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Using Fibre Lasers for Optical Wireless Communications, Optical Sensing and Detection Technologies for Increasing Reliability in Future Applications (including Autonomous Driving Scenarios)

Institute for Microwave and Photonic Engineering

ihf Institut für Hochfrequenztechnik

Graz University of Technology

Using Fibre Lasers for Optical Wireless Communications (OWC), Optical Sensing and Detection Technologies for Increasing Reliability in Future Applications (including Autonomous Driving Scenarios)

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Using Fibre Lasers for Optical Wireless Communications (OWC), Optical Sensing and Detection Technologies for Increasing Reliability in Future Applications (including Autonomous Driving Scenarios)

- Introduction, Motivation, Principles and Basics
- Wireless Technologies / RF compared to FSO (propagation effects on Free Space Optics (FSO), WLAN, DVB-T, Satellite Communications, LMDS)
- Applications / Different Scenarios
- Current and Future Work

1 Introduction / Motivation for Com-bining RF and OWC and Using Fibre Lasers

- To increase the **Data Rates** of the Transmission System
- To improve the **Reliability and Availability** of the Transmission System (including Redundancy and Site Diversity)
- To increase the **Cost Efficiency** of the Trans-mission System
- Fibre Lasers - **higher Output Power /** new light sources
- Achievable by Combination, because of
  - Different Propagation Behaviour
  - Different Weather Influences

1 Introduction / Motivation

- Emerging market / demand of social networks (e.g. YouTube, ……..)

- Internet traffic multiplied by the factor of 6 from 2008 till 2012

xDSL is still main Internet access technologies, still lack of reasonable broadband Internet in peripheral regions

DSL

- Limitations by cable length (attenuation)

- Initial copper cable installation often in 19th century (cable failures)

UMTS / LTE (not 100% covered)

- still low density of base stations in non urban area s (low bandwith)

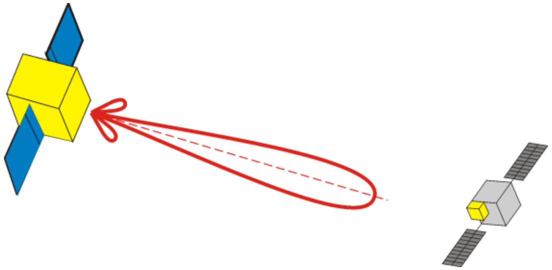
- Alternative access solutions

Dividing an Internet connection into up- and downlink into different media (uplink by WLAN and FSO, downlink by DVB-T)

1 Introduction

Advantages (FSO, compared to other Communication Techniques)

- large Bandwidth
- Focusing / Narrow Beam
- Electromagnetic Compatibility
- minimising ‚electromagnetic Pollution’
- protection of ‚wiretapping‘



- Disadvantage of FSO: **Reliability is** mainly **determined by** local weather **(and not only by electrical and optical components or network infrastructure)**
- **Bad weather conditions - attenuation - limited range**
- **Leads to usage of FSO for the Last Mile Access mainly!!!**
- **Advanced Fibre Lasers and new light sources**

1 Introduction

for Combined and Hybrid Systems

Different Wireless Technologies have different

- **Characteristics in wave propagation**
- **Influence by the weather and the atmospheric conditions**
- **Advantages and disadvantages**

For network applications each transmission technology has specific difficulties and challenges

Power and timing considerations; echoes and multipath propagation require proper modulation techniques; appropriate channel coding and information regeneration

The combination of different Wireless Technologies is the addition (the summation) of the **Advantages of the single systems**

2 Considered Wireless Technologies

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Optical Wireless compared to RF Wireless and “Wireless Technologies” used in the different scenarios

- Propagation effects on FSO and differences to common Wireless Technologies
- FSO systems and first combinations with LMDS
- Digital Video Broadcasting-Terrestrial (DVB-T)
- Wireless LAN (WLAN)
- Satellite Communications
- Combination with 5G and LTE (!Autonomous Driving!), incl. VLC and LiDAR

!!!! Combinations in parallel and serial setups !!!!

2.1 FSO – Channel and Wavelengths

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Reliability of Optical Wireless – the FSO Channel

Attenuation mainly caused by:

- Molecular absorption (always the same value depending on height and molecules in the air
- Scattering on particles (molecules, aerosols, fog, clouds, rain, etc.)
- Atmospheric turbulences (scintillations, variation (change) of the refractive index)

2.1 Weather Influence on FSO

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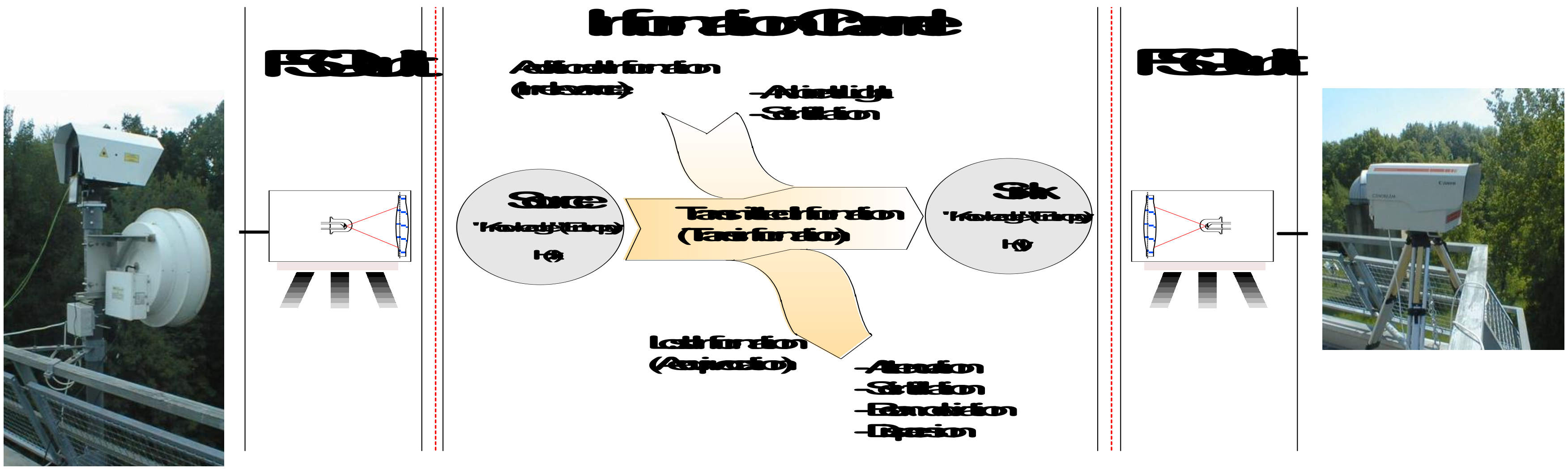
The optical channel is significantly different from the RF channel!

Fog, Clouds and Snow mainly affect the reliability of Optical Wireless links



Type 2 FSO-System **Type 3 FSO-System**

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2.1 Scattering on particles

- **Rayleigh-Scattering (only Rayleigh-Scattering results in a visibility of 350 km); proportional f ^{4} – important for very small particles only** (much smaller than the used wavelength)

- **Visibility is mainly influenced by additional Scattering (Mie-Scattering) – important for the larger particles in clouds and fog** (particles of the same size like the used wavelength)

⇒ chances for Advanced Fibre Lasers and powerful light sources

2.1 Mie Scattering shows for comparison of FSO and Microwave

- For a **stand-alone FSO system, fog** can cause attenuation of **up to 100 dB/km in the climate around Graz, while rain** can cause attenuation up to **25 dB/km in a heavy thunderstorm** at a rain rate of 150 mm/h, which is comparatively less important.

- The **same rain rate** can cause up to **50 dB/km** attenuation for a **microwave link** (up to 35 dB/km for 40 GHz), while **fog** does not particularly matter, and increased humidity causes **less than 5 dB/km.**

2.1 Fog attenuation / measurements

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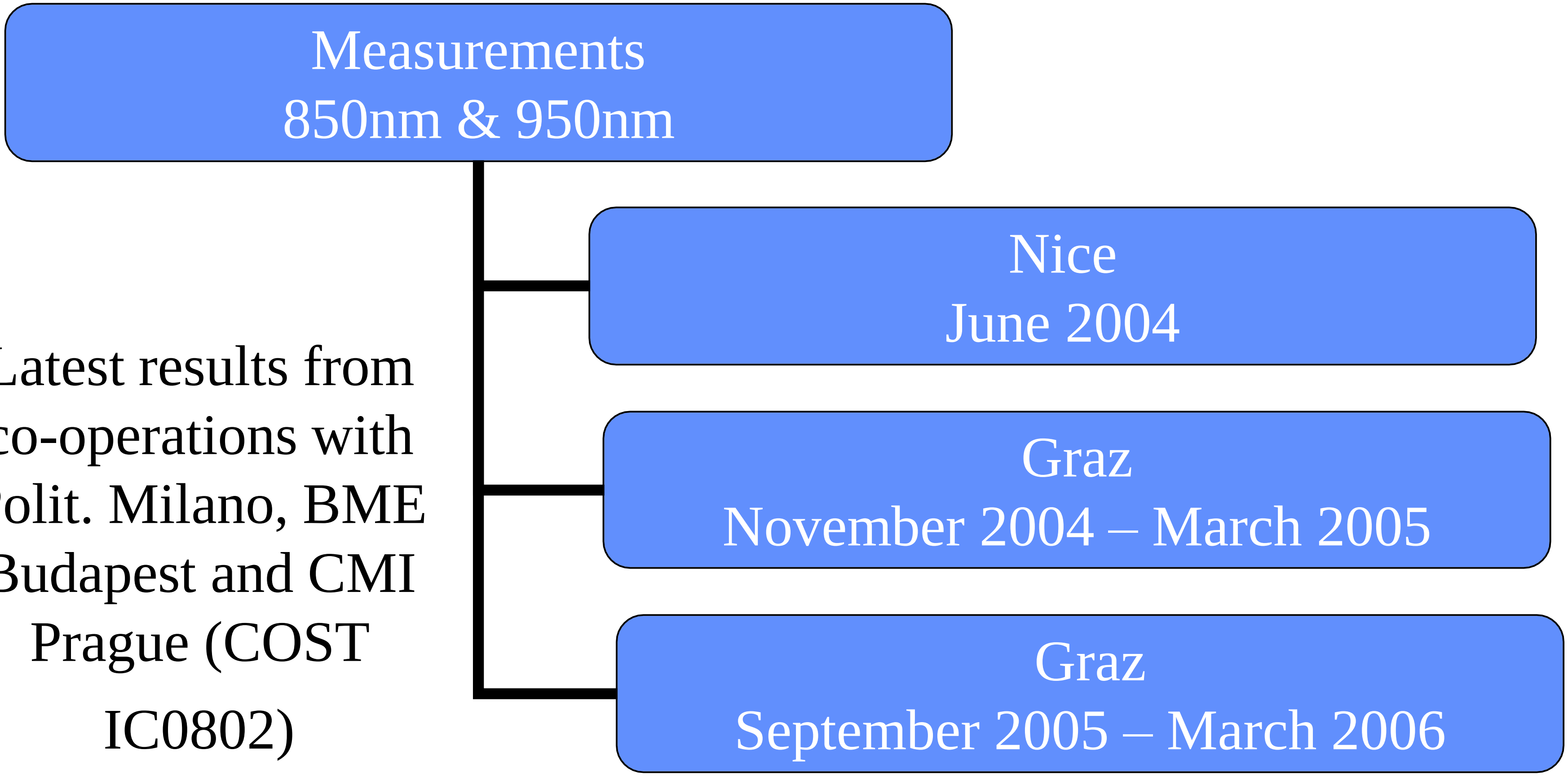


Latest results from co-operations with Polit. Milano, BME Budapest and CMI Prague (COST IC0802)

Ongoing and further work within COST 270, SatNEx I and II, COST IC0802, COST IC1101, COST CA15127 (RECODIS)

2.1 Micro-physics of fog

- **Radiation fog (continental / city fog); like spec. Attenuation in Graz: 30 dB/km (slow changes)**

  particle diameter ~ 4 µm,

  liquid water content between 0.01 and 0.1 g/m^3

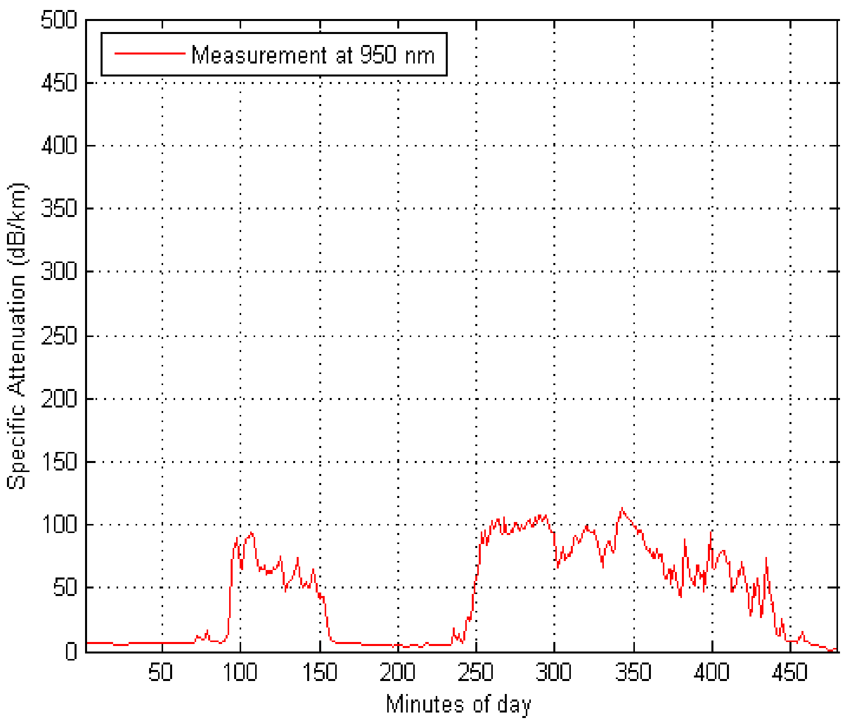
- **Advection fog (maritime fog); like spec. Attenuation in Nice: 300 dB/km (fast changes)**

