THE ROLE OF LIFI FOR 6G IN BUILDINGS

Volker Jungnickel

Make Your Light Smarter – Turn It Into Data

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Acknowledgement

Thank you to

- Dominic Schulz
- Kai Lennert Bober
- Malte Hinrichs
- Sepideh Kouhini
- Sreelal Maravanchery
- Jonathan Schostak
- Peter Hellwig
- Giulio Boniello
- Julian Hohmann
- Jonas Hilt
- Anagnostis Paraskevopoulos
- Ronald Freund

and all our partners in industry and funded projects

ELIoT

SESAM

Bundesministerium für Bildung und Forschung

AIRBORNE

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VISION

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Content

The Role of LiFi for 6G in Buildings

- What is LiFi?
- Technology
  - Frontends, Channel, Modulation, MIMO
  - Integrated Positioning, Integration with Wi-Fi and 5G
- Use cases
  - Indoor: Residential. Medical, Industrial
- Standards
  - G.9991, **IEEE P802.15.13**, IEEE P802.11bb
- 6G in Buildings
  - Techno-economics of small cells
  - Heterogeneous system concept: FTTH, FTTR, Wi-Fi 7/8, LiFi
- Summary

What is LiFi?

Key Facts

- Wireless communication using light
- Mobile, bidirectional, high-speed data
- No RF needed, unique light properties

Unique Selling Points

- Dense deployment (100 Mbit/s/m^2)
- Light does not pass through walls
- No interference with radio
- Unregulated optical spectrum

Use Cases

- Indoor:
  - Industry, hospitals, residential
- Outdoor:
  - Fixed wireless access, vehicle-to-vehicle communications

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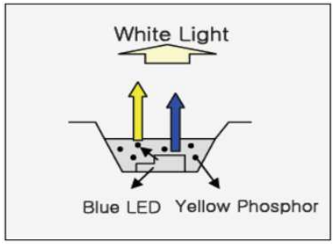
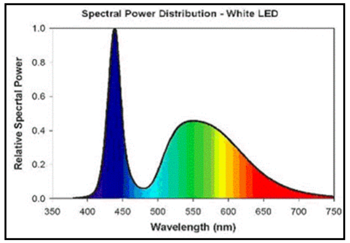
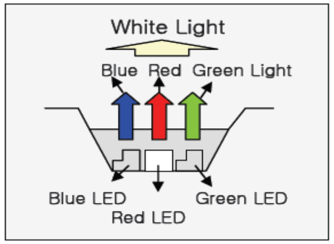
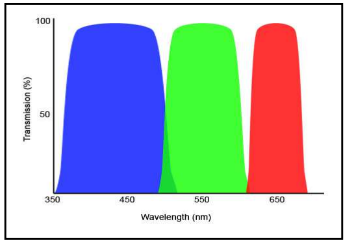
Transmitter

Visible vs. infrared LED

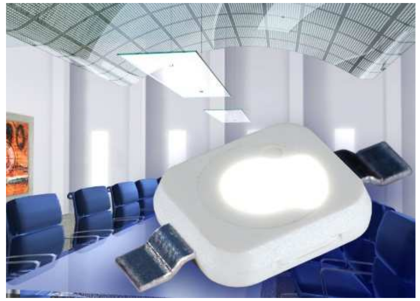


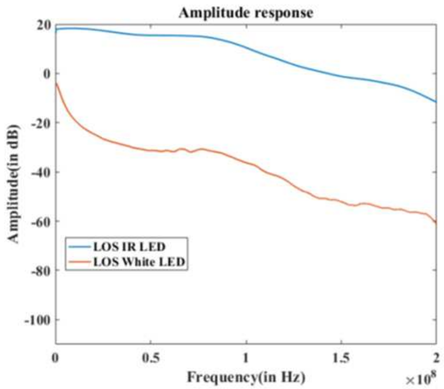






- **Blue LED + phosphor**
  - Blue LED is fast (~20 MHz)
  - Phosphor is slow (~2 MHz)
  - Low-cost, simple driving
- **R+G+B type**
  - wavelength-div. multiplex
  - ~15 MHz per LED chip
  - Higher cost





