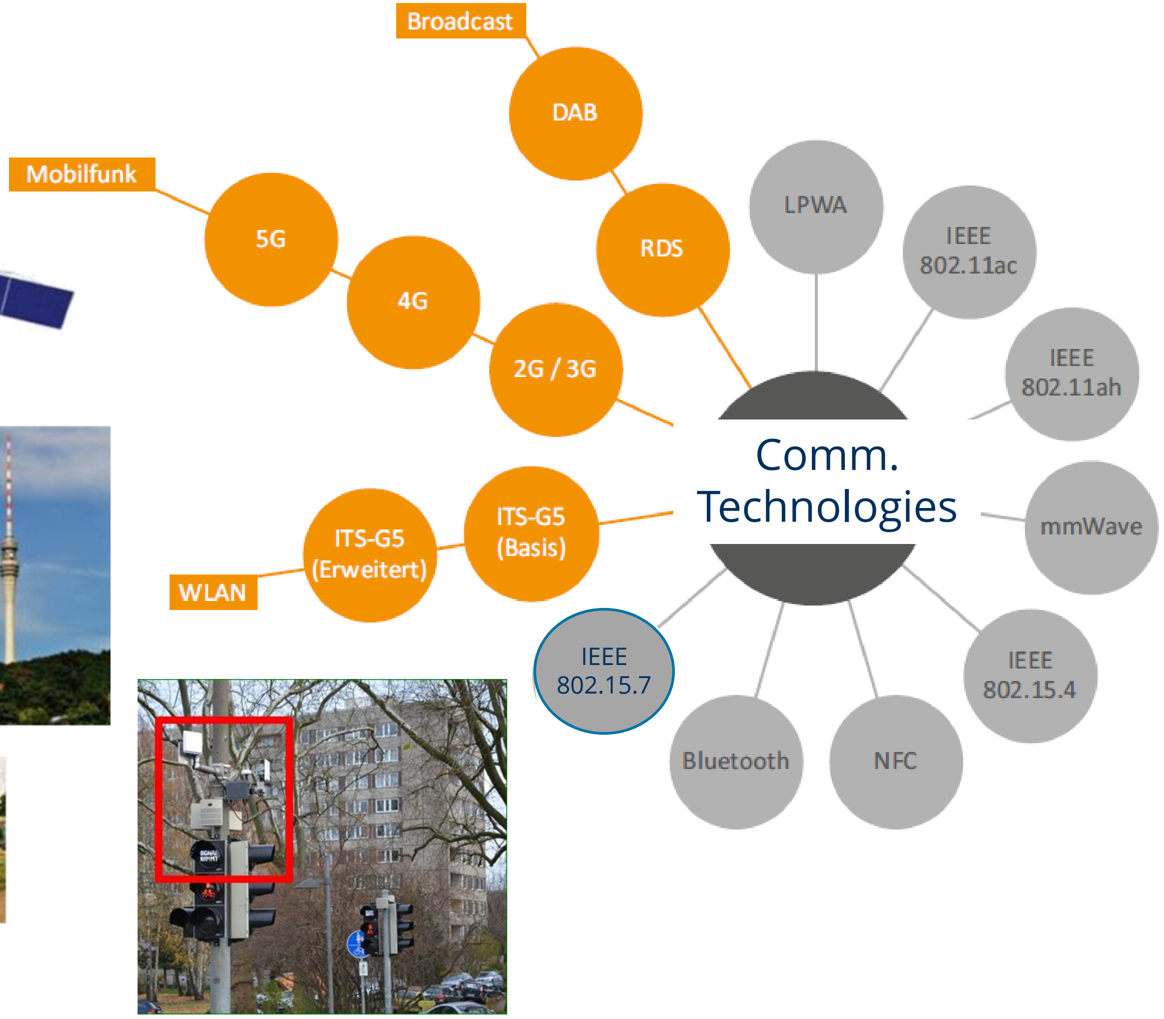
Everything moves and all is Conneced

Video at the end
Autonomous driving without traffic lights with LiFi as a part of critical V2X infrastructure

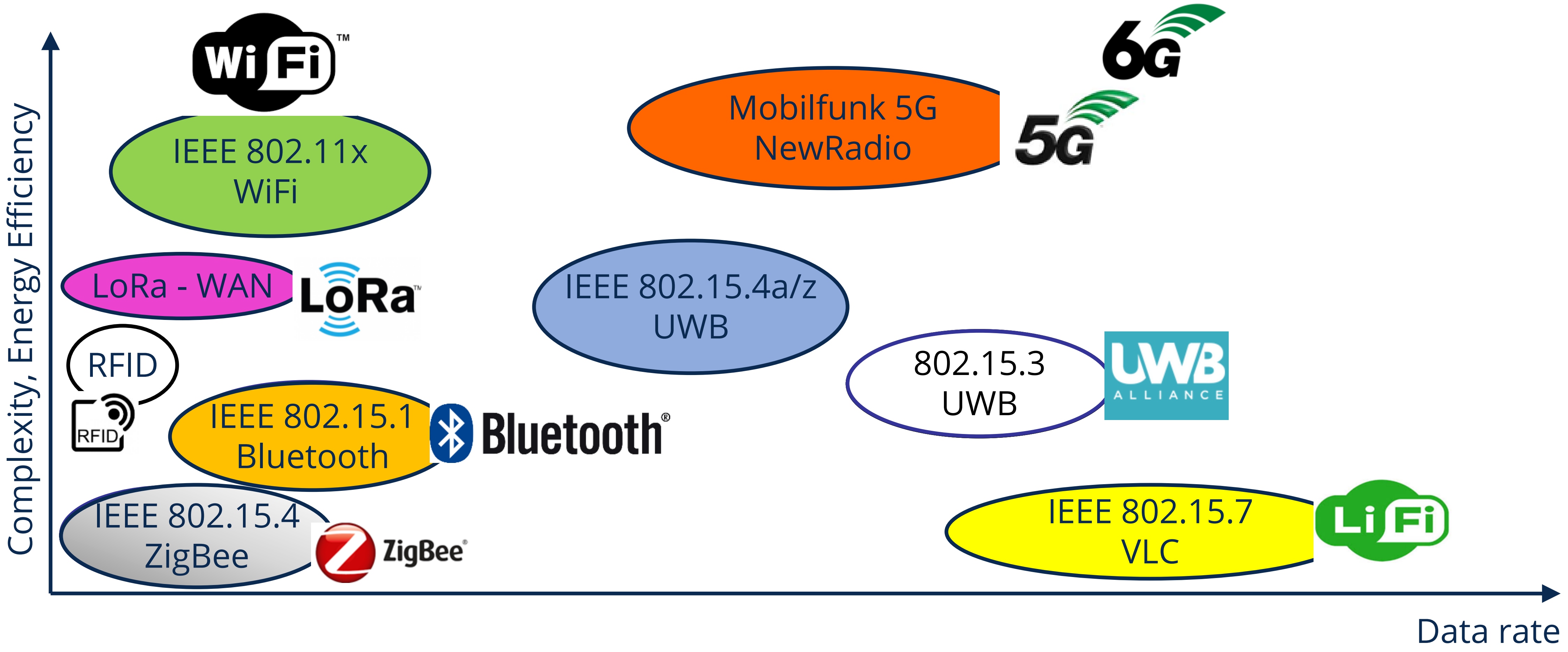
Source: TTI-Education-Script, 2020, TU Dresden, Faculty Transportation+TrafficScience

2 Variety of technologies and services for V2X / Classification





2 Variety of technologies and services for V2X / Performane



2 Information Technology Aspects / Chain and block structur

Source: TTI-Education-Script, 2020, TU Dresden, Faculty Transportation+TrafficScience