  particle diameter ~ 20 µm,

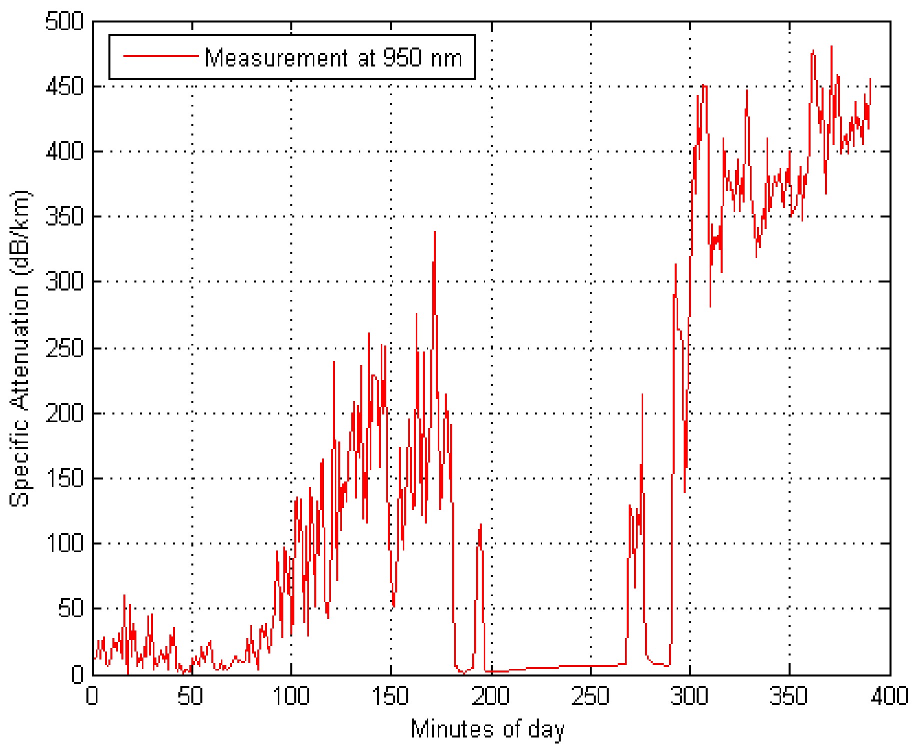
  liquid water content 0.2 g/m^3

2.1 Specific attenuation of fog

Graz



Nice

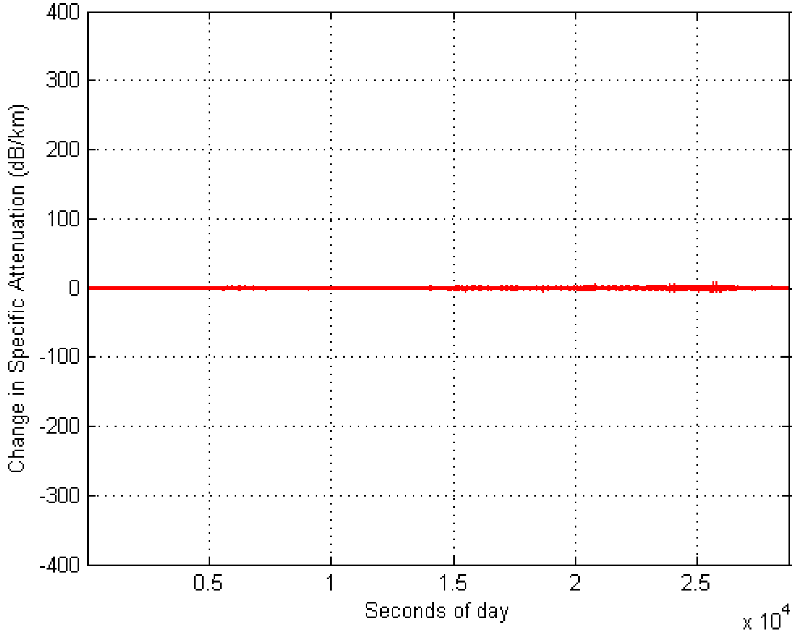


Max. Attenuation measured in Graz (120 – 150 dB/km)

Max. Attenuation measured in Nice (up to 780 dB/km)

2.1 Changes in specific attenuation of fog

Graz



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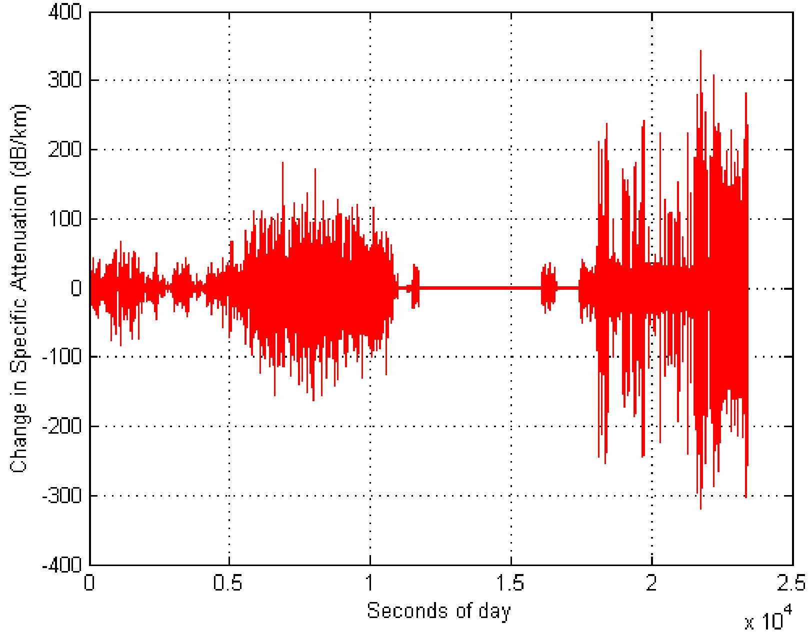
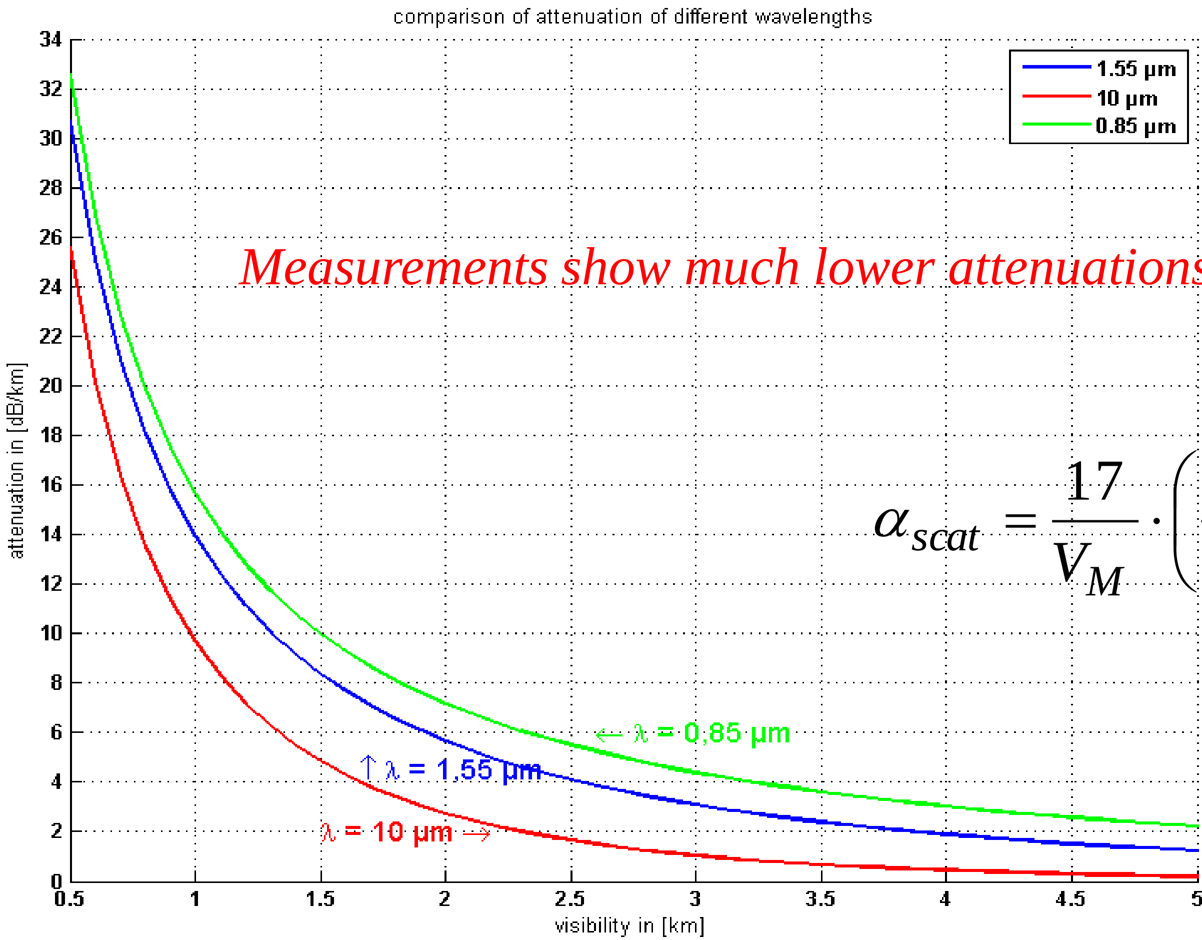


Time Behaviour

2.2 Wavelength Comparison – Attenuation and Visibility

Attenuation



Measurements show much lower attenuations for 10 µm

$$\alpha_{scat} = \frac{17}{V_M} \cdot \left(\frac{0{,}55}{\lambda} \right)^{0{,}195 \cdot V_M}$$

Visibility

Empirical Equation as Figure: for λ = 0.85 µm (green) and λ = 1.55 µm (blue) [33], including 10 µm (red);

[33] Lentke H., *Connection of data networks (LAN) directly through the atmosphere using infrared light*, CBL GmbH (Dietburg, D)

2.2 Wavelength Selection

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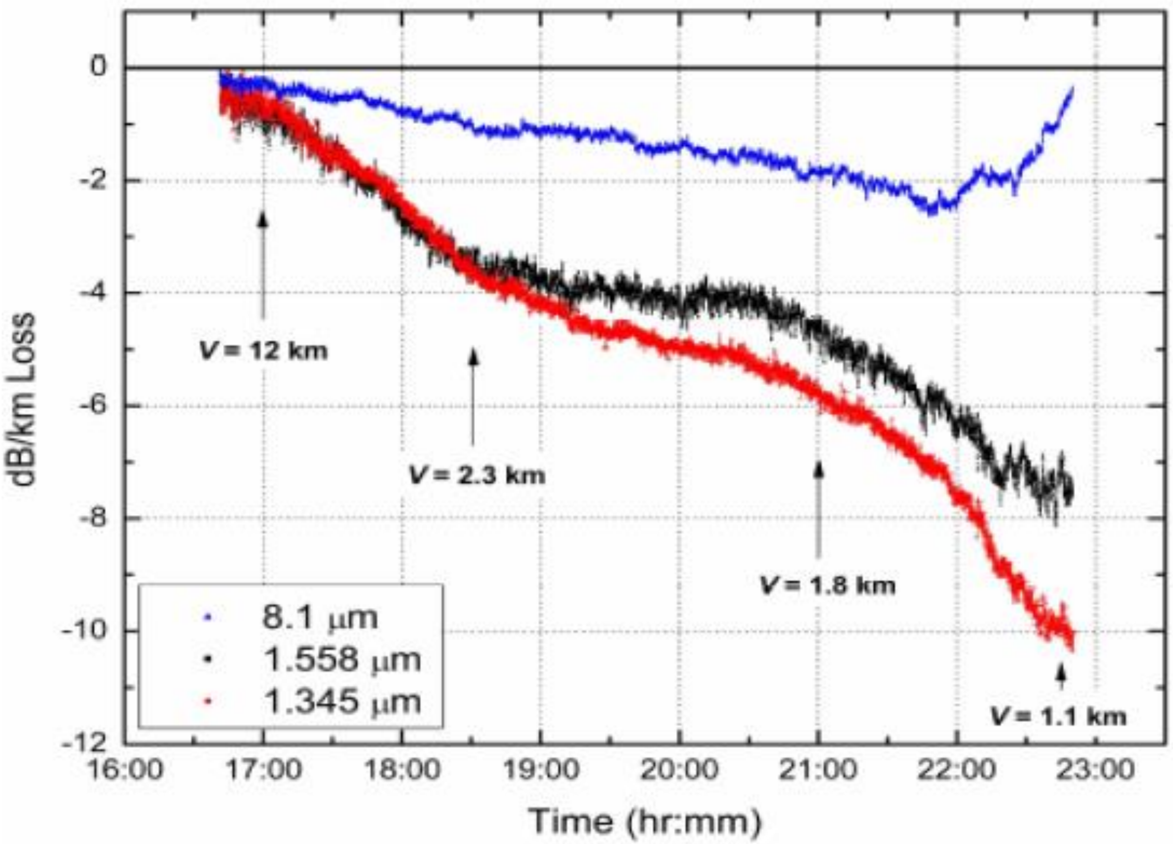
1.5µm or 10µm??