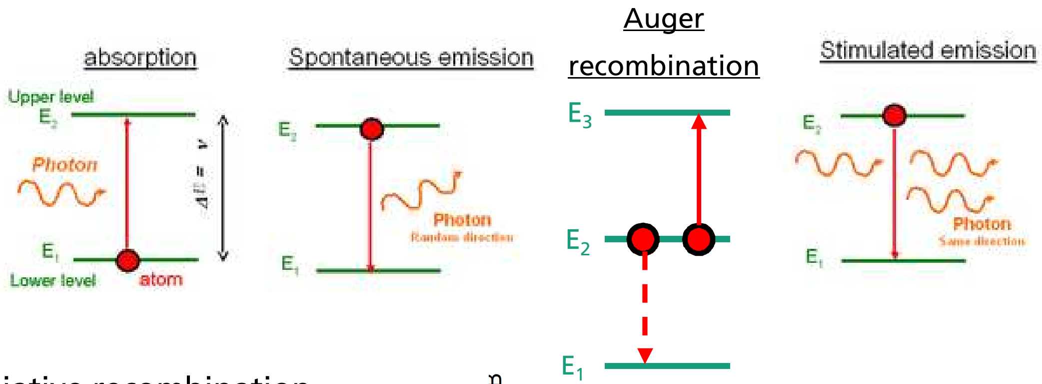
Lessons learned

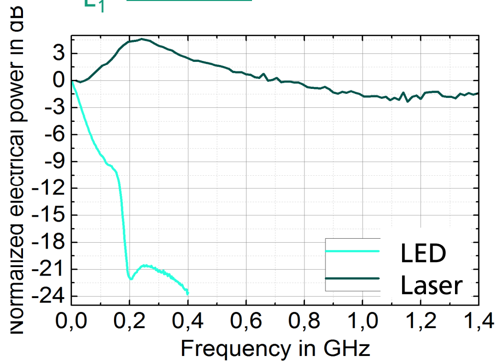
- use infrared (800 nm to1000 nm) instead of visible light
- higher efficiencies of LED and photdetectors, avoid wavelength conversion

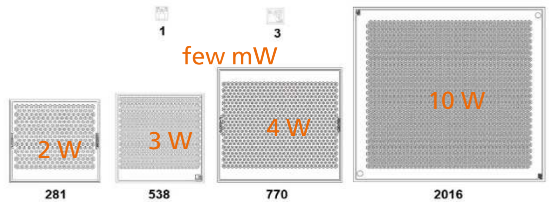
Laser vs. LED

Role of stimulated emission

- Absorption
  - electron to 1st excited state
- Spontaneous emission
  - excited electron back to ground state → radiative recombination
- Auger recombination
  - first electron to ground state, second into 2nd excited state
  - no photon (non-radiative) → less energy-efficient, non-linear
- Stimulated emission
  - external photon forces excited electron into ground state
  - second radiative process → faster, more energy-efficient, more linear
- Laser = light amplification by stimulated emission of radiation
  - vertical-cavity surface emitting laser (VCSEL) arrays exist for LIDAR
  - VCSEL arrays act like LED but are more efficient and faster







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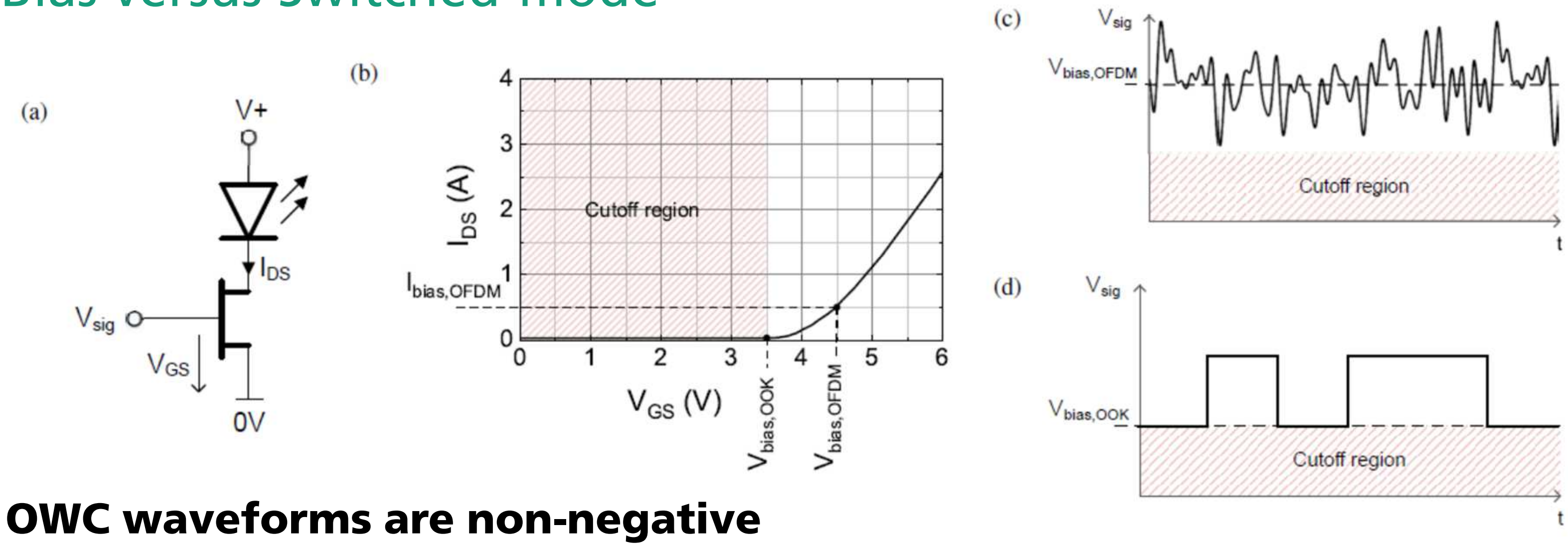
Drivers