B
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g
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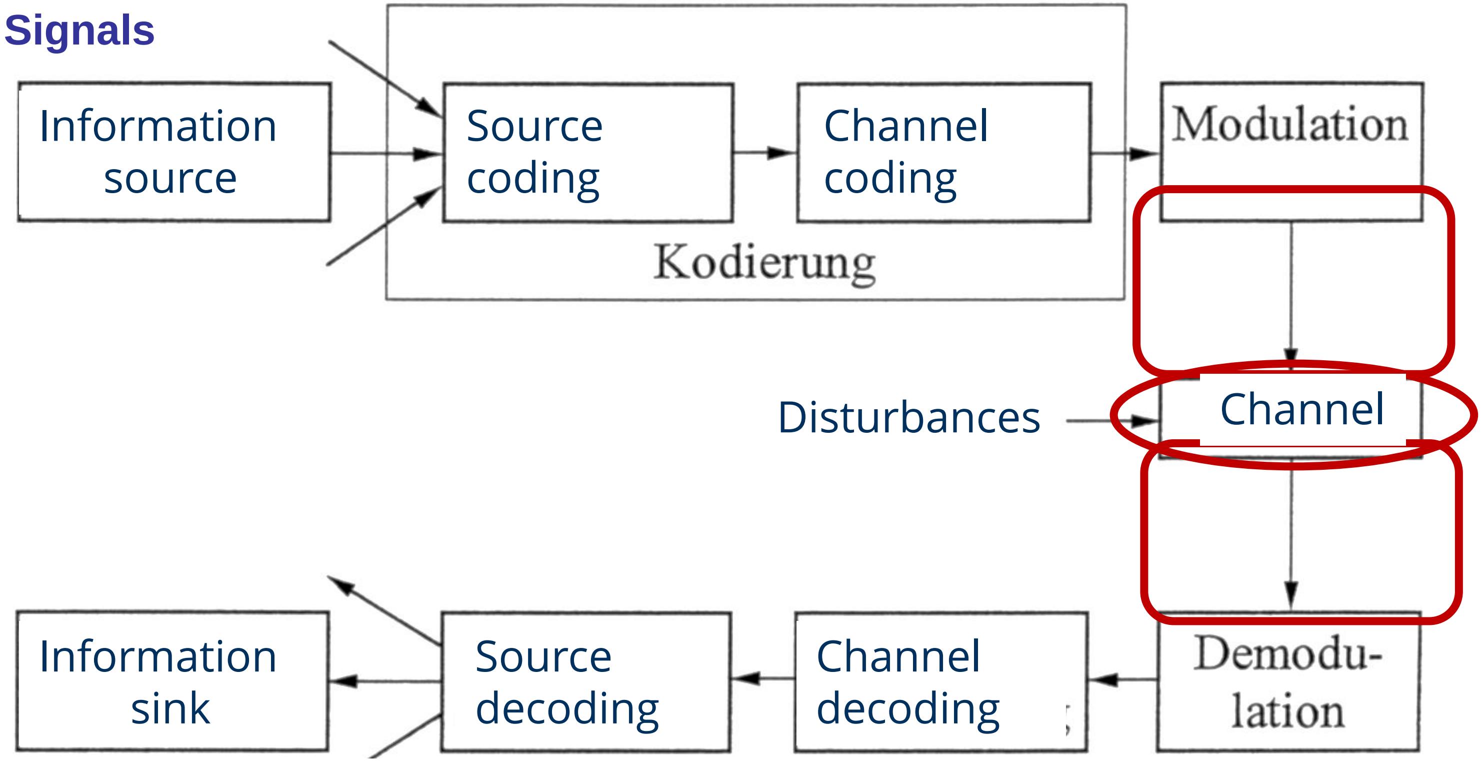
Signals

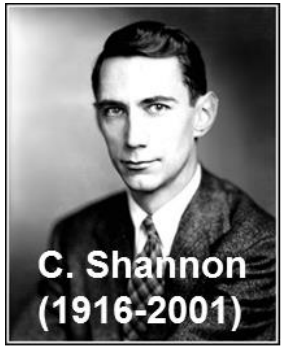


E
n
d

Transmitting Element (Antenna, ... ?)

Receiving Element (Antenna, ... ?)

2 Information Technology Aspects / Shannon bounds



Shannon Channel Capacity Theorem (1948)

$$C = B \cdot ld\left(1 + \frac{P_S}{P_N}\right)$$

$$ld(x) = \frac{lg(x)}{lg\,2}$$

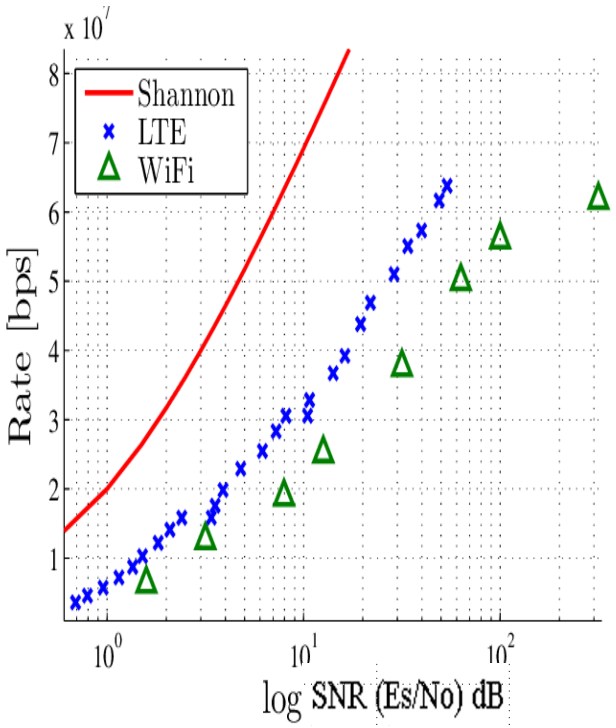
$$\frac{P_S}{P_N} >> 1$$

$$C \approx \frac{B}{3} \cdot \underbrace{10 \cdot \lg\left(\frac{P_S}{P_N}\right)}_{SNR_{dB}}$$

Bandwidth B / [MHz]

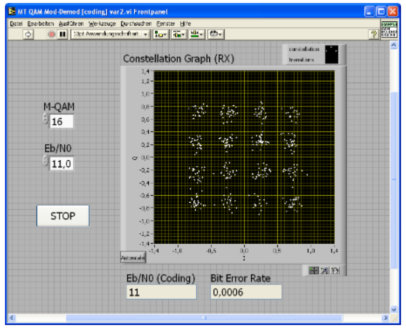
Channel capacity C max. Data rate [Mbps]

Signal-to-Noise Ratio SNR / [dB]



Quelle: https://www.researchgate.net/

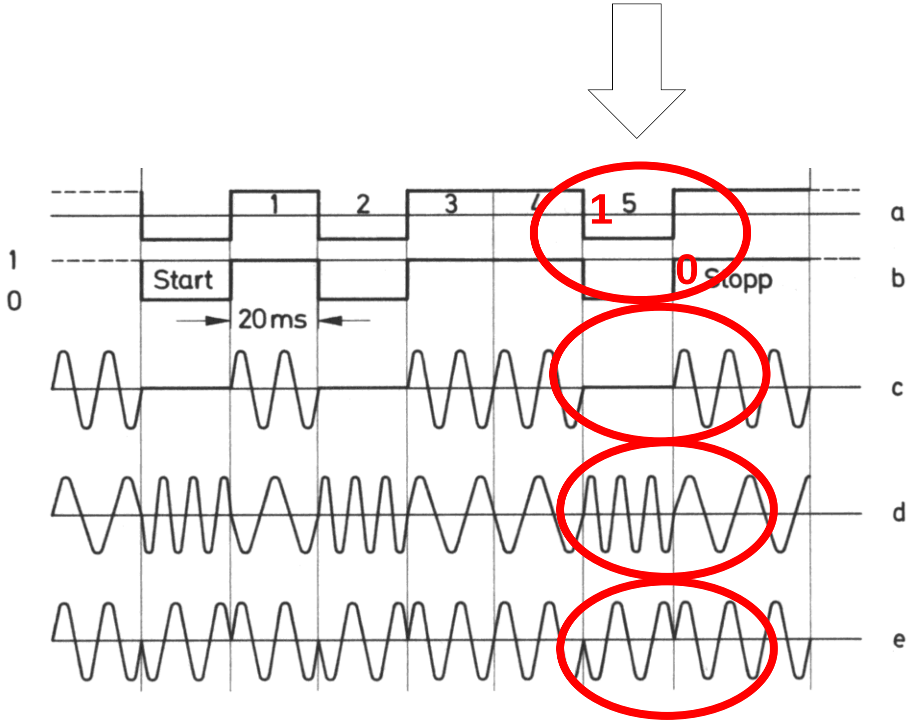
2 Information Technology Aspects / Modulation scheme



⇒ Carrier parameters:

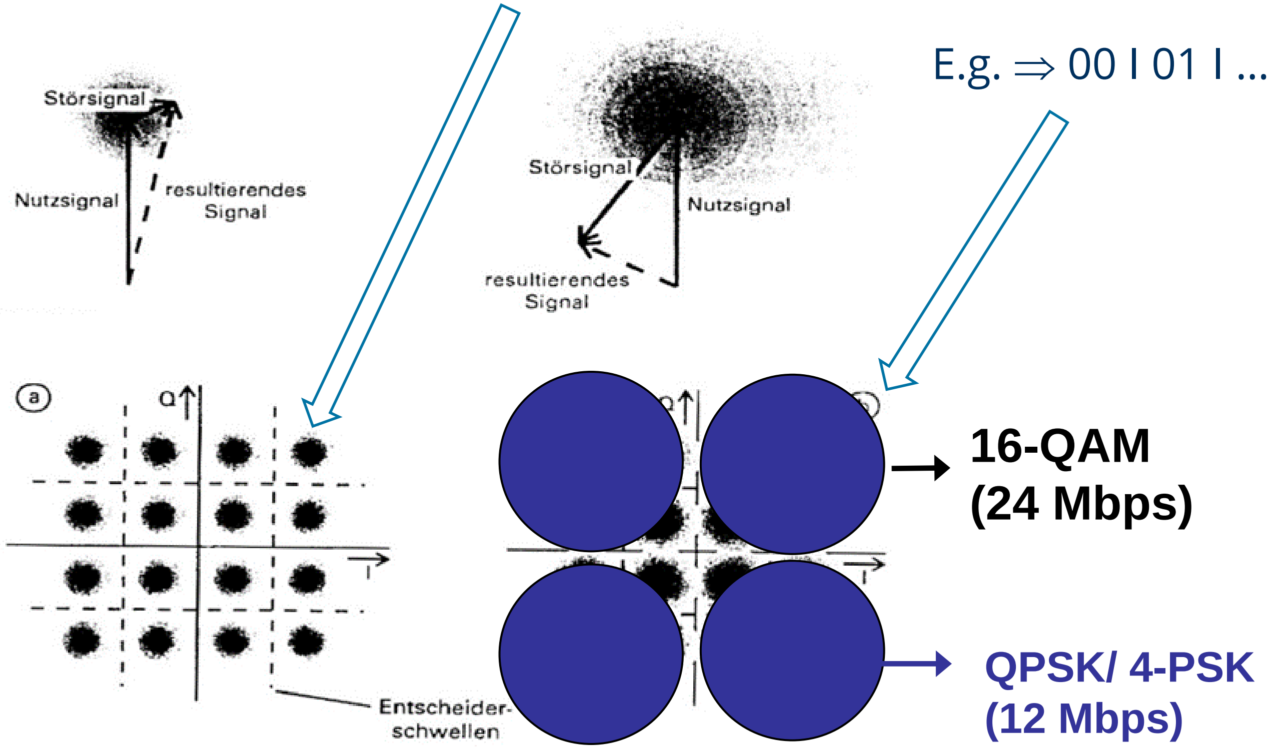
$s_T(t) = S_0 \sin[\omega_0 t + \varphi_0]$

ASK FSK PSK



E.g. ⇒ 0000 I 0001 I …

E.g. ⇒ 00 I 01 I …



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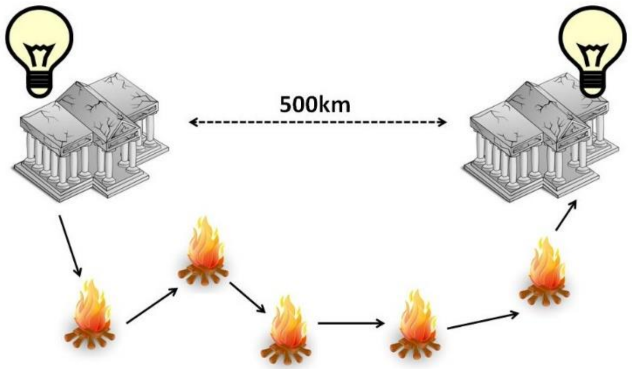
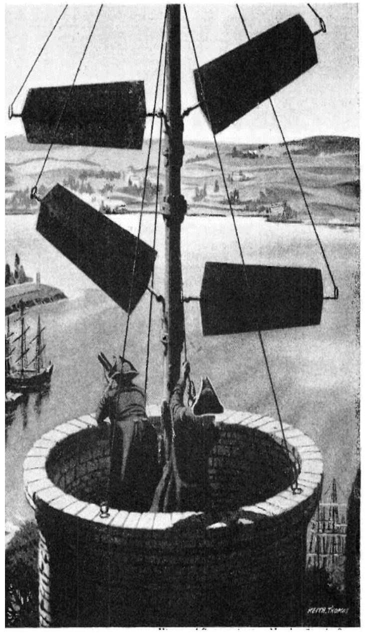
3 Visible Light Communication – Theoretical and Practical Foundation

⇒ History / Background

- Light has been used for data communication since a few thousands of years
- Smoke and fire signals were used for transmission of short message over significant distances
- Greek victory over Troja in the 12th century BC was delivered by means of fire signaling over a 500 km distance from Troja to Argos
- Later, signaling towers were built for the purpose of optical communication
- First optical telegraph was developed in 1794 (Paris to Lille in 6 min. over 200km - because of mechanics …)
- Optimized over signaling arms (paddels) , efficient encoding/encryption with a higher data rates could be realized





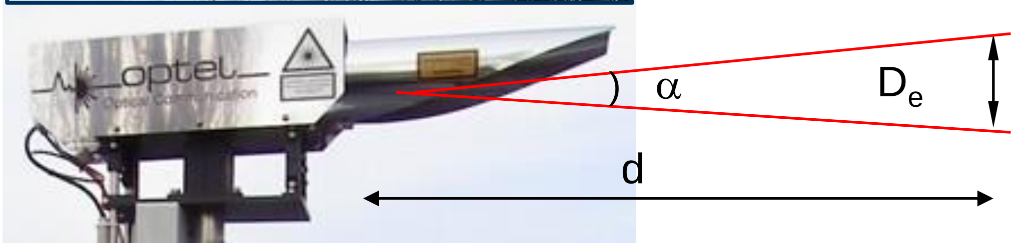
Source: TTI-Education-Script, 2020, TU Dresden, Faculty Transportation+TrafficScience

3 Visible Light Communication – Theoretical and Practical Foundation

⇒ History / Free Space Optics (FSO) with Laser

Requirements
- electrical pulse sequence
- Optical transmitter
- Beam focus
- Optical receiver
- Line of sight

Beam Divergence	Beam width 500 meters	Beam width 1,000 meters
1 mrad	0.5 m	1 m
2 mrad	1 m	2 m



Geometric attenuation

$$a_{geo}/dB = 20 \cdot \log\left(\frac{\alpha \cdot d}{D_e}\right)$$

Power loss
- Optical loss (transmittance of the optics with approx. 4dB)
- Geometric loss (divergence of optical beam, e.g. 4mrad)
- Alignment loss
- Atmospheric loss (scattering, absorption, turbulence, ...)