The 1550 nm wavelengths with OOK and direct detection are widely used in terrestrial fibre-optical transmission lines and are well suited for space transmission

Advances in QCL and progress in HgCdTe photo-diodes and quantum well infrared photo detectors made possible the usage of 10µm wavelength



P. Corrigan, R. Martini, E. A. Whittaker, C. Bethea, "Quantum cascade lasers and the Kruse model in free space optical communication", Optics Express Vol. 17, No. 6, OSA 2009

3 Idea of Combining Wireless Systems

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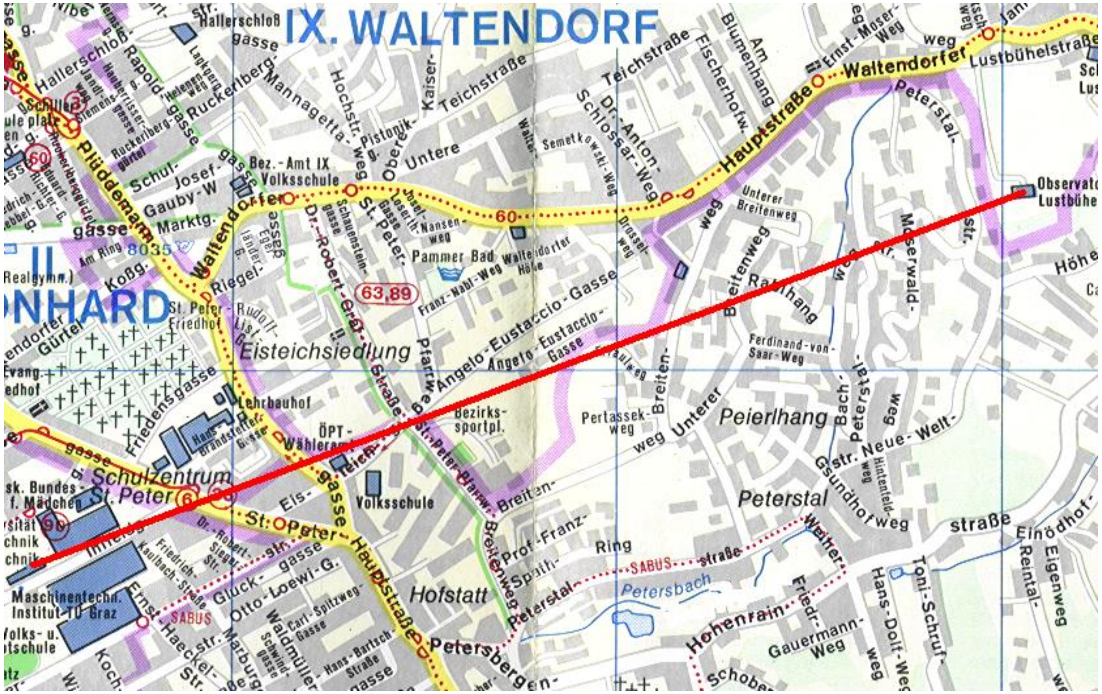
Different Wireless Technologies have different

- **Characteristics in wave propagation**
- **Influence by the weather and the atmospheric conditions**
- **Advantages and disadvantages**

For network applications each transmission technology has specific difficulties and challenges

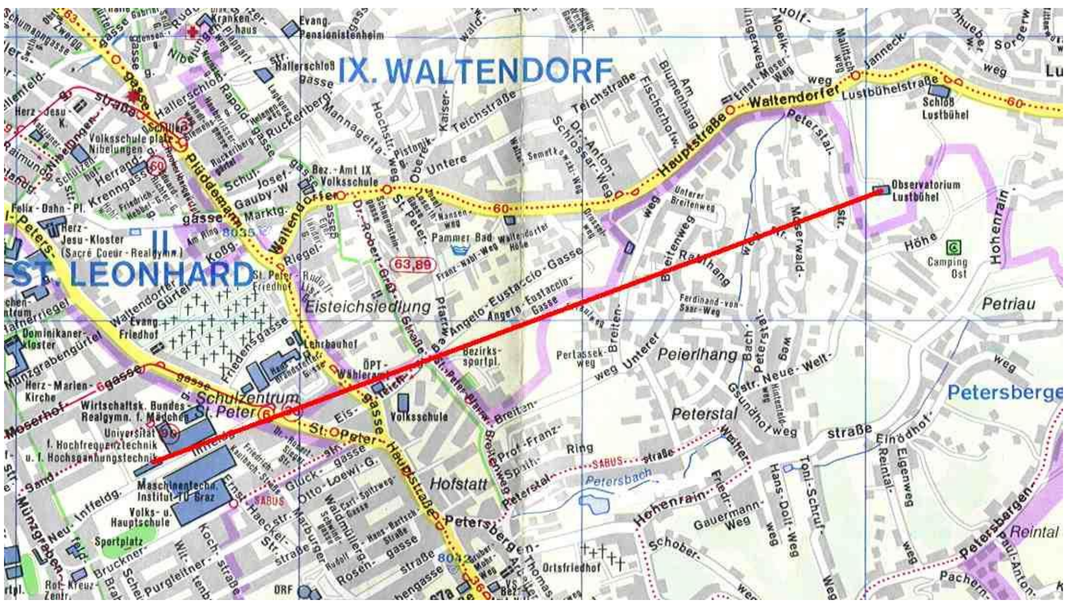
Power and timing considerations; echoes and multipath propagation require proper modulation techniques; appropriate channel coding and information regeneration



3 Combining FSO and RF links

First experiments started in 2001 / 2002 with Directional Radio Systems and LMDS

Optical links between Graz Inffeldgasse 10 and Observatory Lustbühel (2.7 km)

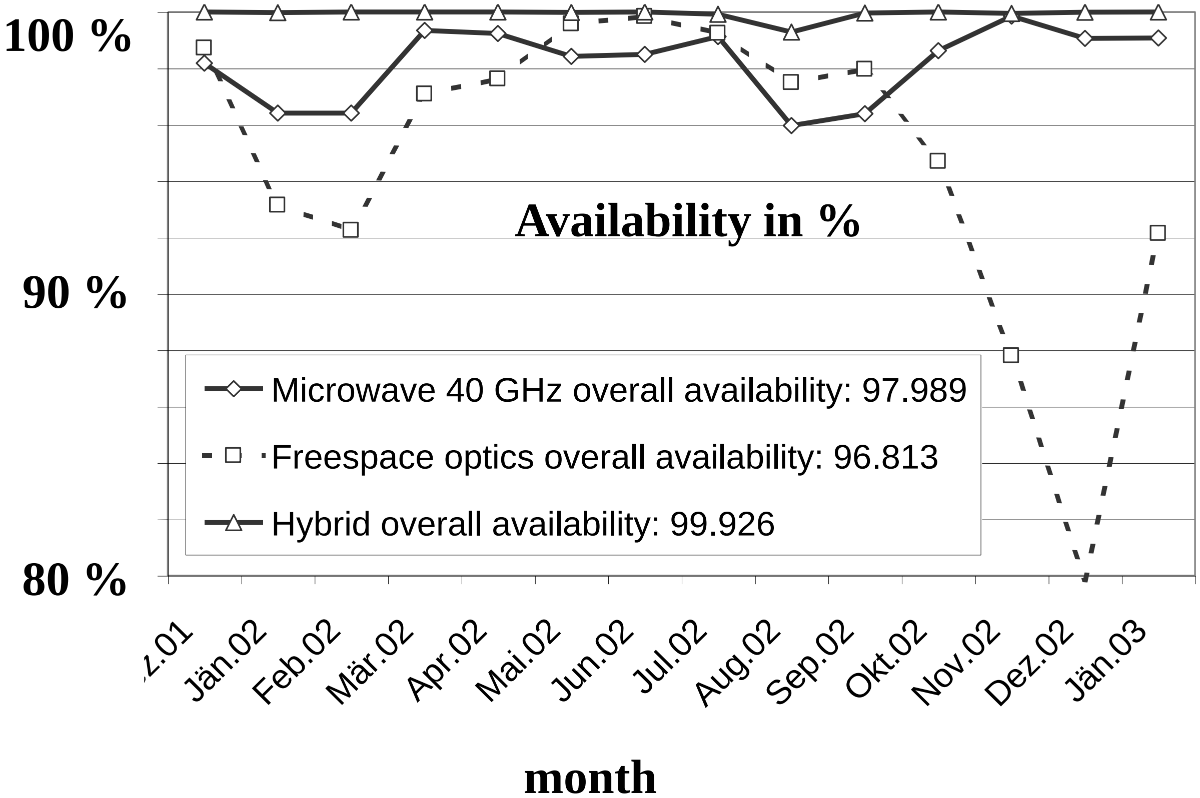


FSO and directional radio

3 First long term experiment of

Combined / Hybrid Systems

LMDS and FSO in parallel



Local Multipoint Distribution Service (LMDS) - a broad-band wireless access technology - planned for digital television trans-mission (DTV)

as a fixed wireless, point-to-multipoint technology for last mile

December 2001 – January 2003

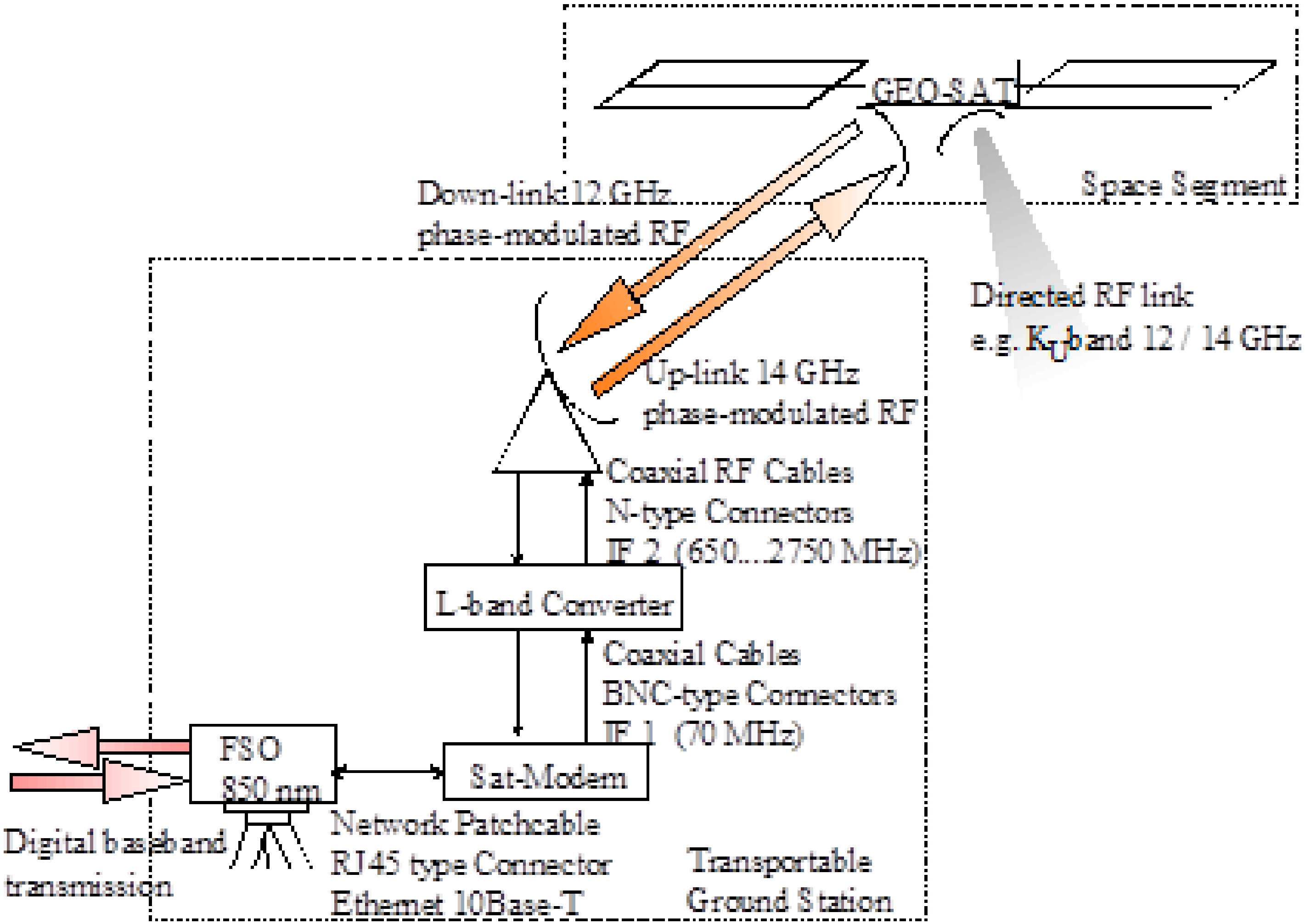
a 40 GHz Microwave system installed at TU Graz

3 Applications / Different Scenarios

Combination Experiments

- FSO systems and first combinations with LMDS (shown)
- Satellite Communications
- Wireless LAN (WLAN) (in CIMIC exercise)
- Digital Video Broadcasting-Terrestrial (DVB-T)
- New ideas with Optical Feeder Links and Visible Light Communications
- Autonomous Driving and Hybrid Deep Space Links

Scenario A: Satellite Communications



As example a usual K_U-Band Satellite Ground Station

Scenario A: Satellite Communications (RF)

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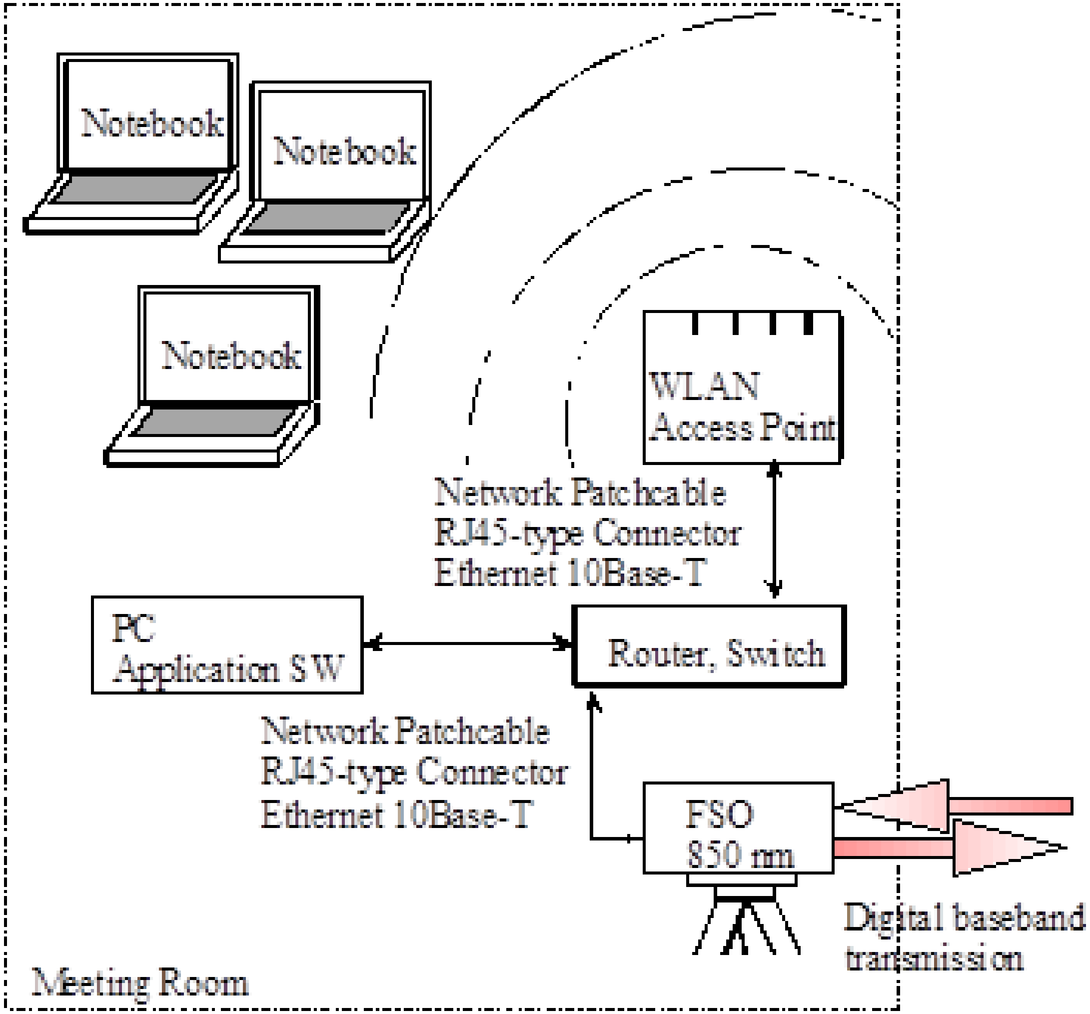
in combination with FSO and / or WLAN