Bias versus Switched-mode

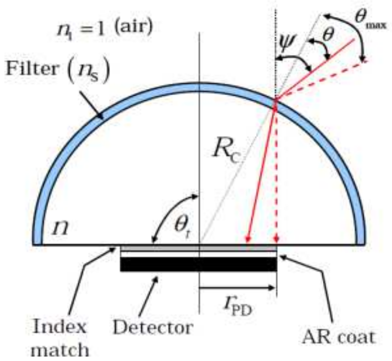


OWC waveforms are non-negative

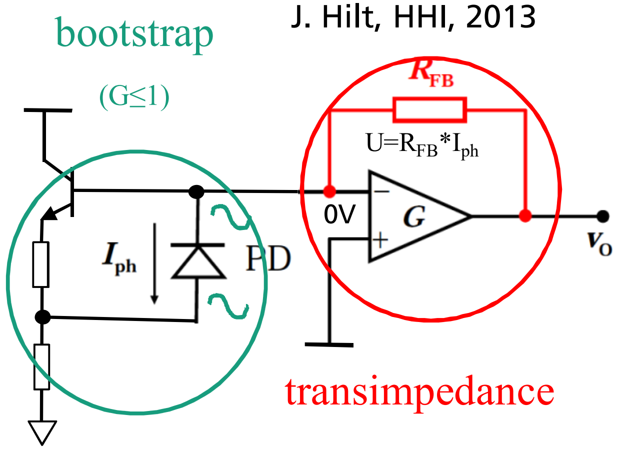
- Bias: around which spectrally efficient modulation can-be applied (e.g. DC-OFDM)
- Switched-mode: operate driver in energy efficient „OFF“ and „ON“ modes (OOK)
- Enables power saving, e.g. in battery-driven mobile devices, equalization is required

Receivers

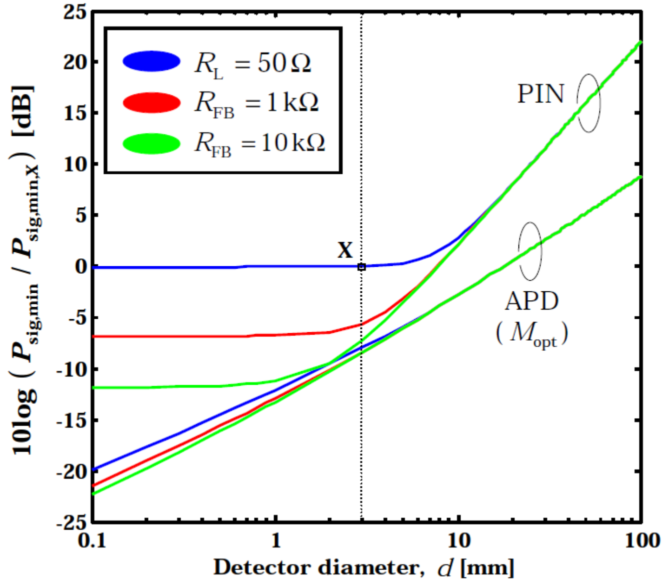
Large-area photoreceiver



J. Hilt, HHI, 2013



J. Vucic, Ph.D. thesis, TU Berlin, 2009



- wide aperture → use optical concentrator
- parasitic capacitance can be reduced using boostrap design → higher BW
- photodiode can have 10 dB higher sensitivity using transimpedance amplifier
- APD gain versus photodiode can be small

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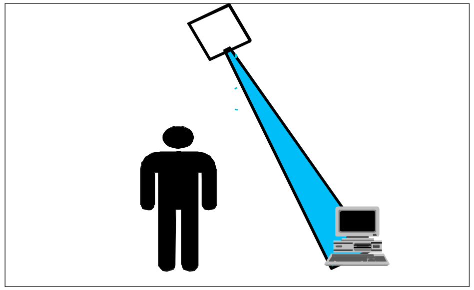
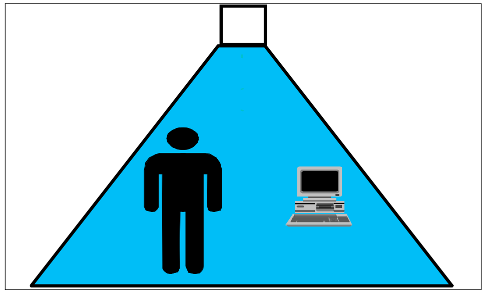
Deployment scenarios