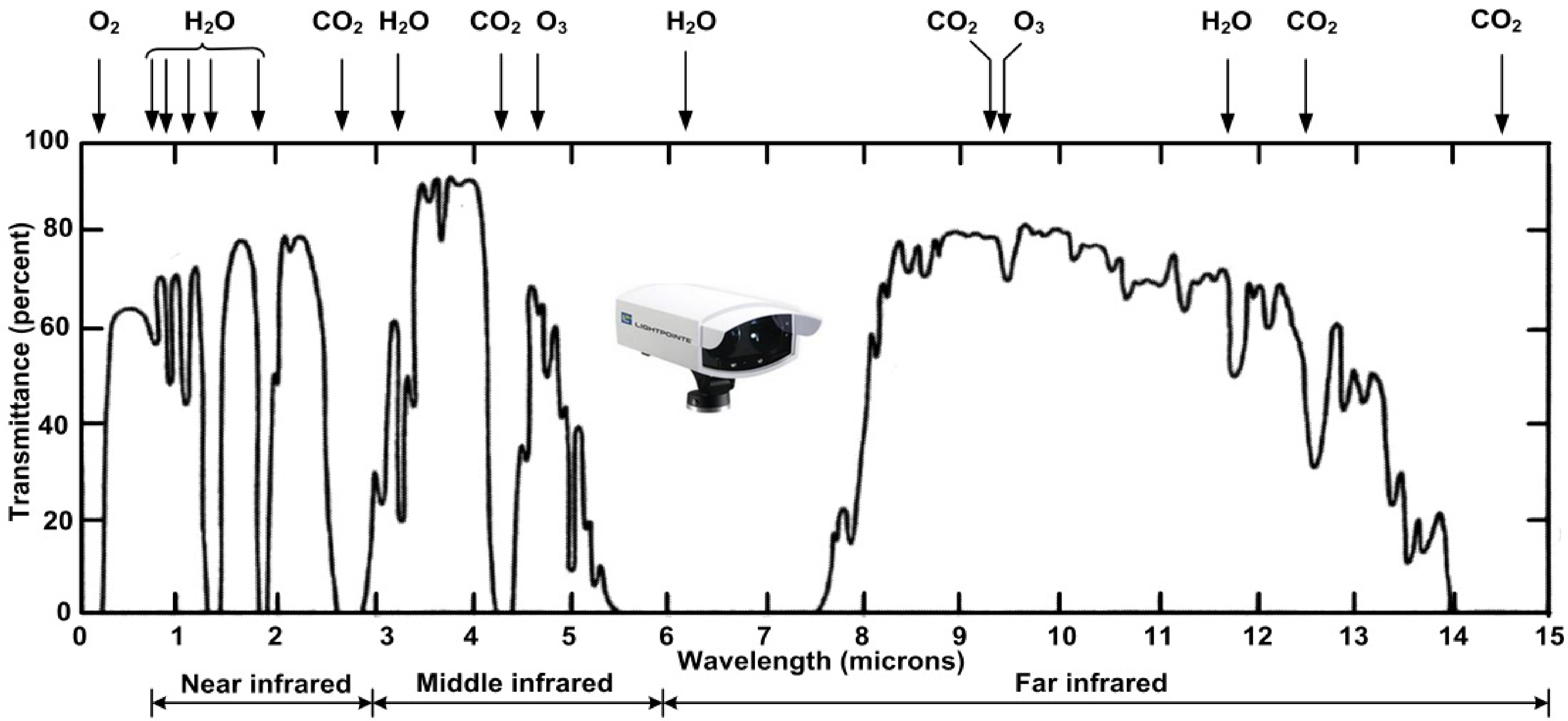
Scattering attenuation

$$a_{Streu} / \frac{dB}{km} = f\,(Visual\ range)$$

$$= \frac{17}{S/km}\left(\frac{0{,}55}{\lambda/\mu m}\right)^{0{,}195 \cdot S/km}$$

3 Visible Light Communication – Theoretical and Practical Foundation

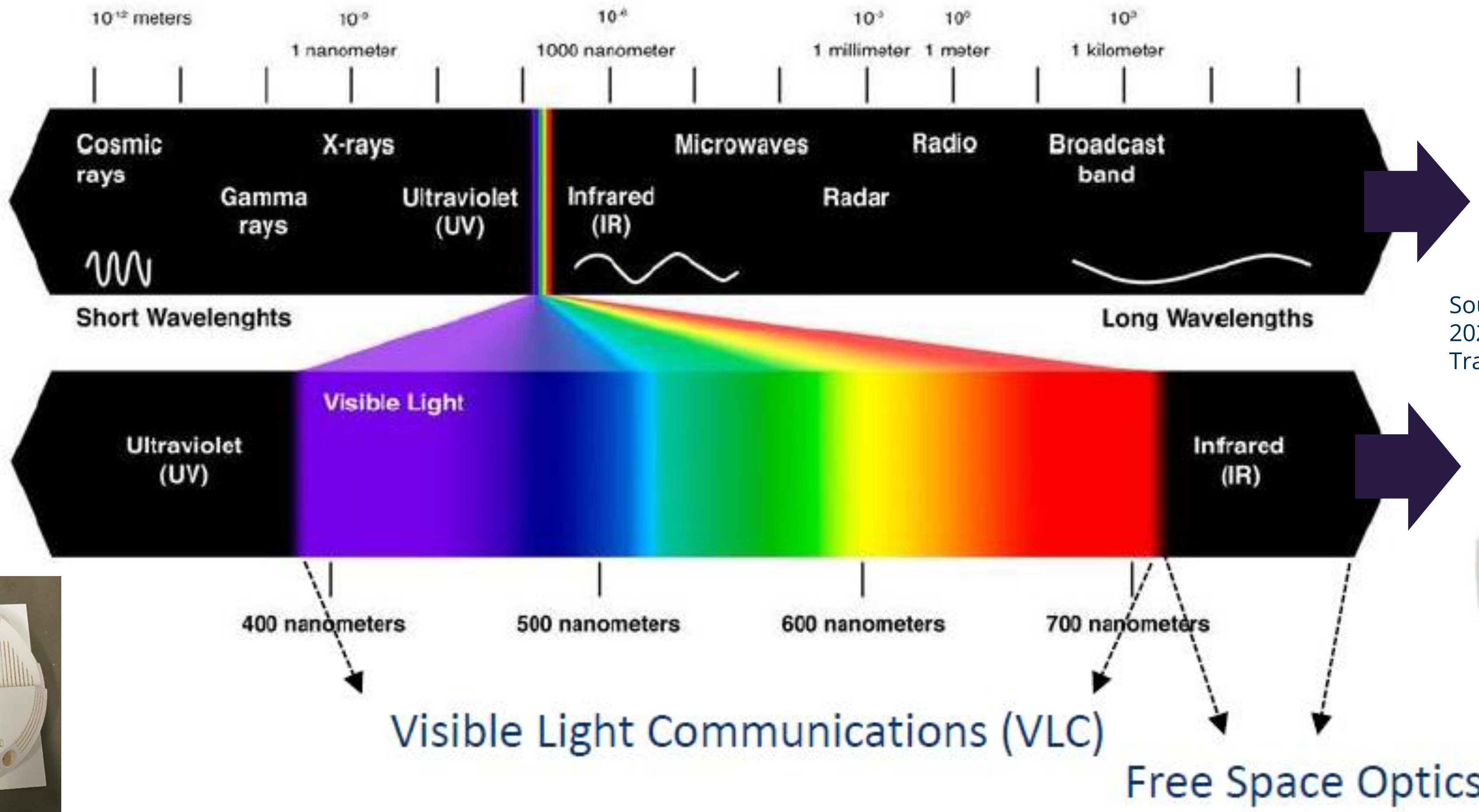
⇒ History / Free Space Optics (FSO) – Optical windows and technical working area