A typical K_U-Band Satellite Ground Station is connected with FSO or / and WLAN to a conference- or meeting room



Scenario A: Satellite Communications (RF)

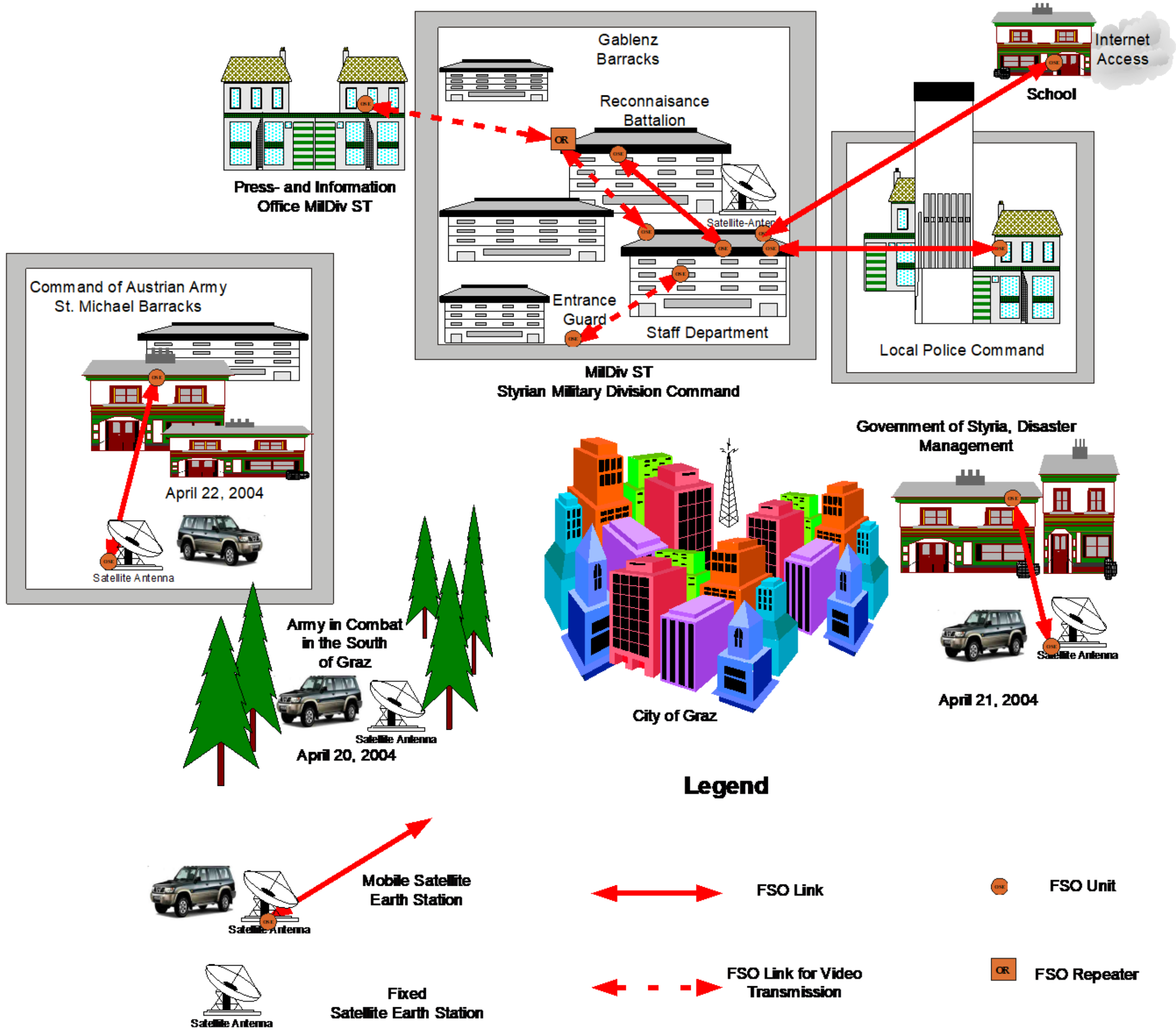
in combination with FSO and / or WLAN

also used in combination with Scenario B: CIMIC Exercise

Video conference and data transmission for the Mil Div ST at the combat in south of Graz

Mobile satellite earth station

Scenario B: CIMIC Exercise



CIMIC

Installation of FSO and Satellites in Civil-Military-Cooperation

Exercise in Styria

Scenario C: DVB-T in combination with FSO and WLAN

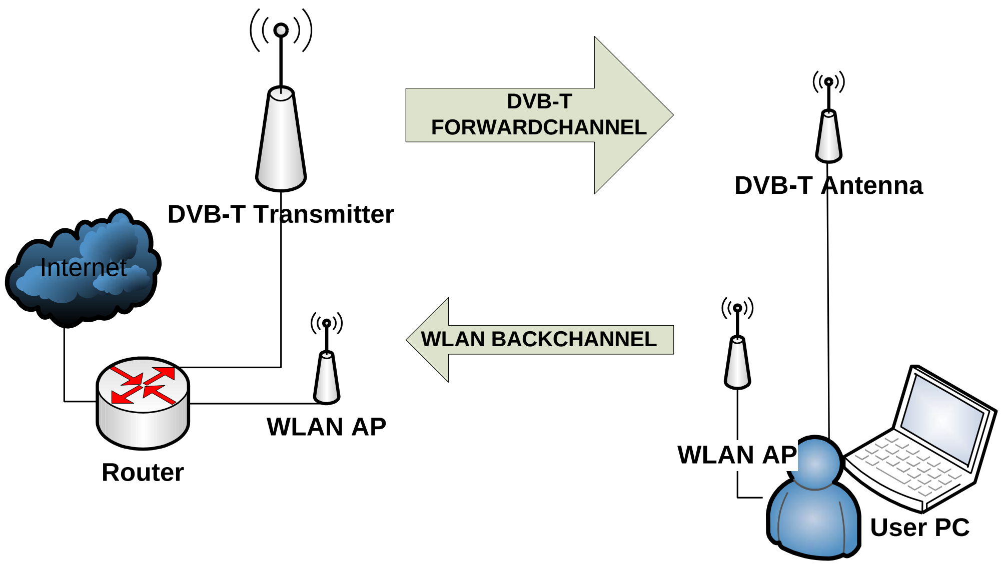
A.) Direct connection

- Using DVB-T as a forward channel (like downlink)
- Using WLAN/FSO as a back channel

B.) Local WLAN relay

- Users in a community area are connected to a WLAN cloud which is concentrated to location with LOS to the core network

Applications and Method

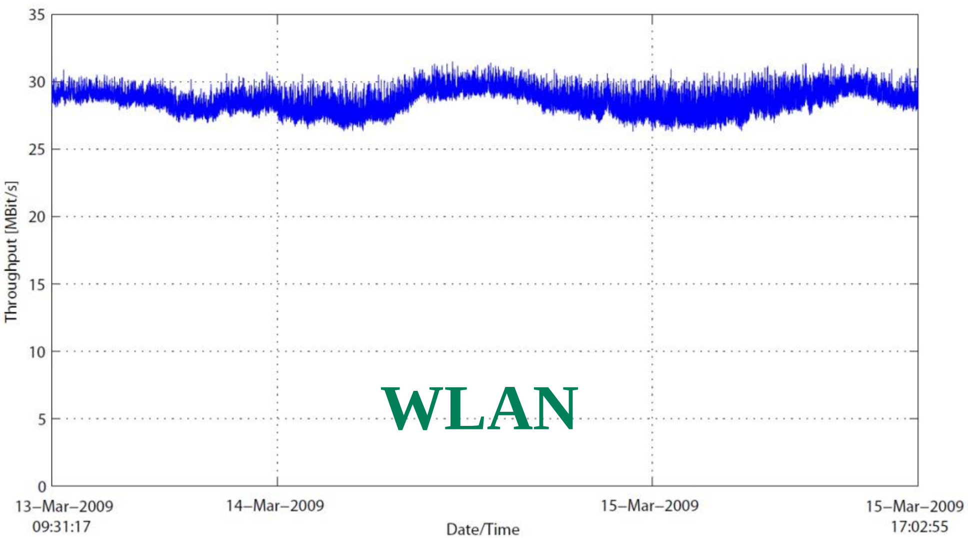


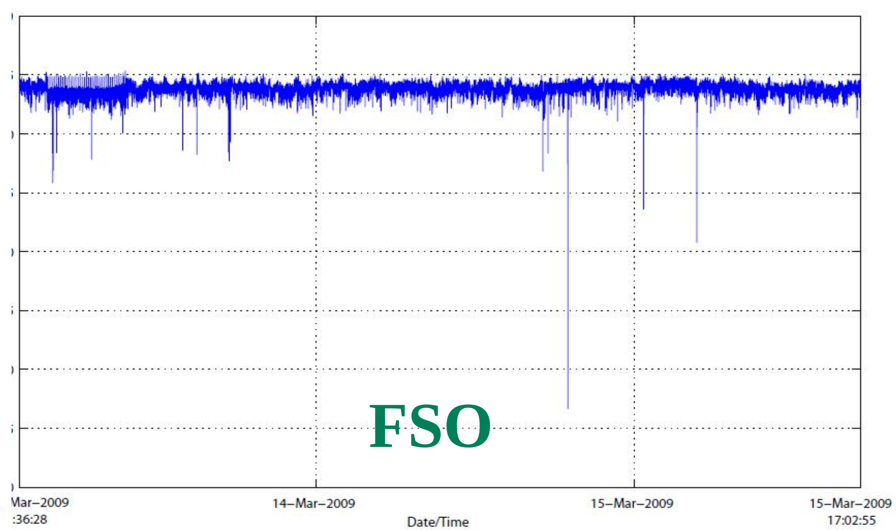
Provided services: http; email; VoIP; VoD; VPN

Scenario C: DVB-T in combination with FSO and WLAN

Results

- The testbed currently is in a free field setup
- Very stable bandwidths for WLAN (~ 30Mbit/s) and FSO (~90Mbit/s) link (distance ~ 2.7km)
- Reasonable quality for http, email and VoIP





Scenario C: DVB-T in combination

with FSO and WLAN

SEE TV-WEB

Project: Tackling the ''Digital Divide'' in SEE TV-WEB by using the capacity of DTT networks

led to Pilot Presentations in the contributing countries, project finished end of 2014 / begin of 2015

Austrian Pilot in January 2014 in Graz and Reutte (Tyrol)

Scenarios …… in International Projects

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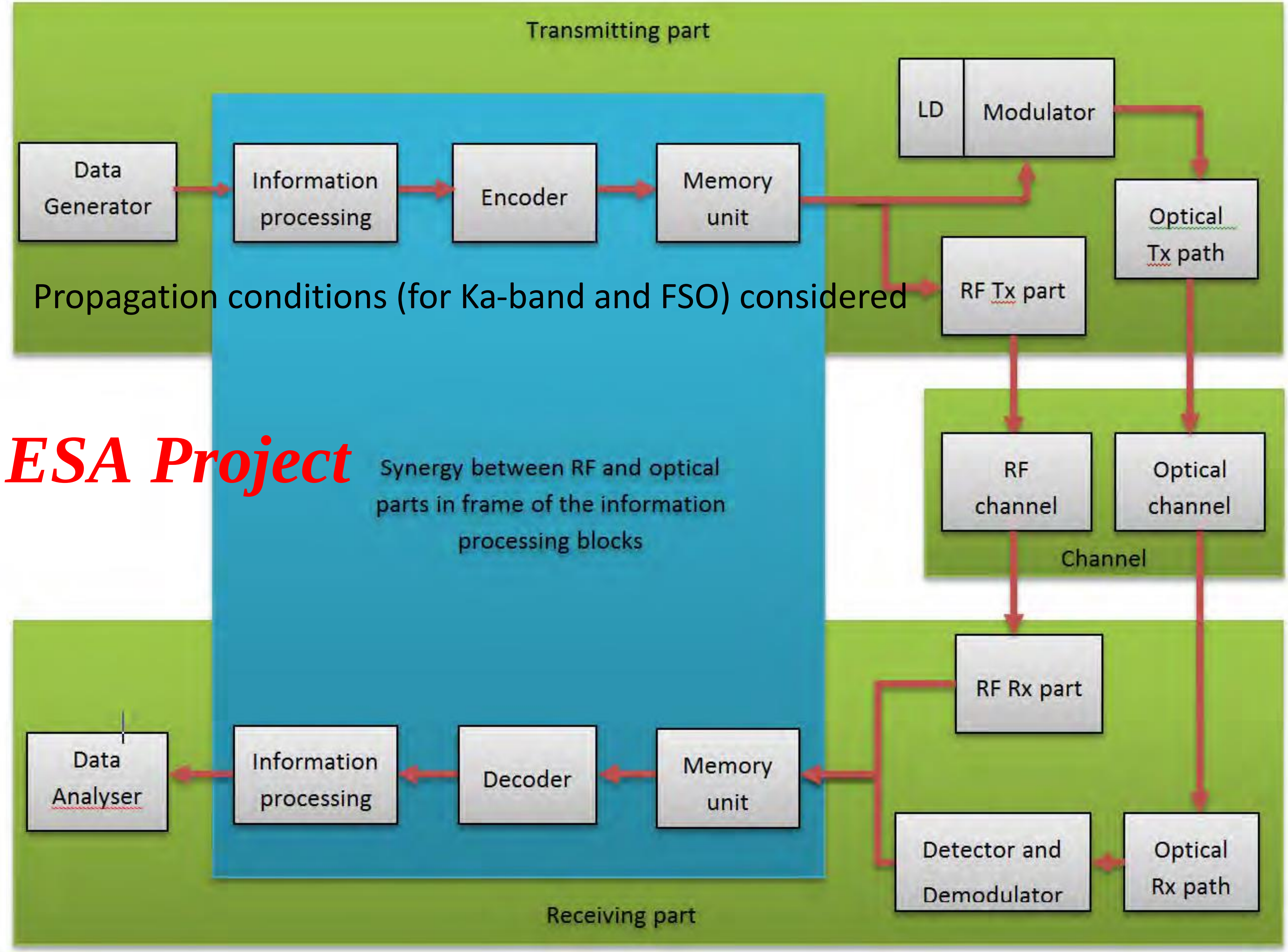
HybridPDT: **System Study of Optical Communications with a Hybridised Optical/RF Payload Data Transmitter**

COST Action MP1401: **Advanced fibre laser and coherent source as tools for society, manufacturing and lifescience**