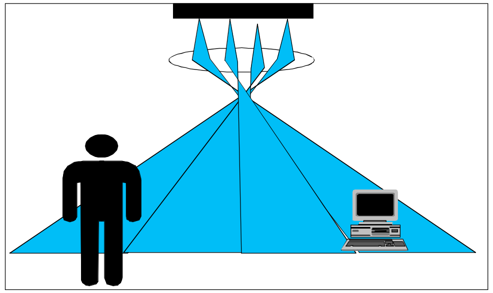
- Directed LOS



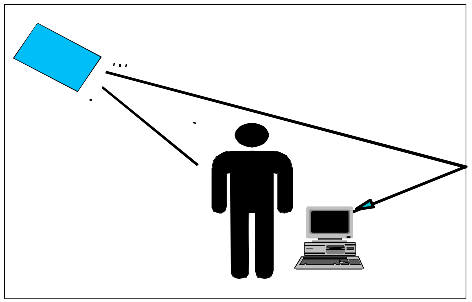
- Non-directed LOS



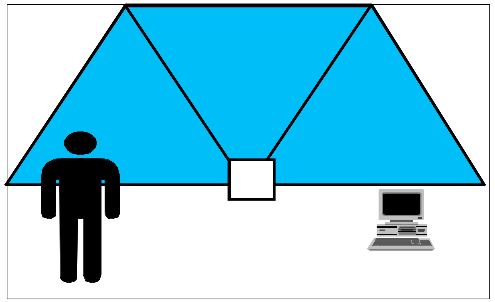
- Switched-beam LOS



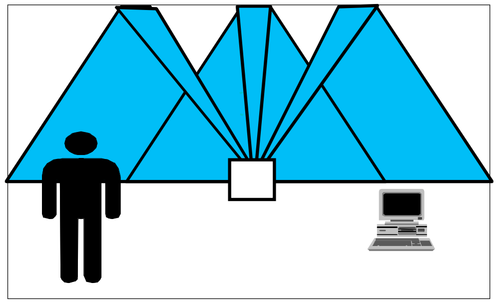
- LOS + NLOS



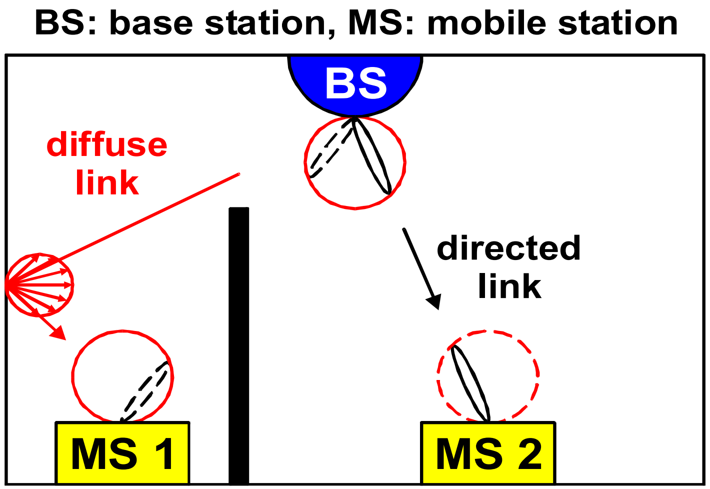
- Non-directed NLOS

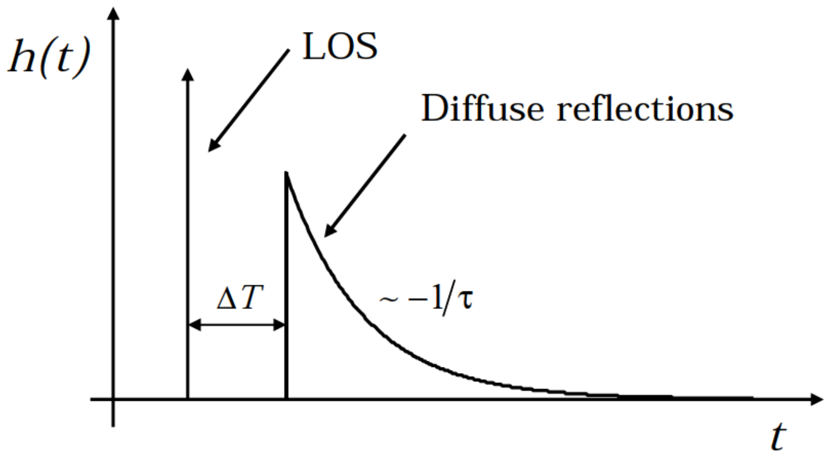


- Multi-spot NLOS



Channel model





- Line-of-sight (LOS)
  - high power
  - high bandwidth
  - blocking is critical
- Non-LOS (NLOS)
  - diffuse reflections → less power
  - lower bandwidth (few 10 MHz)
  - blocking is less relevant

3D environment capture using LIDAR

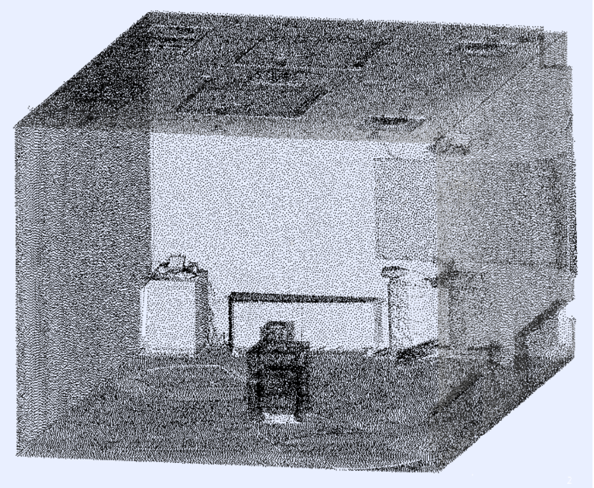
Reduce the effort for defining objects

- LIDAR Scanner: Leica RTC360 (wavelength: 1550 nm)
- Scanned at multiple locations in the room
- Output data of LIDAR: (x,y,z) coordinate, surface normal, and reflectance parameter of each detected point

Sreelal M. Mana *et al.*, "LIDAR-Assisted Channel Modelling for LiFi," *2022 Optical Fiber Communications Conference and Exhibition (OFC)*, 2022