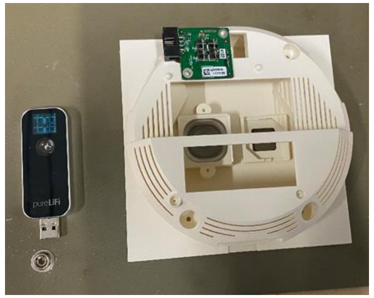
Horizontal atmospheric transmission

3 Visible Light Communication – Theoretical and Practical Foundation

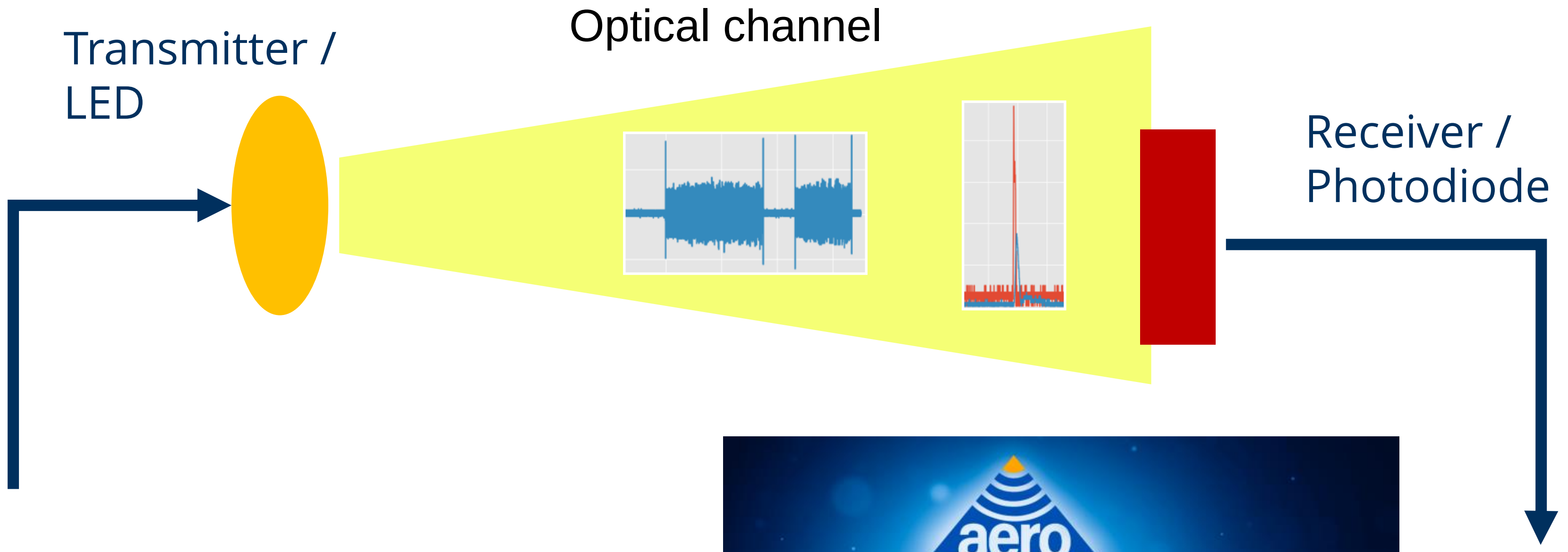
⇒ Free Space Optics (FSO) and Visible Light Communication (VLC) – Frequency range / classification

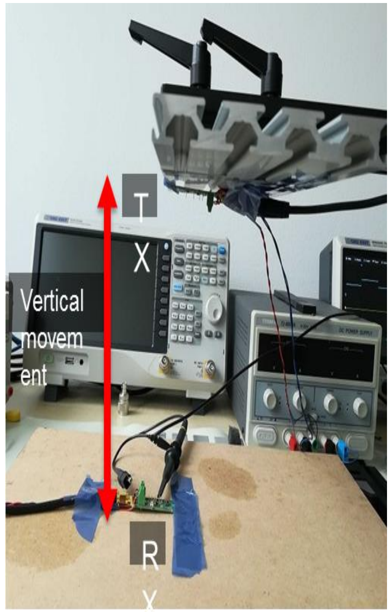


Source: TTI-Education-Script, 2020, TU Dresden, Faculty Transportation+TrafficScience



3 Visible Light Communication – Theoretical and Practical Foundation





- Signal generation
- Pulse shape modulation
- Coding
- Information supply

Start up company Munic/Germany

- Raw data evaluation
- Channelequalization
- Decoding
- Data receiving

3 Visible Light Communication – Theoretical and Practical Foundation

⇒ Motivations for Using Visible Light Communication (VLC)

- Energy efficiency (infrastructure ready)
- Low-cost hardware (smart LED lamps)
- Huge unregulated bandwidth (spectral view)
- License-free operation (outside from regulation)
- High signal-to-noise ratio (beam focusing)
- Interference immunity (beam isolation)
- MIMO-functionality (RGB-color mix)
- Very hight data rates up to 10 Gbps
  (higher modulation: QAM, MCM, DCSK)
- Area spectral efficiency (space diversity)
- Electromagnetic compatibility (RF-free)
- Data security (jamming-/spoofing-free)
- Interoperabiliy (IEEE 802.15.7-Standard)

$$C \approx \frac{B}{3} \cdot \underbrace{10 \cdot \lg\left(\frac{P_S}{P_N}\right)}_{SNR_{dB}}$$

Bandwidth B / [GHz]

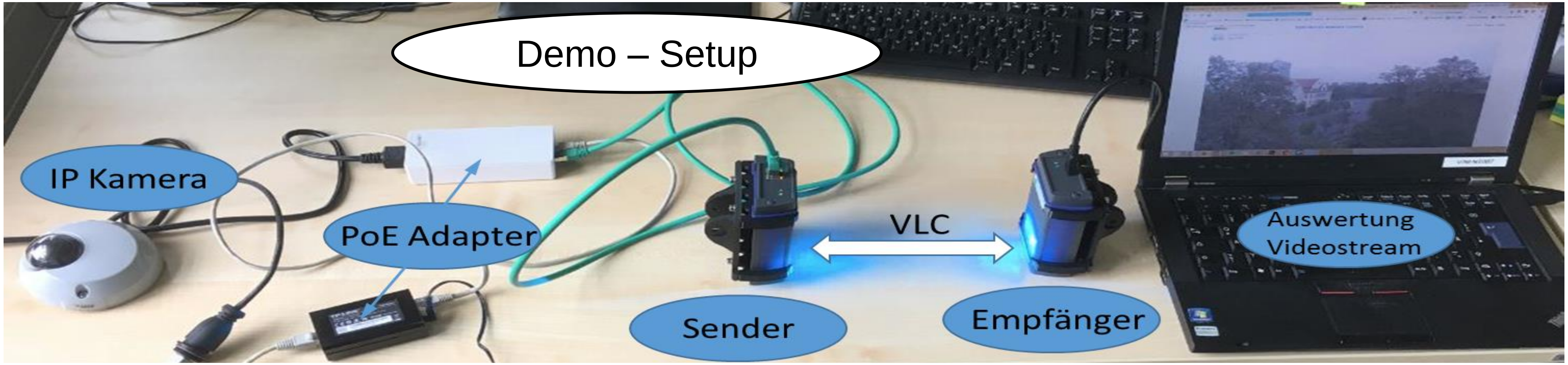
Channel capacity C max. Data rate [Gbps]

Signal-to-Noise Ratio SNR / [dB]

Source: TTI-Education-Script, 2020, TU Dresden, Faculty Transportation+TrafficScience

3 Visible Light Communication – Theoretical and Practical Foundation

⇒ Experiment test and technical environment (500 Mbps)