COST Action CA15127 (RECODIS): **Resilient co-mmunication services protecting end-user applications from disaster-based failures and** **COST CA 16220** **"Euro-pean Network for High Performance Integrated Microwave Photonics"**

TRITON: **Heterogeneous Integration of Milli-meter-Wave Technology (related to COST CA 16220)**

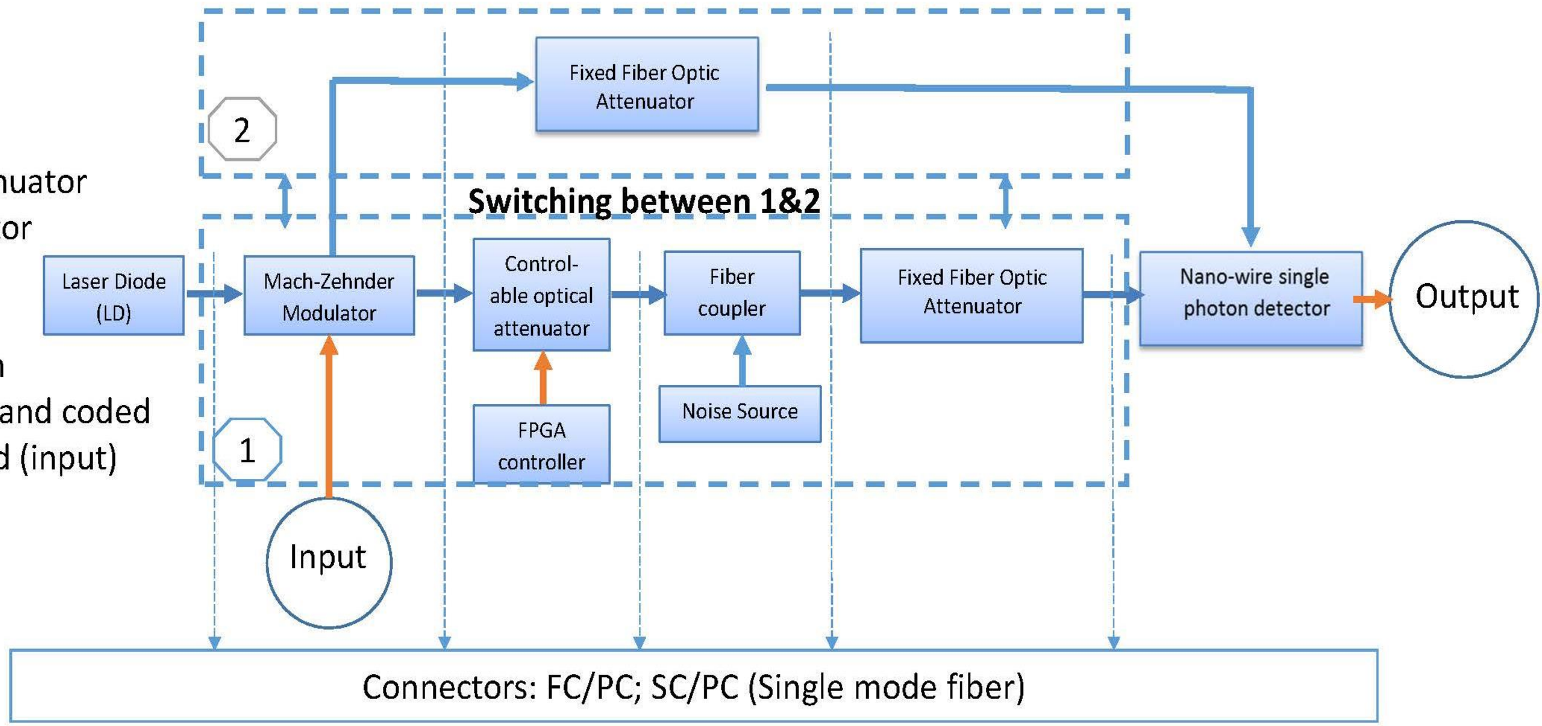

Transmitting part
Data Generator
Information processing
Encoder
Memory unit
LD
Modulator
Optical Tx path
RF Tx part
Propagation conditions (for Ka-band and FSO) considered
ESA Project
Synergy between RF and optical parts in frame of the information processing blocks
RF channel
Optical channel
Channel
RF Rx part
Data Analyser
Information processing
Decoder
Memory unit
Detector and Demodulator
Optical Rx path
Receiving part

ESA Project

Breadboard design

- **Main components:**
  - Laser
  - Modulator
  - Variable optical attenuator
  - Single photon detector

- **Main problems:**
  - PPM Synchronization
  - How the modulated and coded data will be delivered (input)



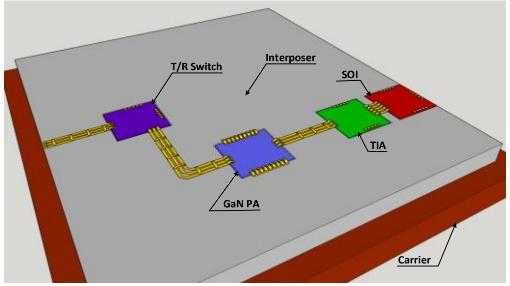
Optical path
Electrical path

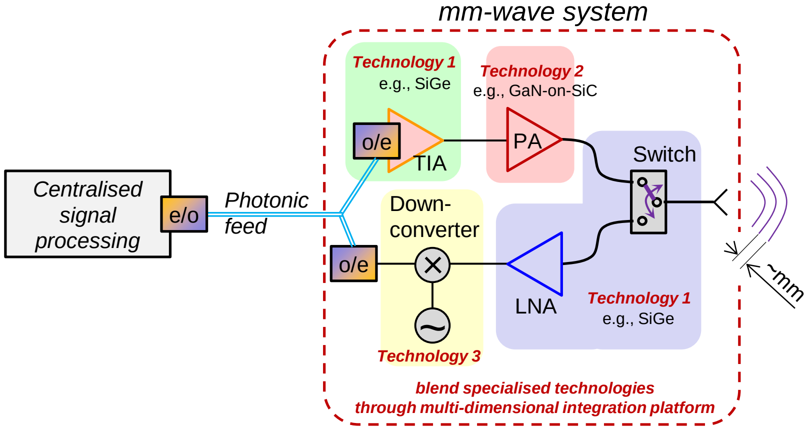
Advanced Fibre Lasers in Space Applications??

Triton - Heterogeneous Integration of Millimeter-Wave Technology

➢ **Research goals:**

- **Heterogeneous integration**
- **Implementing photonic to mm-wave radio link transition (National partners)**
- **Supported technologies:**
  - ➢ Si CMOS interposer
  - ➢ SiGe: Transimpedance amplifier (TIA)
    Low noise amplifier (LNA)
  - ➢ GaN-on-SiC: Power amplifier
  - ➢ Flexible and large scale
    2.5D hetero integration





4 Future Applications

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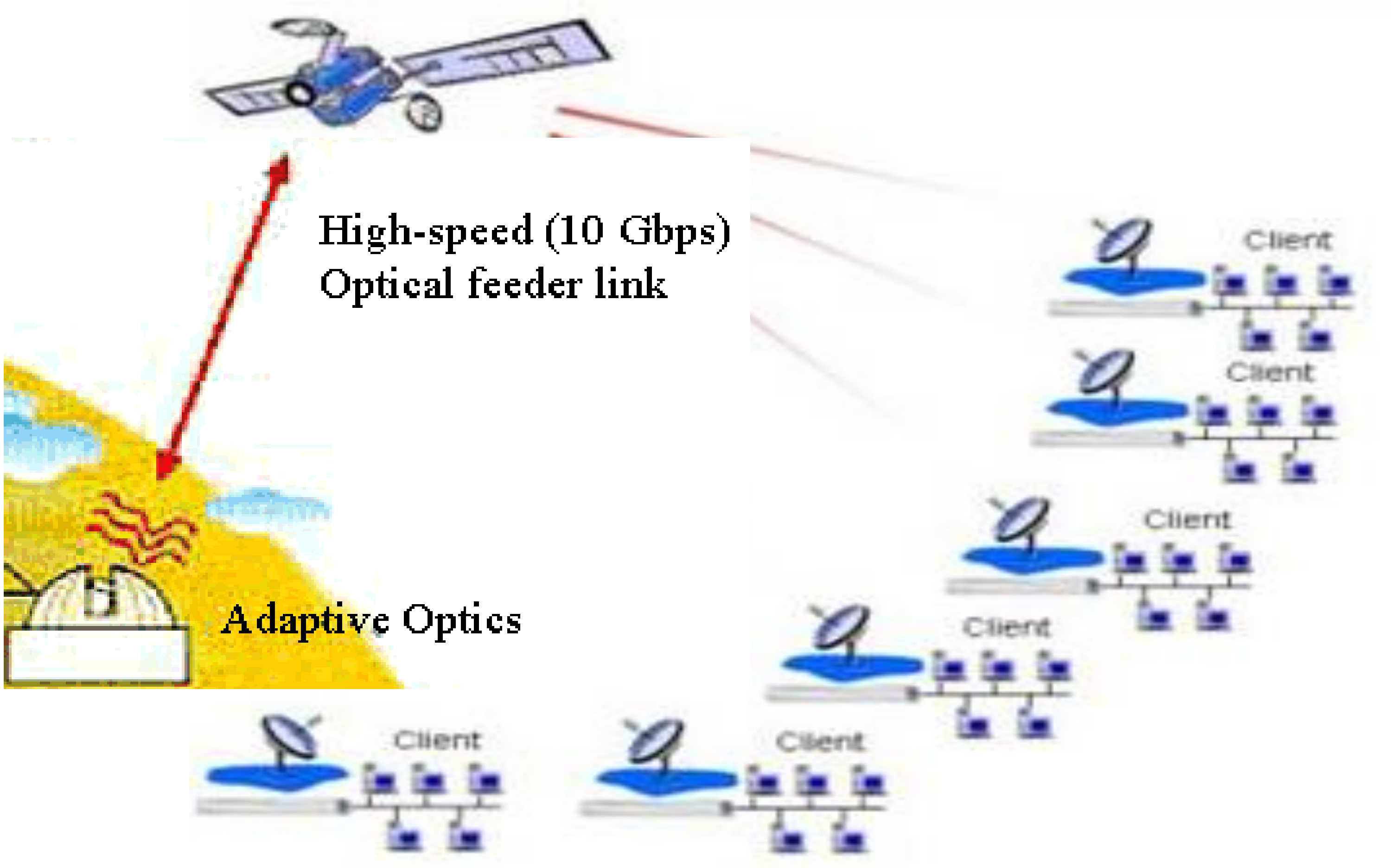
- **Ongoing and further tests / evaluation of Quality of Internet- and multimedia services**
- **For Broadband Connectivity in regions of weak tele-communications infrastructure (mountains, tourism)**
- **Proposals for Optical Feeder Links and Visible Light Communications**
- **Combination of FSO and RF technologies (including Site Diversity / Redundancy)**
- **Combination scenarios for Autonomous Driving and Deep Space Communications**

4.1 FSO as uplink for Broadcast Satellites

Uplink instead of RF- with Optical Feeder Link

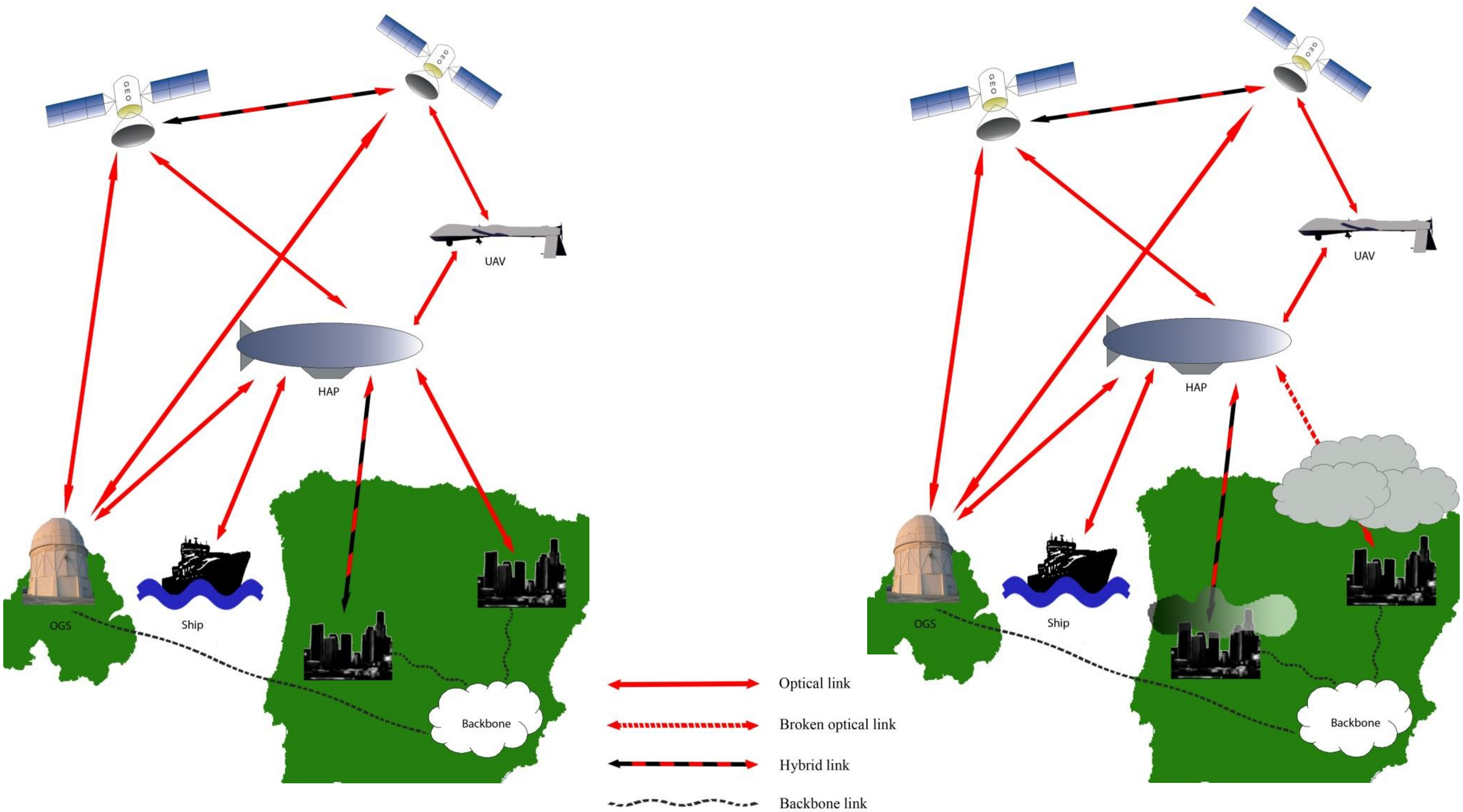


4.2 Visible Light Communications

Backchannel with RF, WLAN, IR etc.