First scanning location

Second scanning location



Final point cloud data of the room

Channel modelling

Simplify the generation of MIMO channels for LiFi

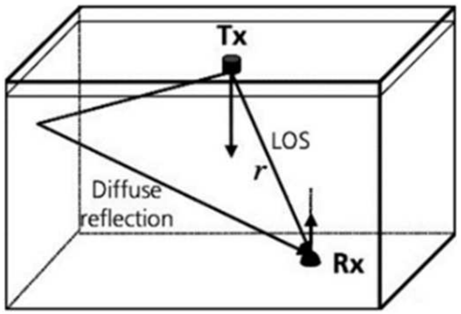
Sreelal M. Mana et al. "An Efficient Multi-Link Channel Model for LiFi," *IEEE PIMRC*, 2021

- Channel modelling in frequency domain rather than in time domain
- **Channel model = LOS + NLOS**
- **LOS:** Based on orientation, distance and optical parameters of Tx
  - $H_{LOS}(f) = V_{Tx,Rx} \cdot L_{Tx,Rx} \cdot e^{-j2\pi f \tau_{Tx,Rx}}$

    $L_{Tx,Rx}$ is the transfer coefficient between Tx and Rx

    $\tau_{Tx,Rx}$ is the delay time

    $V_{Tx,Rx}$ is the visibility factor : (estimated using hidden point removal algorithm)



- **NLOS channel model**
  - First 1-3 reflections, $H_{diff}(f)$ → Frequency domain model
  - Higher order reflections, $H_{diff_{high}}(f)$ → Integrating sphere model

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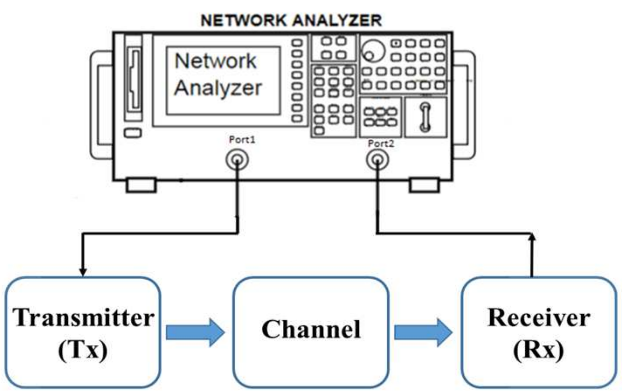
Validation of models by measurements