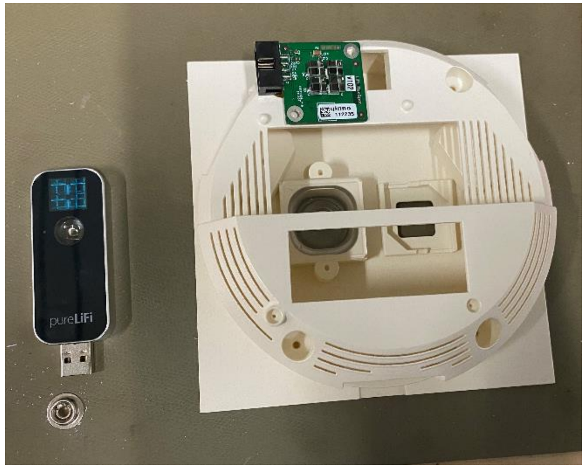


FIREFLY
WIRELESS NETWORKS

Device
Link
Link Performance
IP
Ethernet

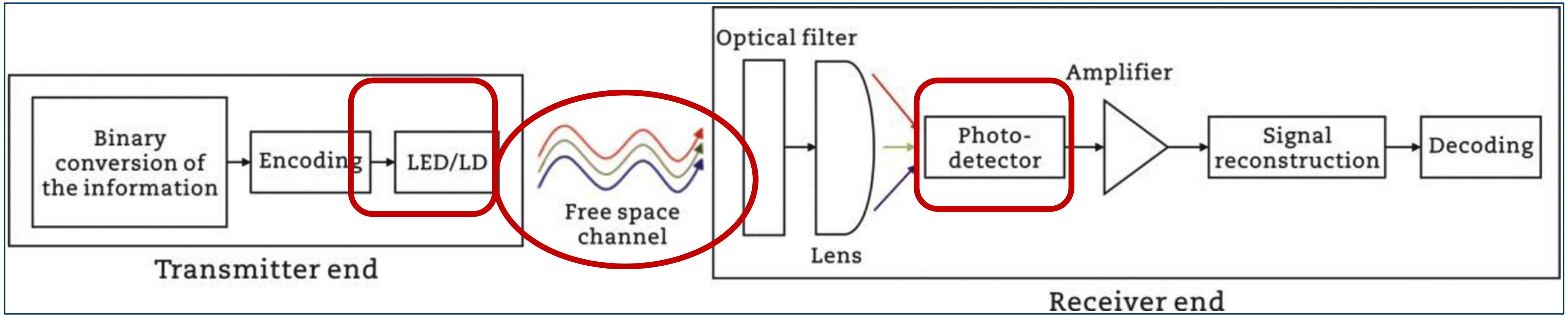
Available Connections

Device ID	MAC Address	Phy Tx (Mbps)	Phy Rx (Mbps)
2	00:04:e7:01:01:32	467	478



3 Visible Light Communication – Theoretical and Practical Foundation

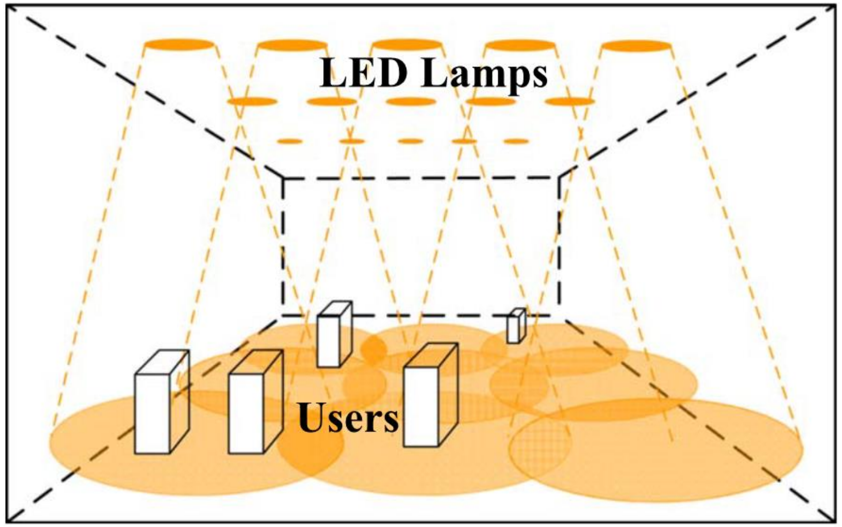
⇒ Experiment test and technical environment (10 Gbps)

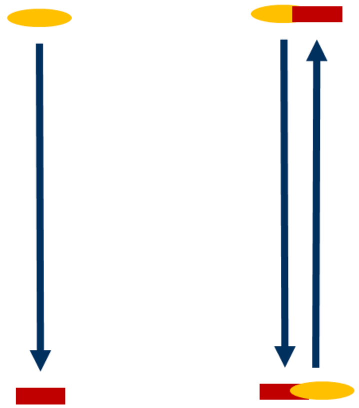


3 Visible Light Communication – Theoretical and Practical Foundation

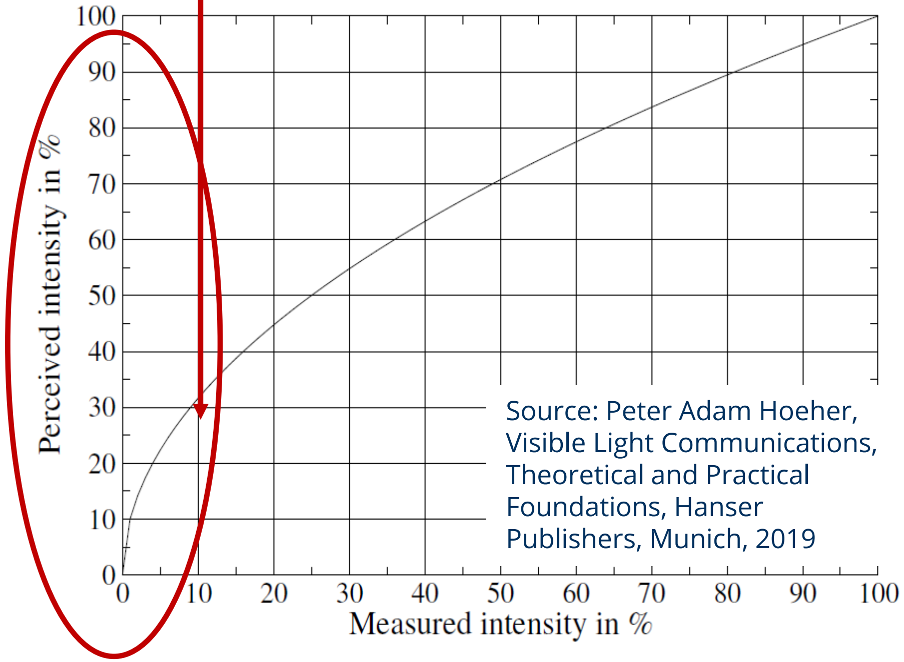
⇒ Problems and boundaries for Using Visible Light Communication (VLC)

- Deactivation / Switching of light (IR, RF and residual light processing)
- Shadowing blocking (LOS missing but NLOS / diffraction or scattering possible)
- Interference with daylight (outdoor) and artificial / consumer Light
- Two way communication (Up-/Downlink, Duplex communication)
- Limited bandwidth per LED with 2MHz (white), 20 MHz (RGB), 50 MHz IR, but up to 500 MHz blue/cyan GaN-LEDs expected)
- Visibility for optical relaying





Ratio of perceived brightness to measured brightness



Source: Peter Adam Hoeher, Visible Light Communications, Theoretical and Practical Foundations, Hanser Publishers, Munich, 2019

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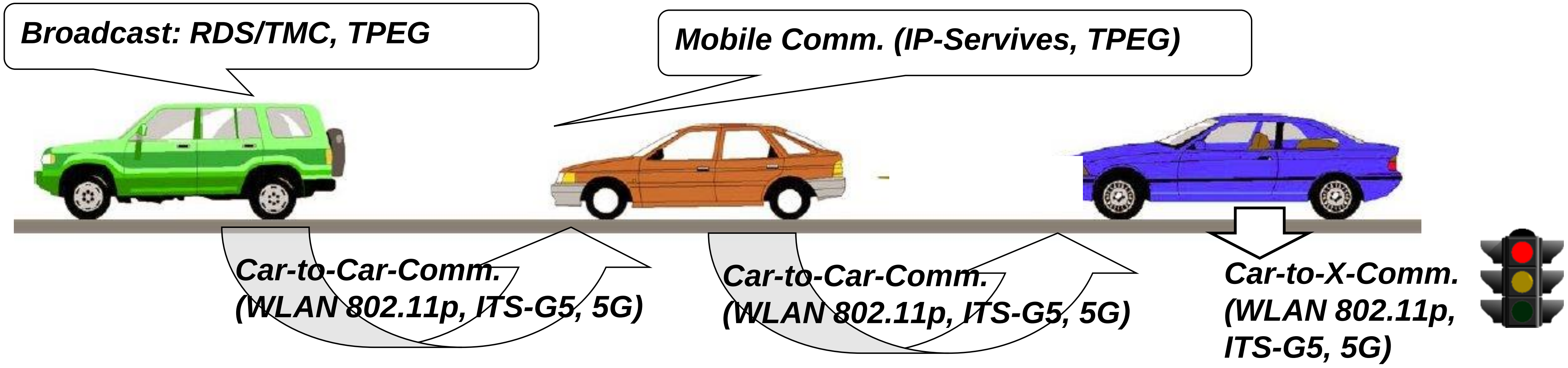
4 Challenges and Potentials for VLC-based Mobility Systems

⇒ V2V and V2X: State of the art



⇒ LiFi / VLC Use case with V2V

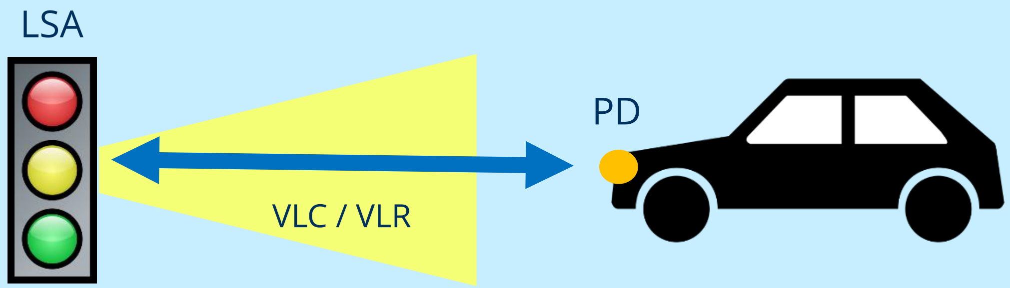
- bidirectional communication (D2D)
- ranging (distance measurement)
- Monostatic/bistatic environment detection