4.3 Site Diversity and Redundancy

(within a 2009 ESA study, also usable for hybrid links)



4.4. Vehicle to X Communication

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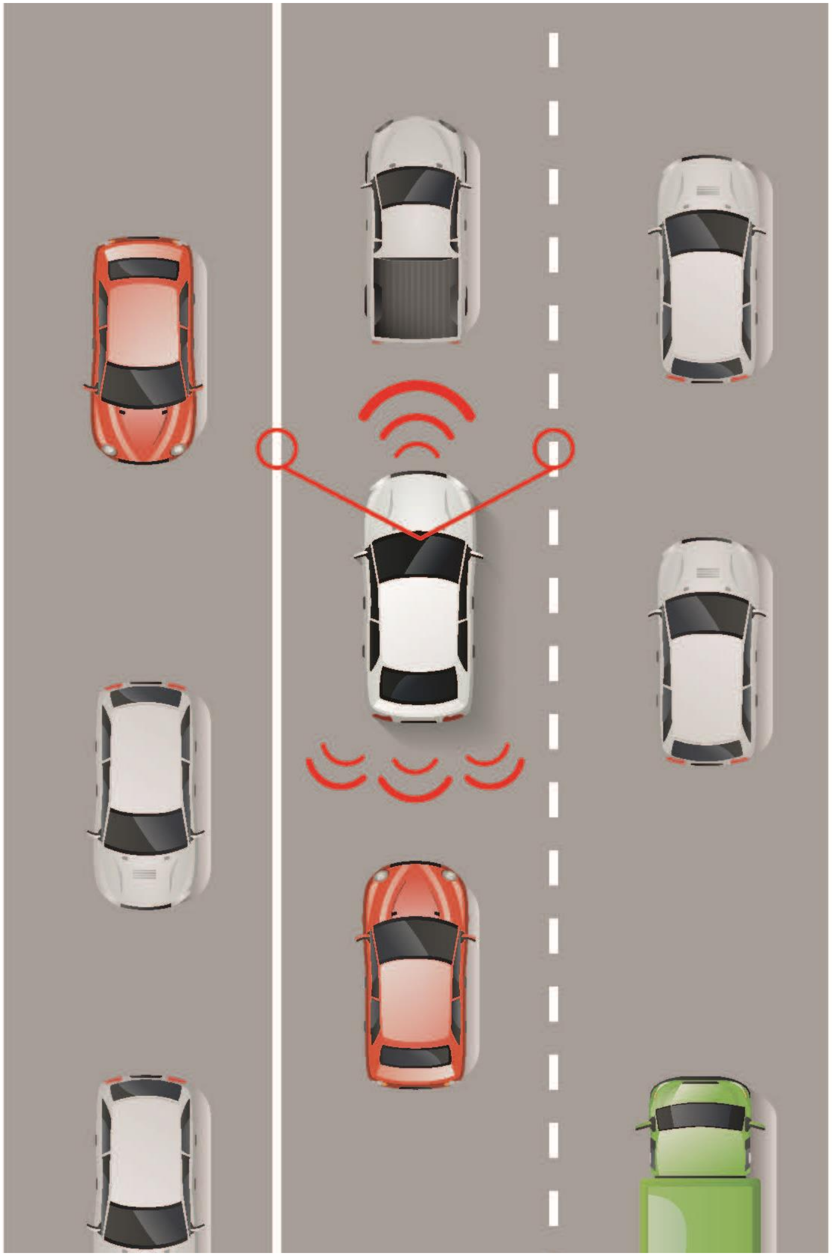
Austrian Research, Development & Innovation Roadmap for Automated Vehicles

!!!!!! in-Car and Car to X Communication !!!!!

The Austrian RDI Roadmap for Automated Vehicles serves several purposes:

4.4. Vehicle to X Communication

- **in-Car (Fixed or Wireless)**
  - Sensors and Electronics (incl. NFC and RFID)
- **Car to X Communication**
- **Main Aspects**
  - Costs / Power Consumption / Energy
  - Efficiency / Innovation
  - Reliability / Availability
  - Safety / Security



4.4. Vehicle to X Communication

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BMVIT in 2016

**Austrian
Research, Development
& Innovation
Roadmap for
Automated Vehicles**

!!!!!! Communication is an important factor in-Car and Car to X Communication !!!!!

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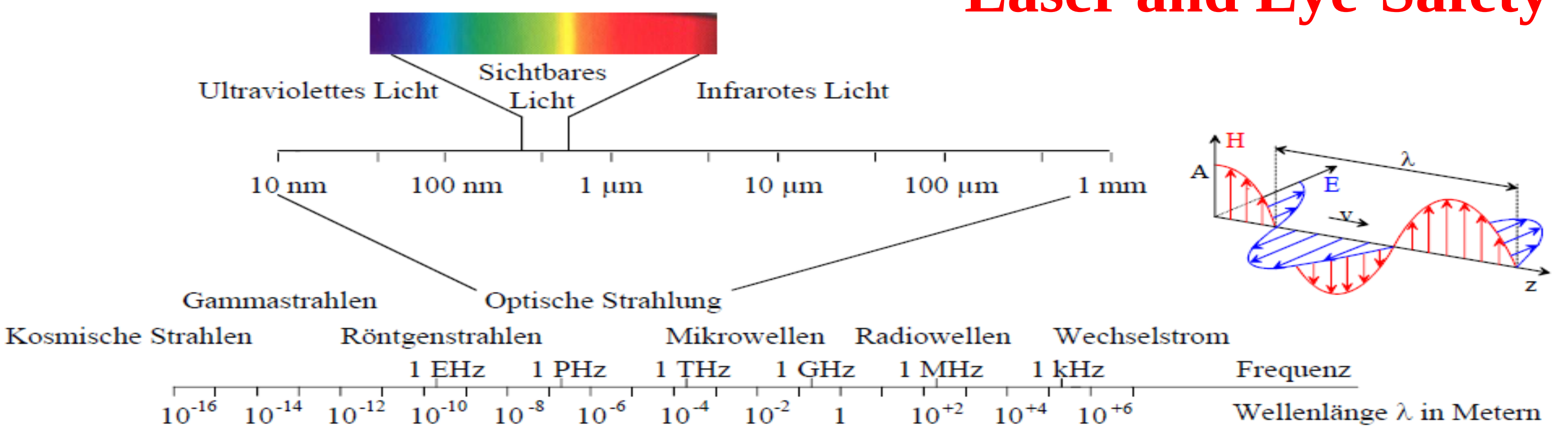
Challenges, Required Parameter, Questions

- Real-Time Capability of the Systems
- Need and Requirements on Infrastructures for Implementation of Automated Driving
- Accuracy of Data (Sensors for Location the Vehicle) and Data-transfer and Communications to Assistant-Systems and Infrastructure
- Technologies (RF, Optic/Photonic) for Automated Driving
- Solutions in Future Wireless Mobile 5G (Big Data),

4.4 Optics and RF

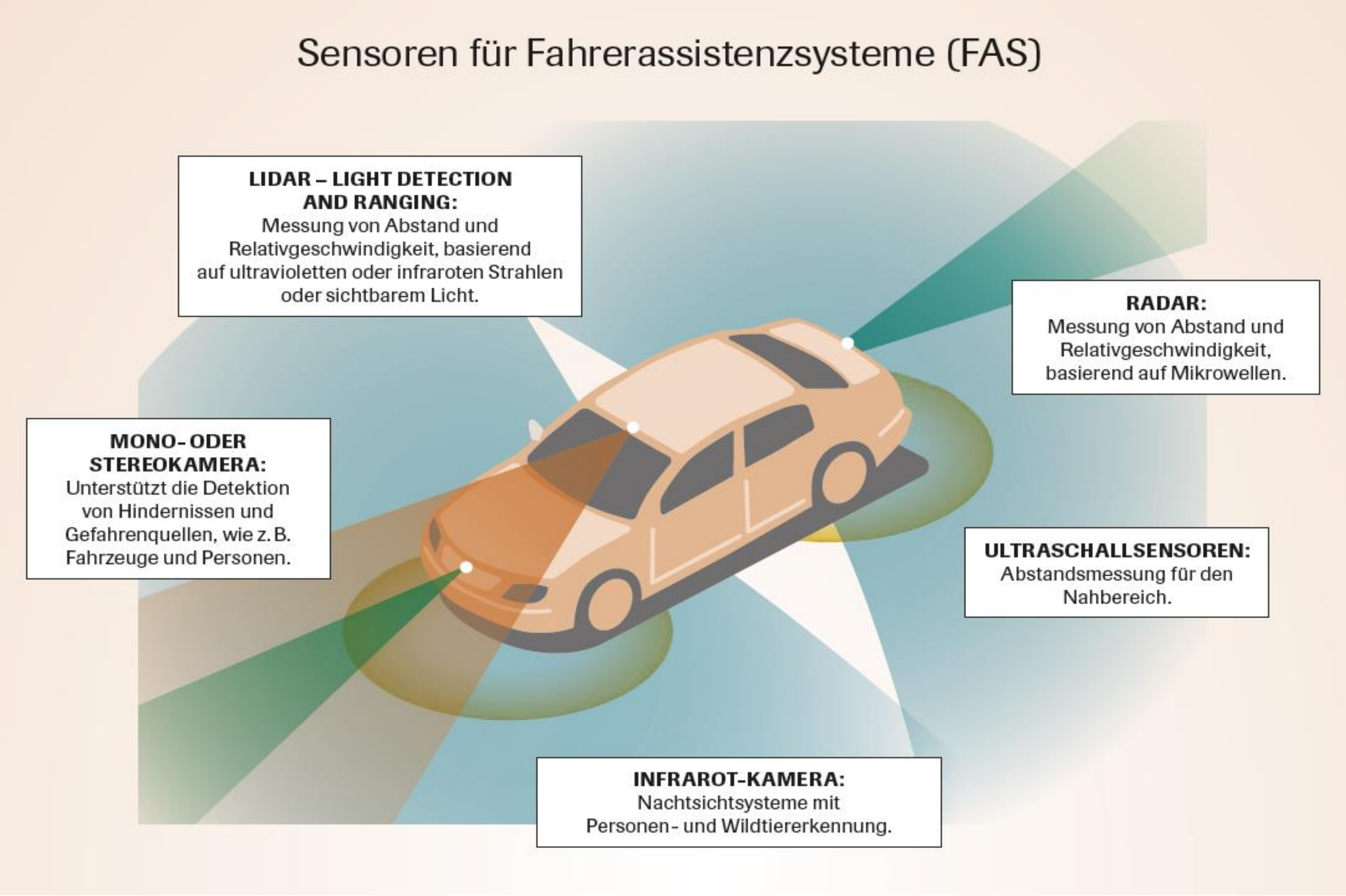
High Carrier-Frequency, high Bandwidth and Data Rate

Laser and Eye-Safety



Bezeichnung	*Spektralbereich*
UV-C	100 nm ..... 280 nm
UV-B	280 nm ..... 315 nm
UV-A	315 nm ..... 380 nm
Sichtbares Licht	380 nm ..... 780 nm
IR-A	780 nm ..... 1400 nm
IR-B	1400 nm ..... 3000 nm
IR-C	3000 nm ..... 1 mm

VDA, Von Fahrerassistenzsystemen zum automatisierten Fahren



Challenges and Questions

(Regarding Vehicle to „X“ (X: other Vehicle, Base-Station, or Infrastructure)

- Optical Links between Cars and to Fixed Transceivers,
- Benefits and Disadvantages of Optics to RF (Radio Frequency), like Energy, Data-Rate
- Spectrum of 5G and Usage of Optical Wireless
- Interoperability and Convergence of the Systems
- National and International Standards, also Relevant for Test-Infrastructure 5G and Optics

4.4 VLC and LiDAR

VLC for Positioning in Tunnels and Communications

- with LED Illumination (Information on LEDs modulated, Position-data), LEDs over Fiber Infrastructure and LAN (also on traffic signals), Detector on Car, Communication with high data rates

LiDAR (light detection and ranging) or LaDAR (laser detec-tion and ranging)

- Supplement to Radar
- Methode of optical Distance- and Velocity Measurements
- Laser-light instead of Radio-waves (Radar: 24GHz and 77GHz; LiDAR: THz)

VLC (Visible Light Communication)

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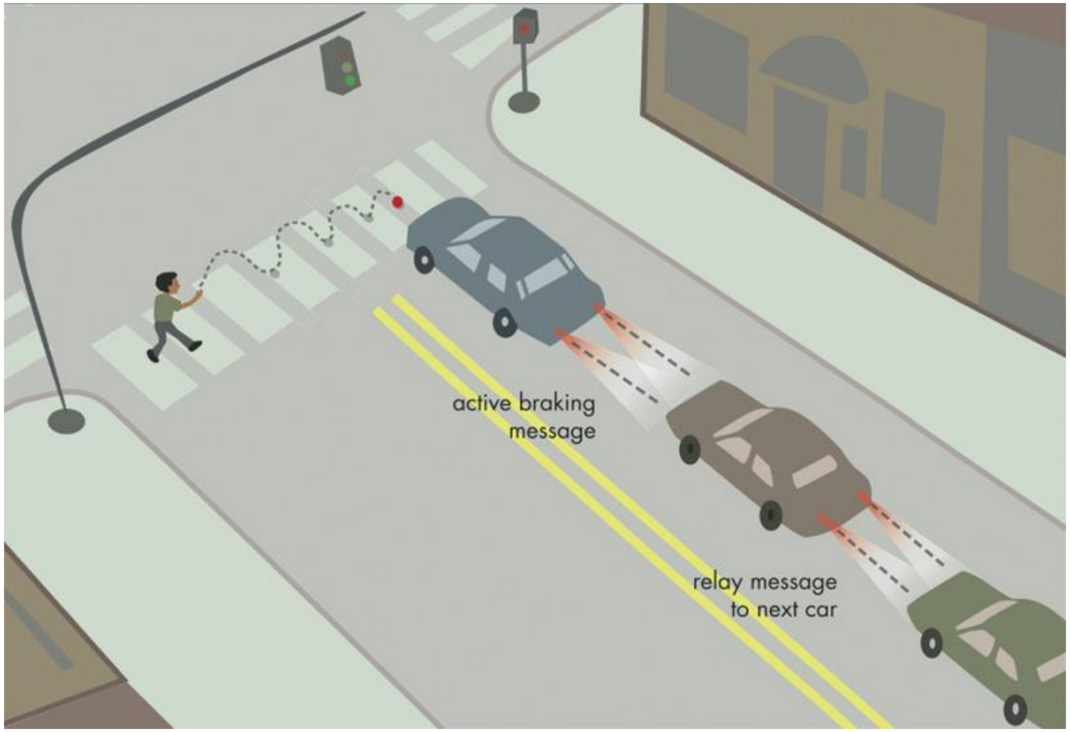
Communication Car to X (Car / Infrastructure)