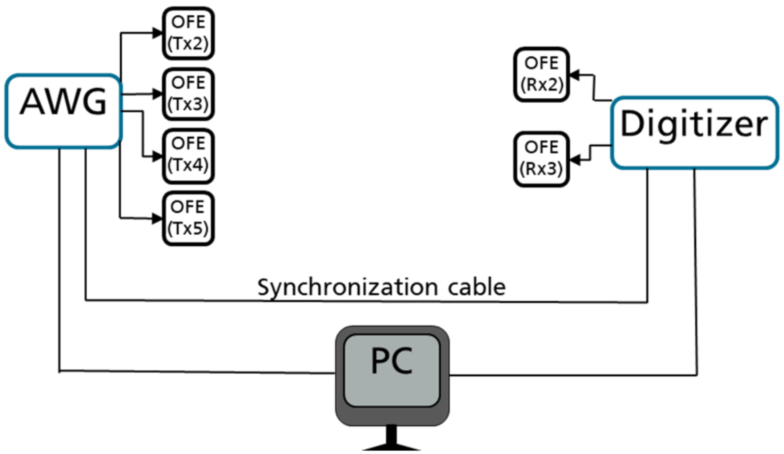
Experimental setup

- SISO



Using VNA

- MIMO

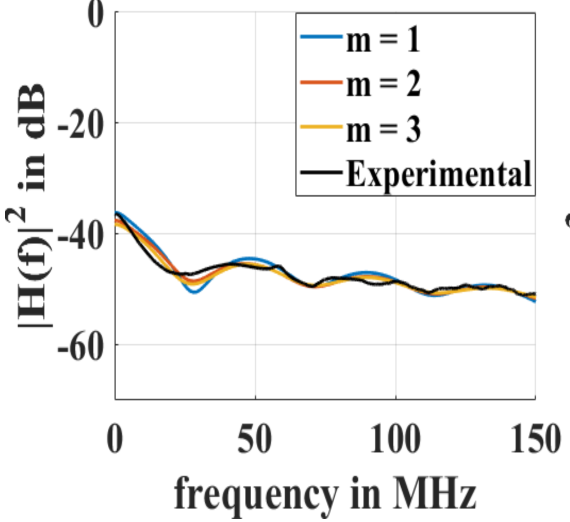


Using LiFi channel sounder

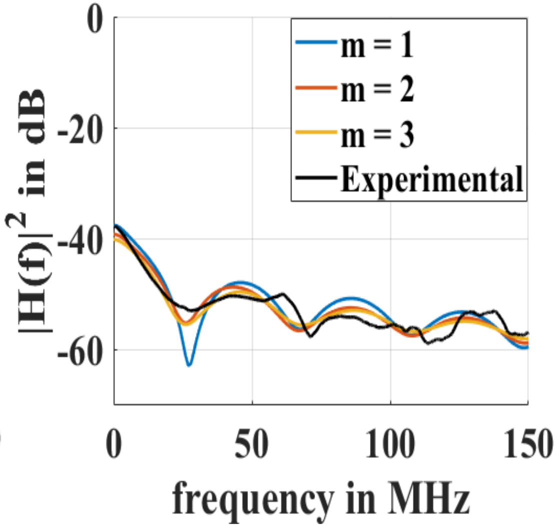
Results

SISO scenario

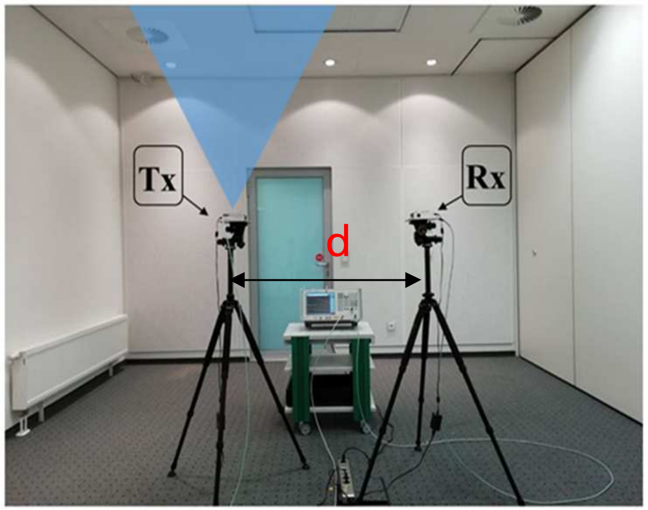
Amplitude response of the channel for d = 2.5 m