Vehicle-to-Vehicle (V2V)

4 Challenges and Potentials for Mobility Systems

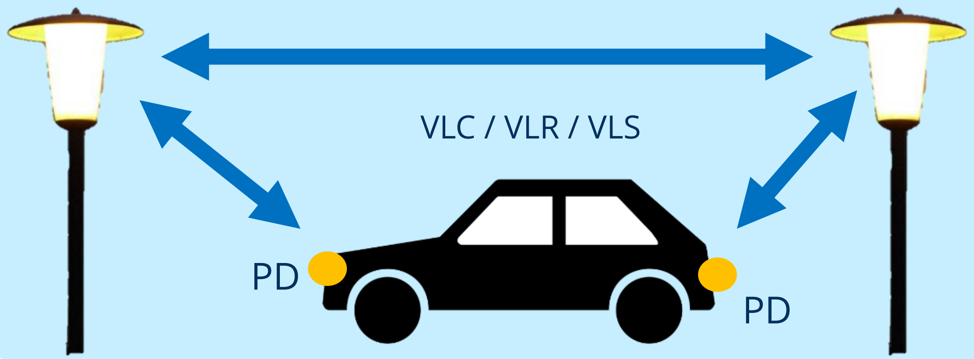
⇒ LiFi / VLC Use case with V2I

Vehicle-to-Infrastructure (V2I)



- Communication - Transfer of signal signs of the traffic light system via communication channel
- Green Light Optimization Speed Advisory (GLOSA)
- Transmission of GNSS correction data + virtual reference station
- Distance measurement to the LSA via ranging / landmark (relative and absolute positioning)

Vehicle-to-Infrastructure (V2I)



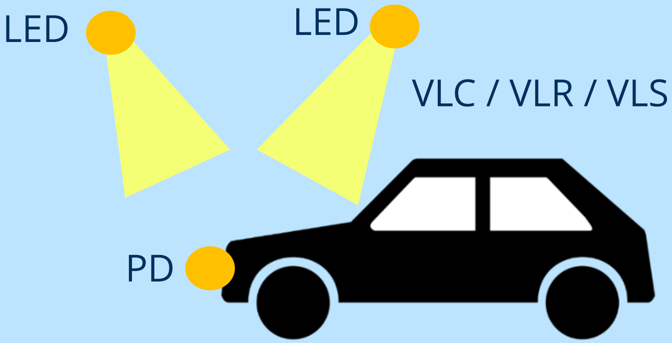
- Communication between streetlights
- Active and passive parking lot detection and vehicle detection
- Application as traffic flow sensor
- Use of the latern as a landmark with specific ID for positioning

4 Challenges and Potentials for Mobility Systems

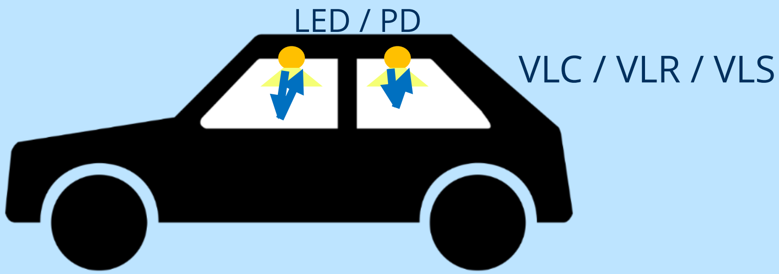
⇒ LiFi / VLC Use case with V2I

Smart Parking - Parkhaus

- Parking lot occupancy
- Information exchange between infrastructure and vehicle
- Tracking of vehicles in the parking garage



Vehicle Passenger Cell



- Seat-selective broadband communication
- Seat occupancy as passive radar
- Typically by means of LED array

4 Challenges and Potentials for Mobility Systems

⇒ **Use Case Testbed Scenario A: Project PHYSICS – Critical infrastructure protection (1)**

TECHNISCHE UNIVERSITÄT DRESDEN

ITVS

DRESDEN concept

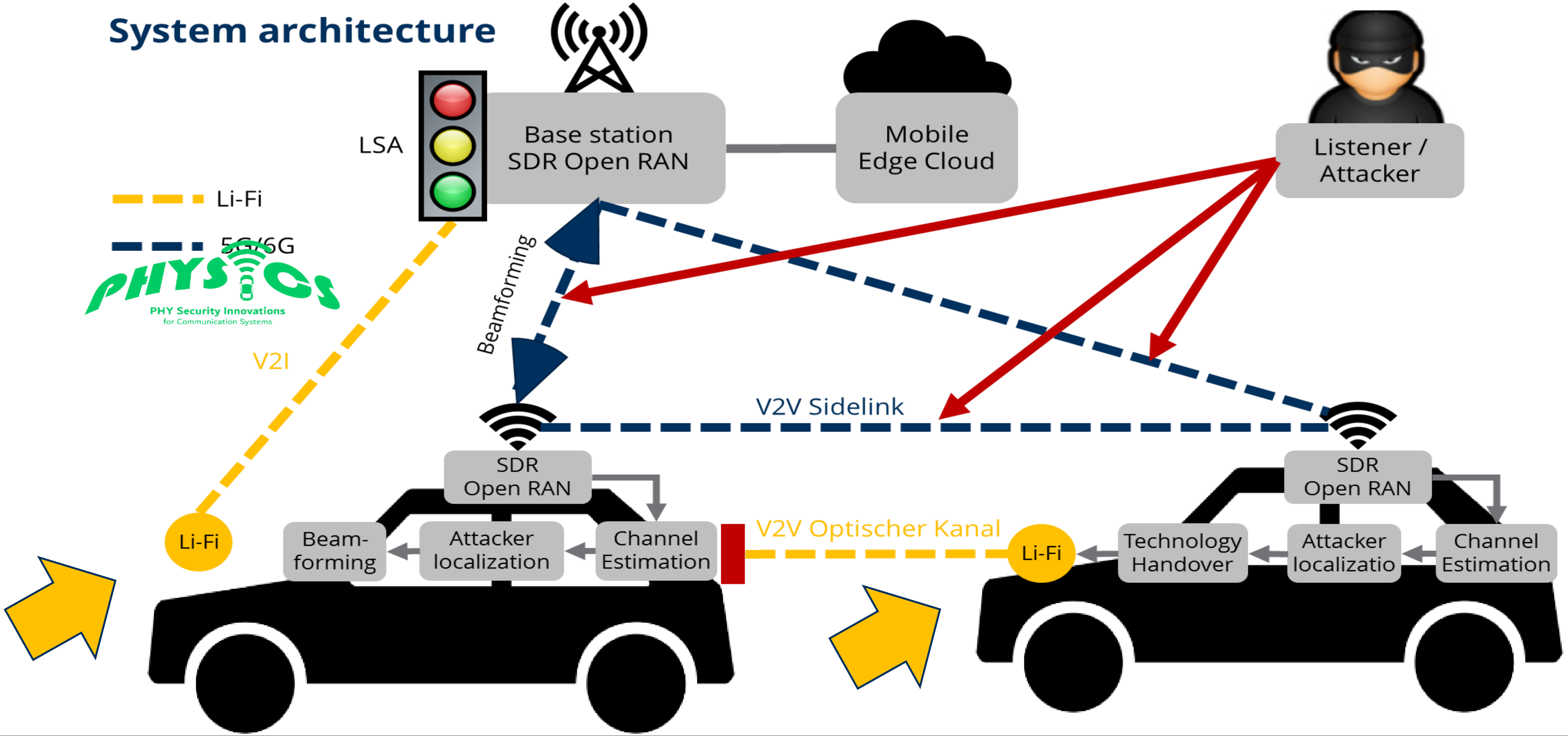
Dipl.-Ing. Jonas Ninnemann
Chair of Transport Systems Information Technology, Institute of Traffic Telematics, TU Dresden

PHY Security Innovations for Communication Systems (PHYSICS)