- LED as Transmitter at the automobile headlight
- Light for Communications at traffic lights or other Infrastructure will be detected



4.4 Car Networks – Network-structure

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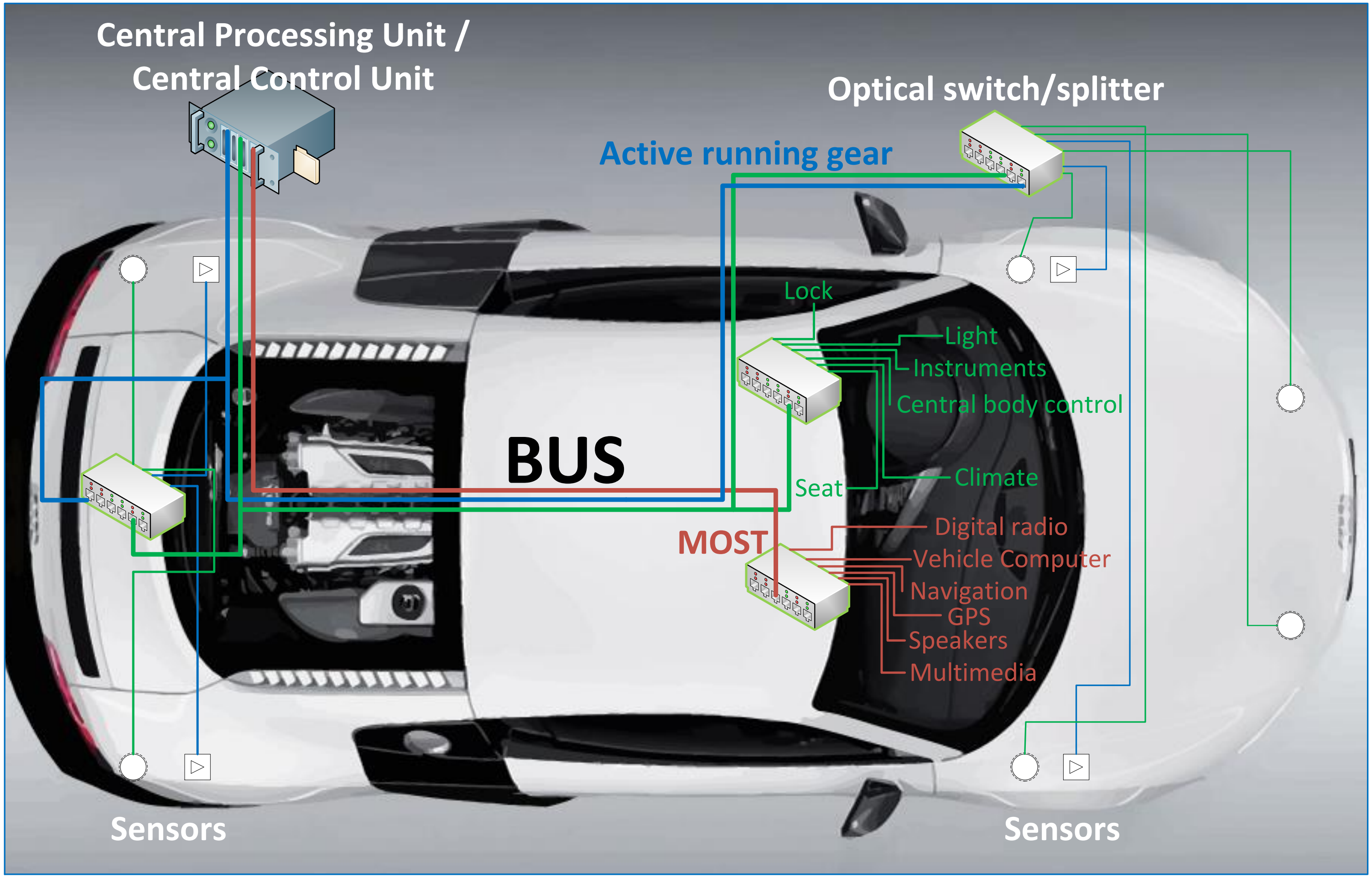

Vehicle shape ©FreeVector

4.4 In-Car Fixed or Wireless

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Replacement of the Controller Area Network (CAN) protocol for future automotive bus system solutions by substitution via Optical Networks

!!!! In-Car Communications and IHF contribution at ICTON 2016 in Trento

5 Conclusion

OWC, FSO, VLC for future applications

- **Quick installation of optical short distance high data links**
- **Broadband links to cross railway, highway or river**
- **Links within companies or institutions (subsidiaries, outposts etc.)**
- **Rapid replacement of broken cable-links**
- **Short term installation (e.g. seminars, meetings, events)**
- **Disaster Management, Disaster Recovery / CIMIC**

- **VLC for autonomous driving, in tunnels and in cities (traffic lights)**
- **VLC Broadband link for data broadcast (incl. Roadside-Stations)**
- **Increase safety and security by using LiDAR and OWC for traffic**
- **VLC, OWC LiDAR using also for railway and tram**
- **VLC, OWC LiDAR for safety of railway and highway crossings**
- **VLC, OWC LiDAR for ships, airplanes etc.**

5 Final Conclusions and further work in FSO

To increase the link reliability and cost efficiency by

- **Combination of FSO and RF technologies**
- **Site Diversity / Redundancy**
- **10 µm wavelength / Fibre Lasers**
- **Alternative Modulation and Coding Techniques**
- **Combination of Optics and RF in general (integration)**

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in Co-operation with

erich.leitgeb@tugraz.at

http://optikom.ihf.tugraz.at

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Results mainly carried out by M. Gebhart, S. Sheikh Muhammad, B. Flecker, M.S. Awan, F. Nadeem, P. Brandl, T. Plank, M.S. Khan, P. Pezzei, P. Unterhuber, P. Mandl, M. Löschnigg, M. Henkel, D. Kraus, M. Hinteregger, Ch. Pock, H. Ivanov, P. Bekhrad

COST IC0802: Propagation tools and data for integrated Telecommunication, Navigation and Earth Observation systems **and IC1101 and SEE TV-WEB**

Newest: CA15127 and ESA HybridPDT

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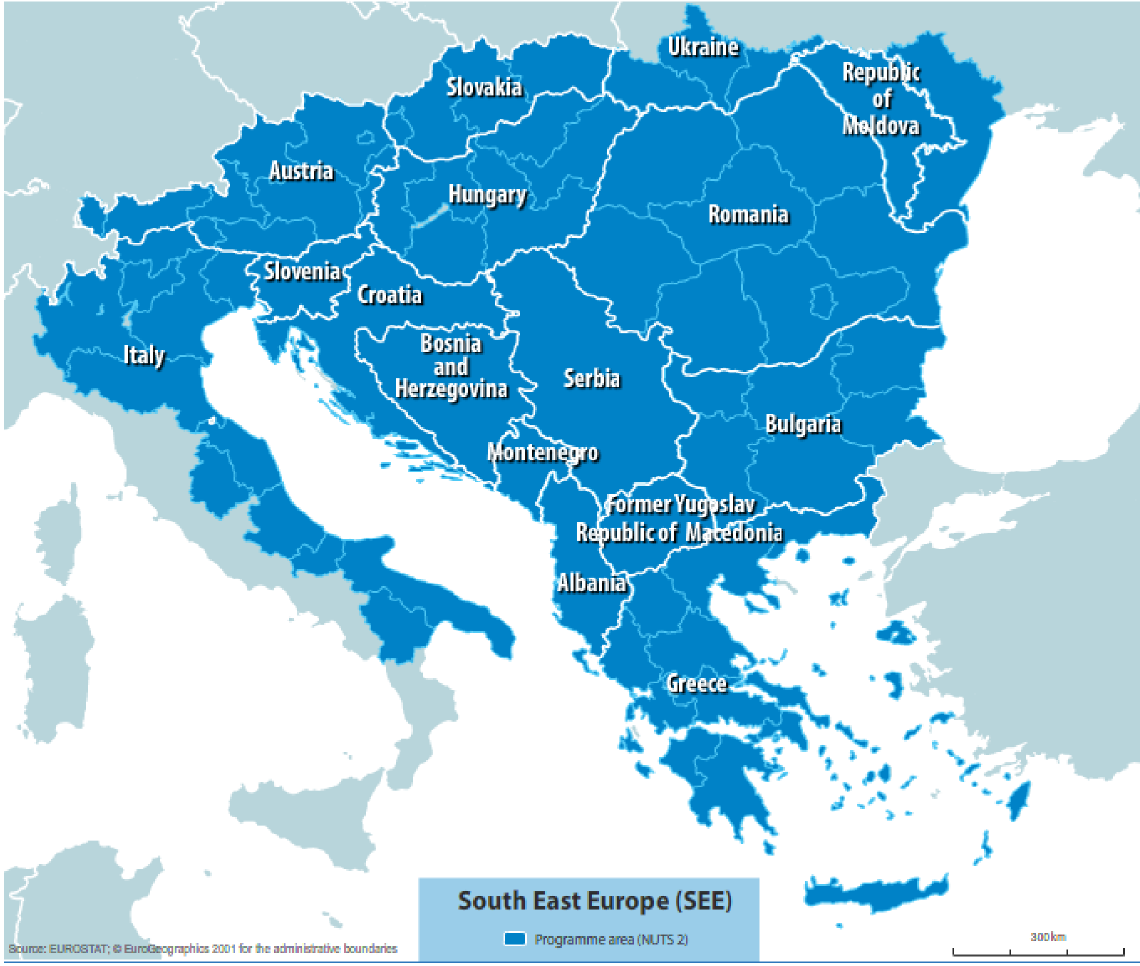
Countries

Tackling the "Digital Divide" in SEE by using the capacity of existing DTT networks



Start: 1st December 2012, for 2 years

Project: South-East European Digital Television

Acronym: SEE TV-WEB

TU Graz
Graz University of Technology

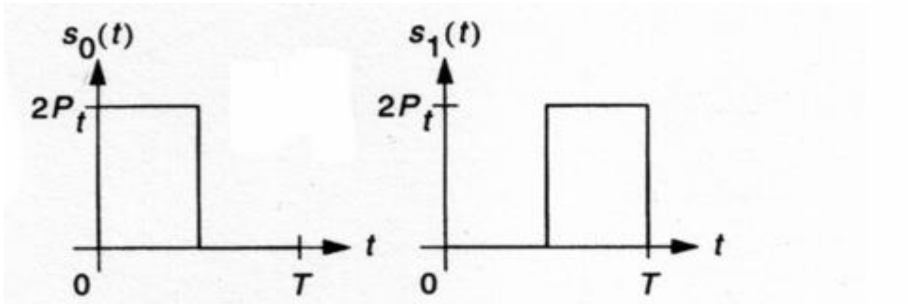
Research projects - Triton
Heterogeneous Integration of Millimeter-Wave Technology

- **Program: Production of the Future**
- **Funded by:**
  - Austrian Research Promotion Agency (FFG)
  - Austrian Ministry for Transport, Innovation and Technology (bmvit)
- **Duration: May 2017 – April 2020**
- **Partners:**
  - Austrian Institute of Technology – Lead partner
  - Vienna University of Technology
  - Infineon Technologies AG
  - ams AG
- **Overall project volume: € 2,7 Mio**