Amplitude response of the channel for d = 3 m

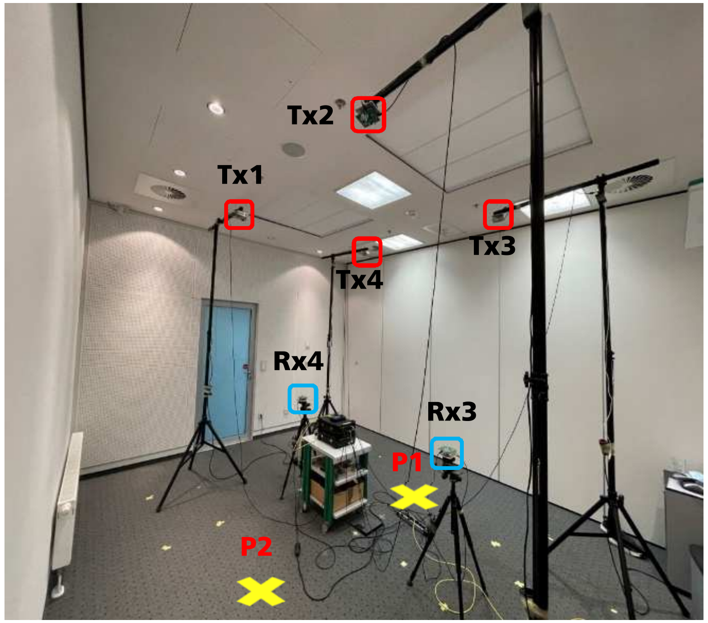


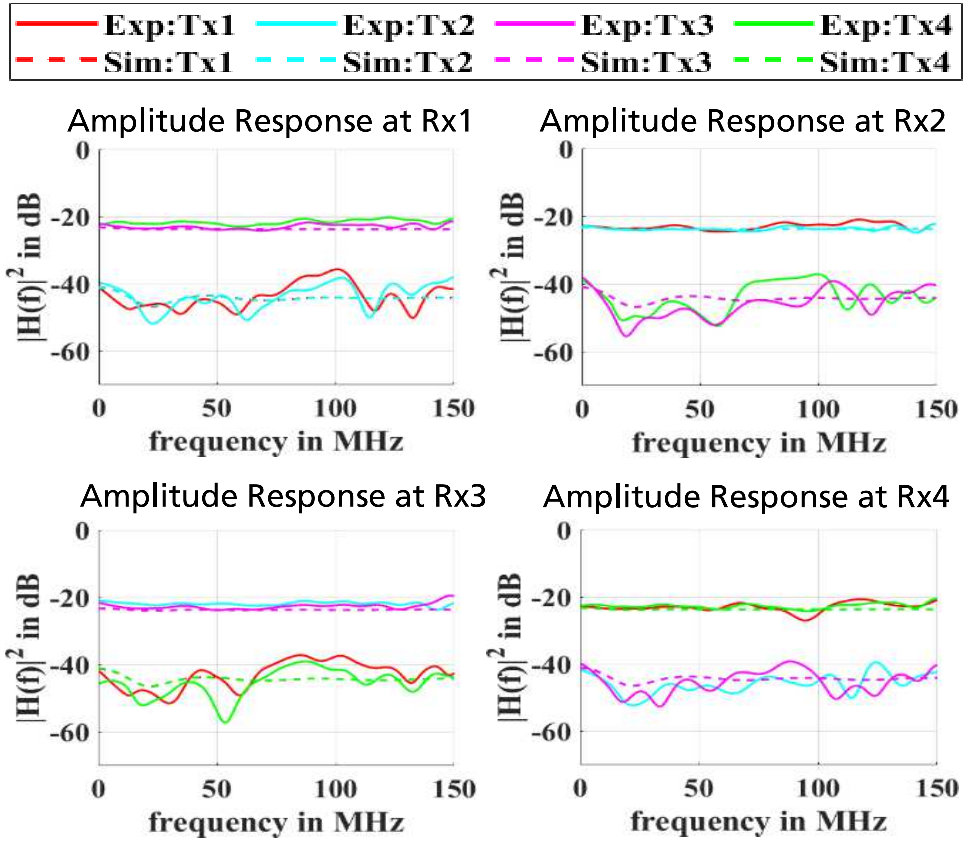
NLOS scenario



Results

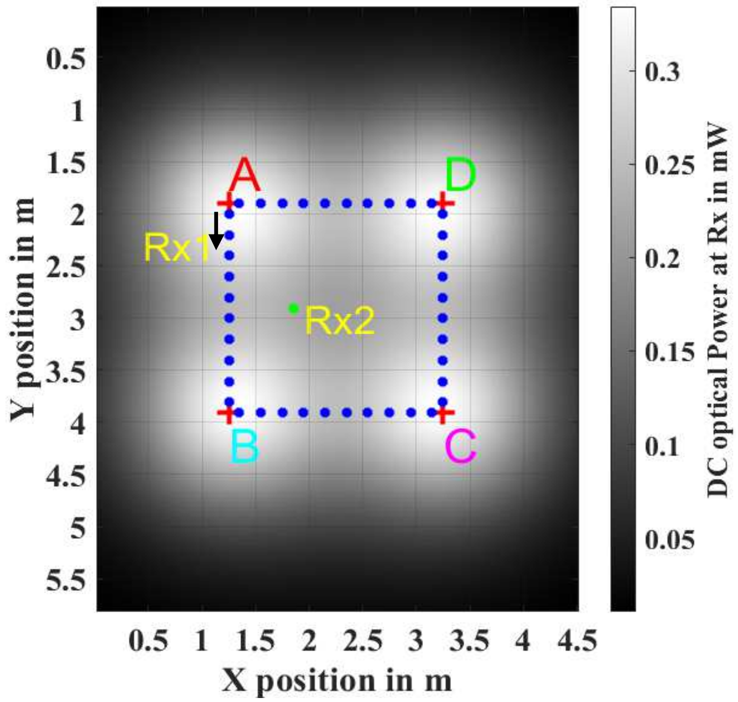
Distributed MIMO setup

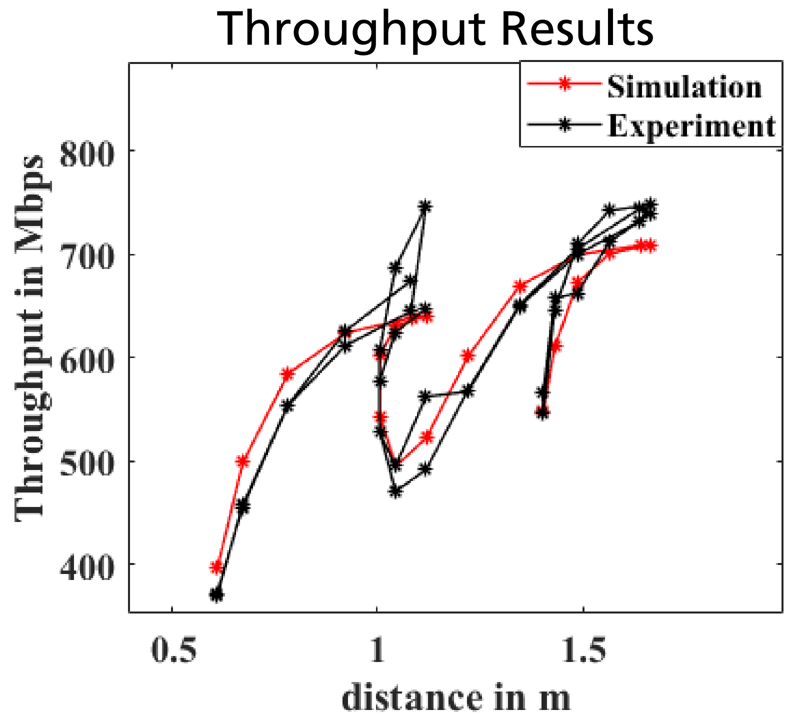




Results

Achievable rate from measured and modeled channels





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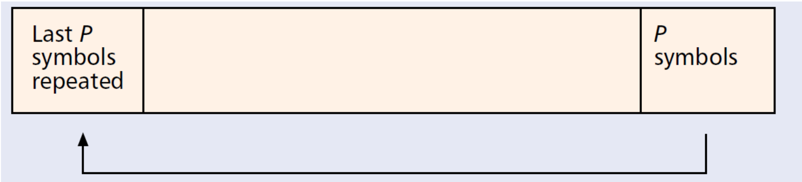
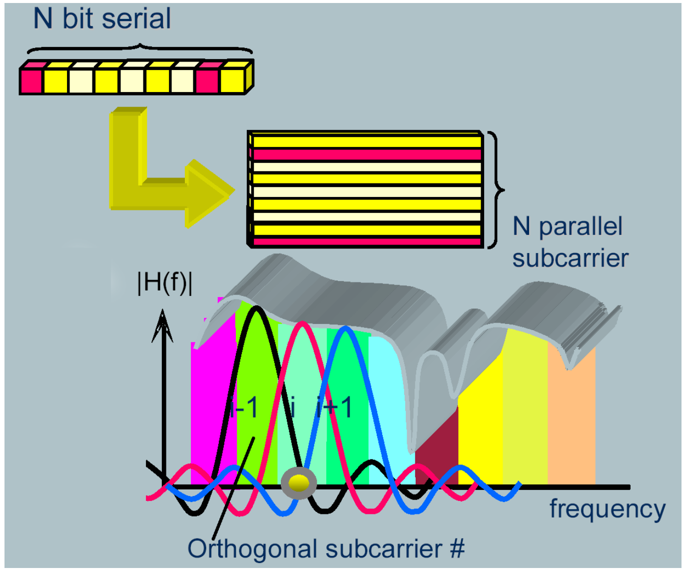
Modulation

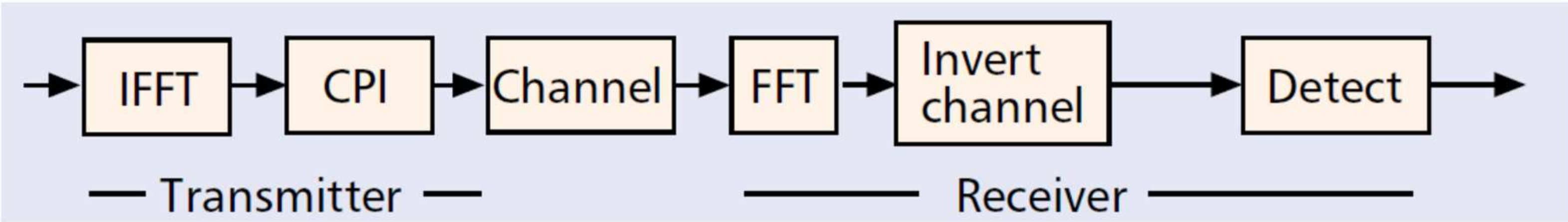
OFDM for high spectral efficiency



- Cyclic prefix overcomes inter-symbol interference
- Circulant matrix gets orthogonal using IFFT/FFT
- Parallel transmission over orthogonal sub-carriers