Januar 2023

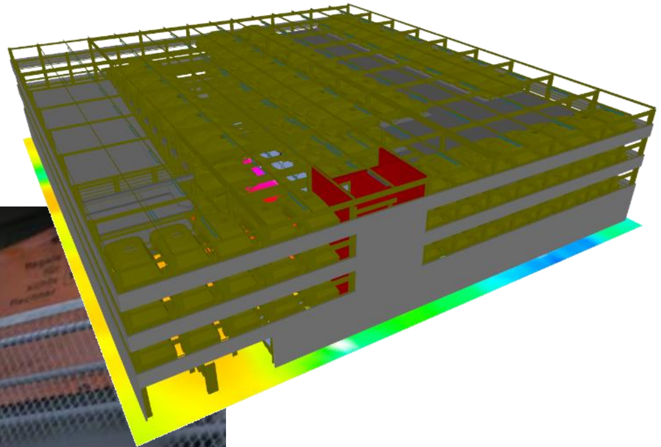
4 Challenges and Potentials for Mobility Systems

⇒ Use Case Testbed Scenario A: Project PHYSICS – Critical infrastructure protection (2)



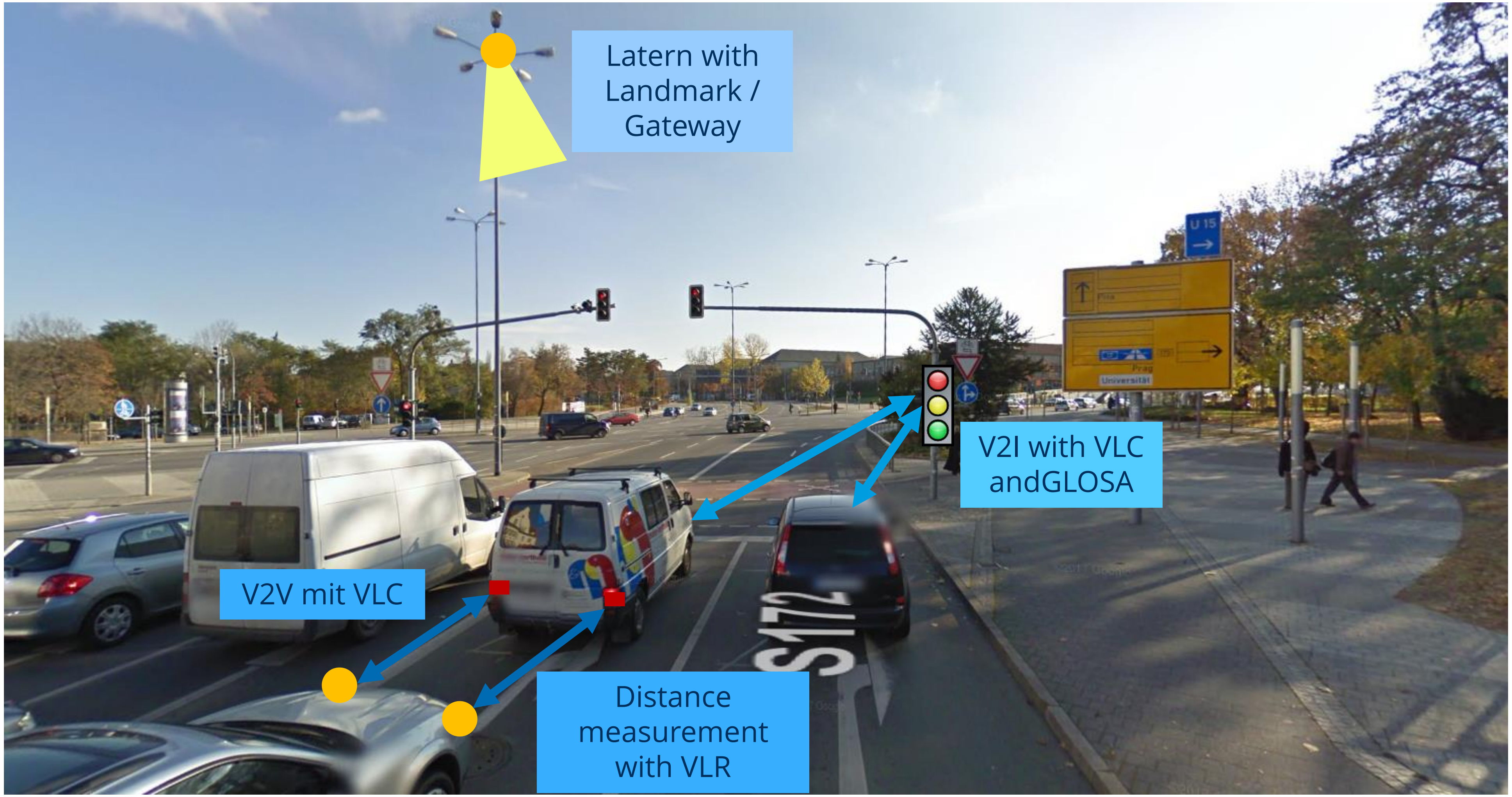
4 Challenges and Potentials for Mobility Systems

⇒ Use Case Testbed Scenario B: Parking Hause BIC Leipzig



4 Challenges and Potentials for Mobility Systems

⇒ **Use Case Testbed Scenario C: Testfeld Highway B170/172**



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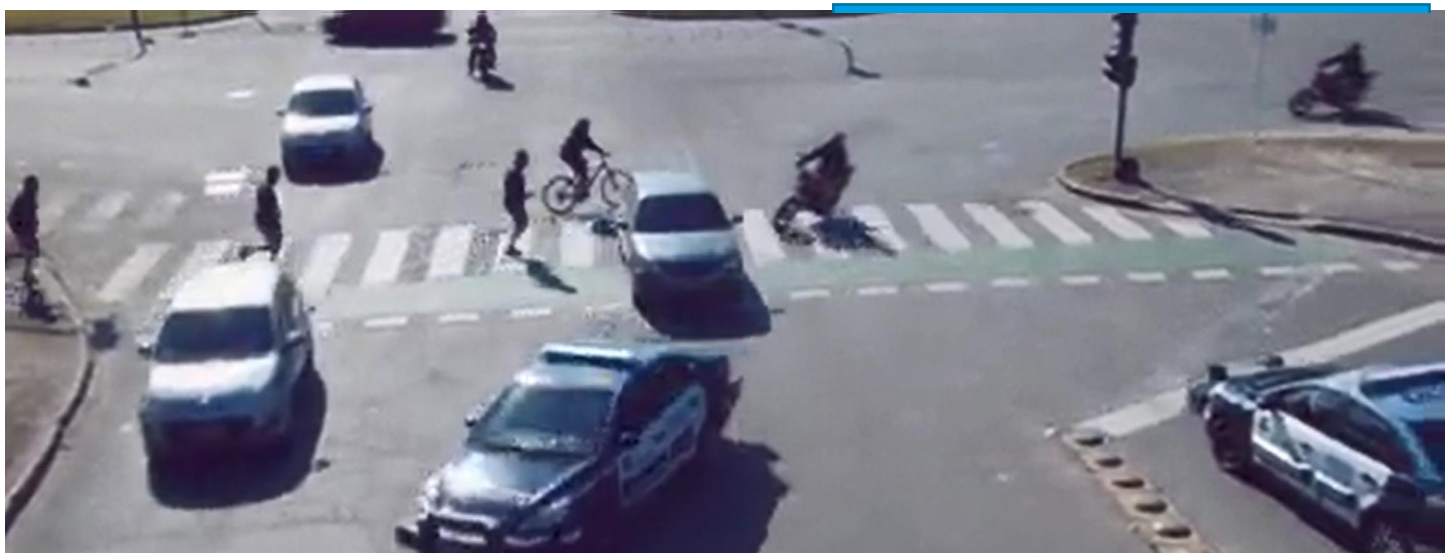
5 Conclusion and future outlook

Autonomous driving



MixFutureTraffic

Fully saved and trusted (VLC?) connected vehicles in mixed traffic types

5 Conclusion and future outlook

- Introduction to VLC / LiFi as the next generation of standardized information technology
- Discussion of the information technology potential and limits of VLC / LiFi
- Challenges and potentials for VLC-based mobility systems, especially for connected and autonomous vehicles
- **Future:** Implementing of sensor-like properties in VLC / LiFi-systems as localization and sensing service (separate slide)

„If I had asked the people what they wanted, they would have said faster horses .“ (Henry Ford / 1863-1947)

Source: www.duden.de

?

Soure: www.edle-oldtimer.de/ford-t-modell

?

Source:https://www.ingenieur.de/technik/fachbereiche/raumfahrt/das-drohne-fuer-lufttransport-menschen/

Thank you for your attention!

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Chair of Transport Systems Information Technology

https://tu-dresden.de/bu/verkehr/vis/itvs?set_language=en