Puls-Position-Modulation

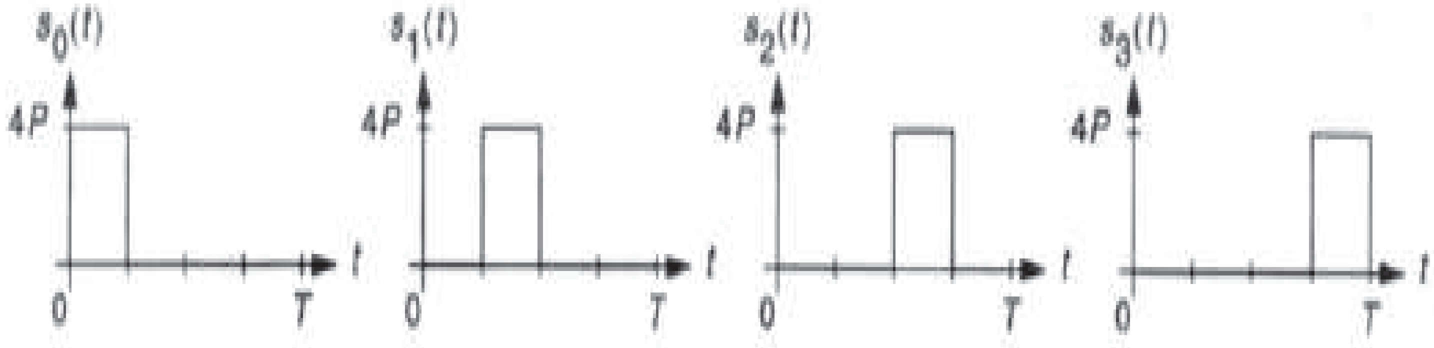
2-PPM,

OOK



$$\frac{d_{OOK}}{d_{\min}} = \sqrt{\frac{2}{L\log_2 L}}$$

4-PPM

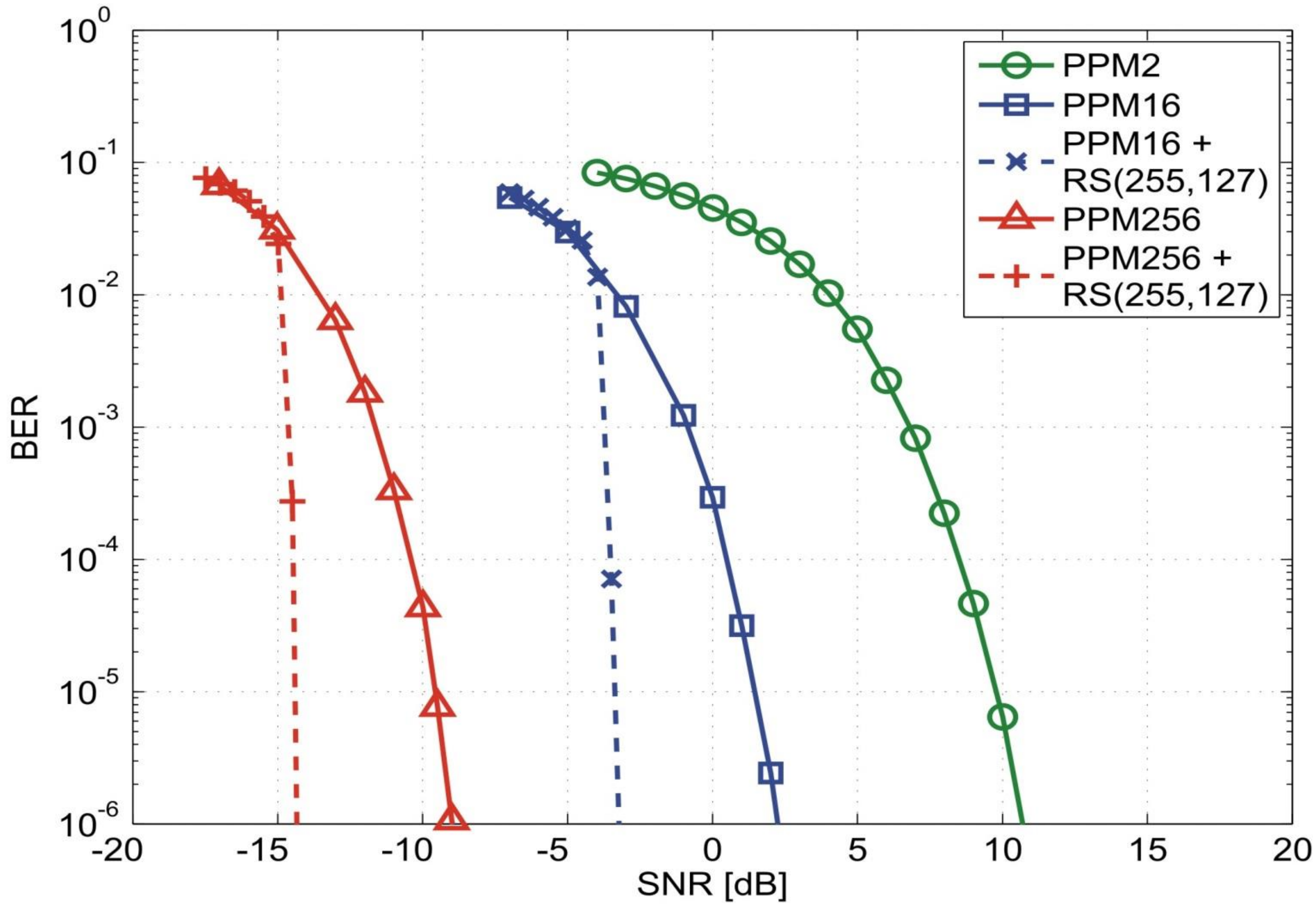


- **L-PAM and QAM** achieve **higher bandwidth efficiency** by sacrificing power efficiency (but power is the major criterion of concern in FSO)
- **L-level PPM** achieves **higher power efficiency** at the expense of reduced bandwidth efficiency
- **4-PPM** requires 3.8 dB less optical power than OOK, and **16-PPM** increases to 7.5 dB better than OOK (but the bandwidth requirement doubles)

RS-coded PPM performance curves

Graz University of Technology

PhD thesis Sajid Sheikh Muhammad (finished 2007)



Motivation for In-Car Optical Communications

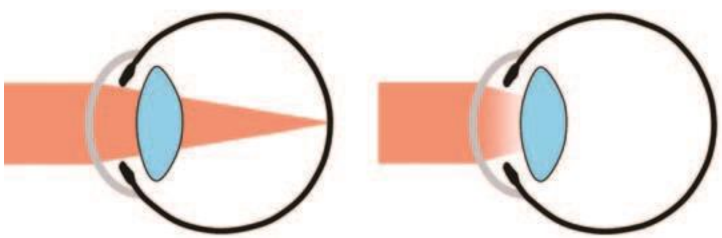
- Future automotive applications will be more sophisticated
  - Communication with environment
    - Buildings, road signs, pedestrians
  - Car-to-Car / Car-to-X
  - Automated & autonomous driving
- Current vehicle bus systems will not be able to handle the increasing network traffic / high data rates
- New approach required
  - Reduce complexity, weight, amount of wiring by using optical fibre

Motivation

- In state of the art vehicles, the weight of wires (mostly copper) add up to 100-150kg
  - Adding more advanced driver assistance systems and their components (sensors, cameras …) will increase the weight further
- Problems with electromagnetic interferences
  - Electromagnetic compliance (EMC)
- Material costs are steadily increasing

Lasersicherheit

- Schädigung des Auges
  - Auge fokussiert Laserstrahlung bestimmter Wellenlängen → Leistungsdichte auf Netzhaut um bis zu 100000-mal höher als auf Hornhaut
  -
    Links: 400-1400 nm
  - Rechts: > 1400 nm



Wellenlänge [nm]	MZB-Wert [W/m²]	Leistung *) [mW]
700	10	0,4
850	20,2	0,78
1550	1000	9,62

***) für Wellenlängen 400 - 1400 nm gelangt diese Leistung ins Auge – der Messblendendurchmesser beträgt daher 7 mm.**

Für die Wellenlänge 1550 nm ist das die Leistung, die innerhalb der Messblende mit 3,5 mm Durchmesser auf die Hornhaut trifft.

maximal zulässige Bestrahlung oder kurz ***MZB Werte***

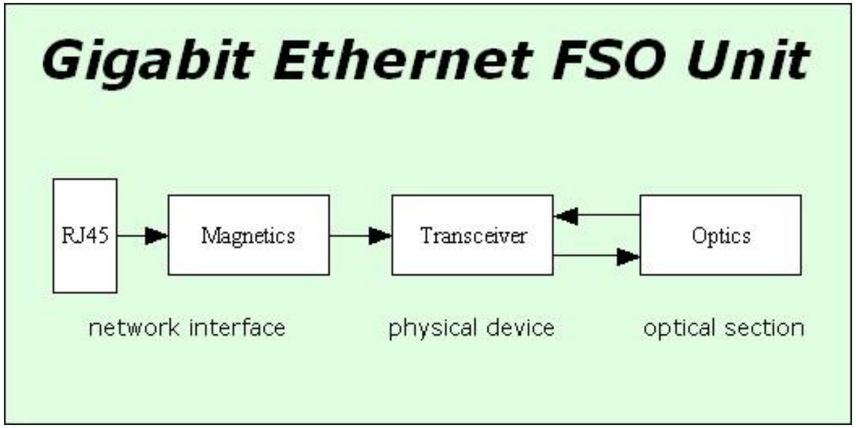
2.3 Experiments showed that FSO is well suited for Access Networks

- **Quick installation of optical short distance links in urban areas (Point-to-Point / Point-to-Multipoint Systems)**
- **Broadband link for railway, highway or river crossings**
- **Links between buildings of companies or institutions (no ‚wire-tapping‘)**
- **Rapid replacement of broken cable-links in emergency situations**
- **Short term installation for mobile / nomadic use (e.g. seminars, meetings, events)**
- **Connections to subsidiaries, storage depots (outposts) of companies or other institutions**
- **For Disaster Management, Disaster Recovery and CIMIC purpose**

2.3 GBit/s Free Space Optics Systems

….. used for experiments (including Last Mile systems developed at TU Graz)

- Multi-Beam design concept, 8 Transmitters, 1 Receiver (in 2004)
- GBit Ethernet (in 2004 very expensive)!!!



- Next Generation of GBit Ethernet
- FSO NG (in modules)

2.4 Digital Video Broadcasting- Terrestrial (DVB-T)

- Relatively new and widespread technology, initiatives from local governments to establish additional DVB-T channels
- Bandwidth per channel from 5 to 23Mbit/s
- IP over DVB standard is already existing (MPE Multi Protocol Encapsulation)
- Outstanding advantages regarding wave propagation and reflections on metallic surfaces or armoured concrete
- Set Top Box needed

2.4 DVB-T

Finalized international project “SEE TV-WEB” for using DVB-T for Internet-Access

Tackling the ''Digital Divide'' in SEE by using the capacity of DTT networks

Acronym: SEE TV-WEB

TU Graz involved 2012 - 2015

2.5 WLAN

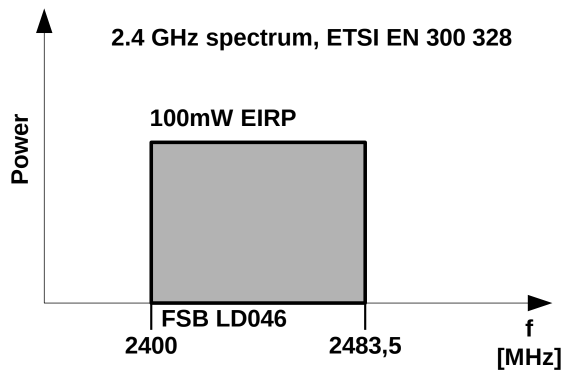
- License free **Wireless LAN**

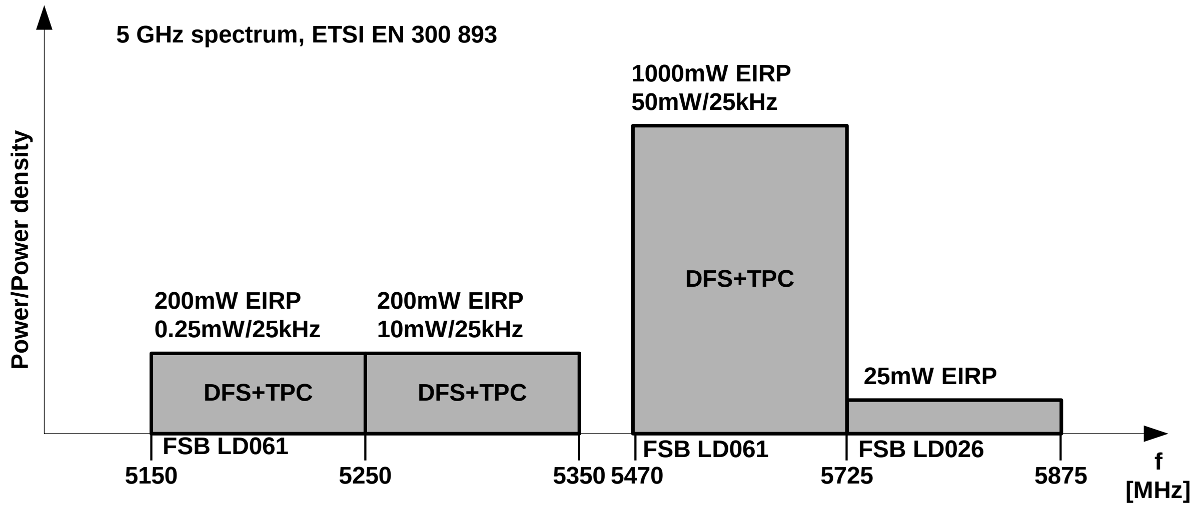
WLAN

-Free to use for everyone
-Possible interferences
-Limited EIRP
-2.4GHz and 5GHz spectra

2.5 ETSI WLAN

Spectra and allowed EIRP

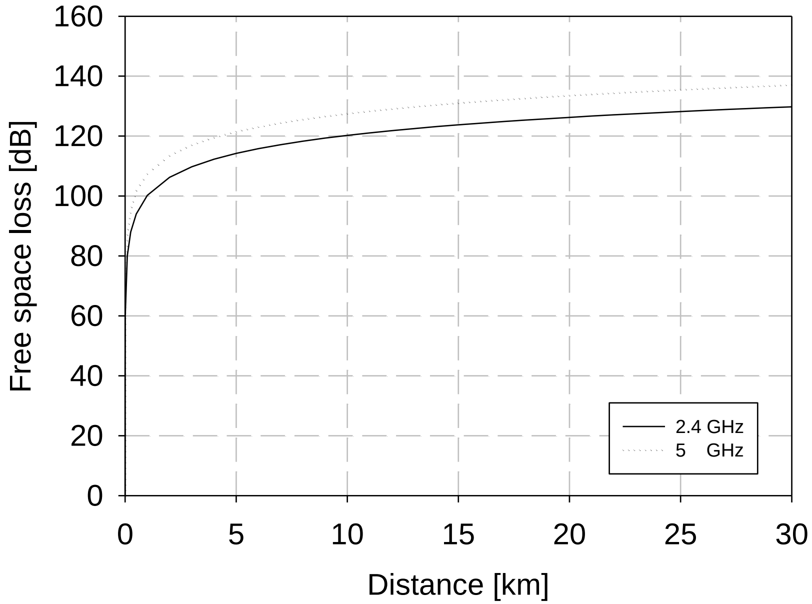


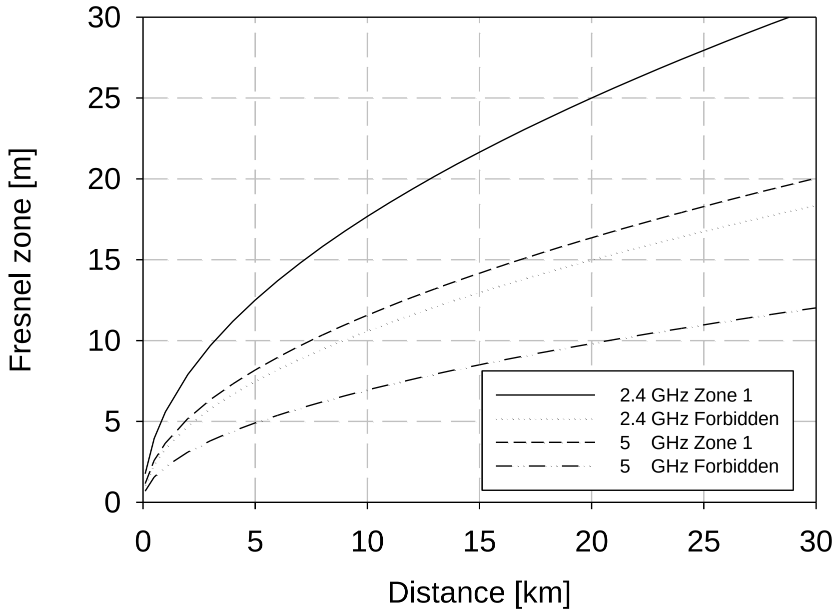


TPC: Transmit Power Control

DFS: Dynamic Frequency Selection

2.5 Free Space Loss / Fresnel Zone





Friis equation:

$$PG(f,d) = G_{TX}(f)G_{RX}(f)\frac{c^2}{(4\pi d^2)f^2}$$

G_{TX}…….Gain transmitting antenna
G_{RX}…….Gain receiving antenna
***f*………..frequency**
***d*……….distance**

Fresnel zone clearance:

$$\nu \approx \frac{h}{r_n} \cong \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

***n*…….Number of Fresnel Zone**
***λ*……..wave length**
***h*……..height of obstacle**
d_1……Transmitters distance to obstacle
d_2……Receivers distance to obstacle