- Adaptive bitloading to realize channel capacity

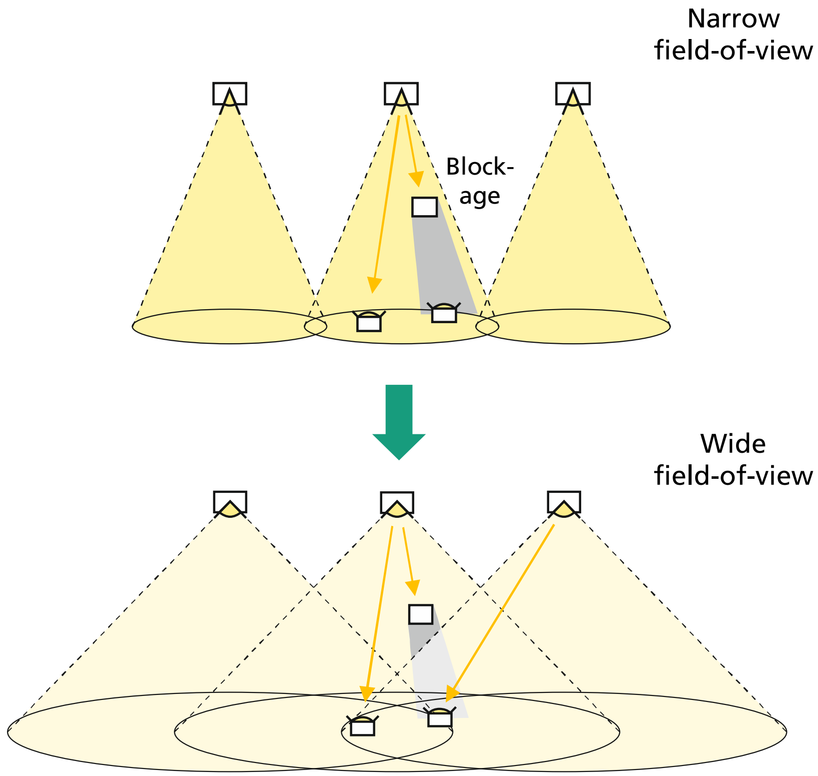


D. Falconer et al., "Frequency domain equalization for single-carrier broadband wireless systems," in *IEEE Communications Magazine*, vol. 40, no. 4, pp. 58-66, April 2002



Why power-efficient waveforms?

- OFDM and adaptive Bitloading
  - overcome limited bandwidth of LED
- Industrial IoT, manufacturing
  - Robust communications
  - LOS gets occasionally blocked
  - Visibility to at least two access points
  - Needs wide, overlapping beams
- Energy efficiency is essential
  - rethink modulation for LiFi
  - cf. battery-driven mobile devices



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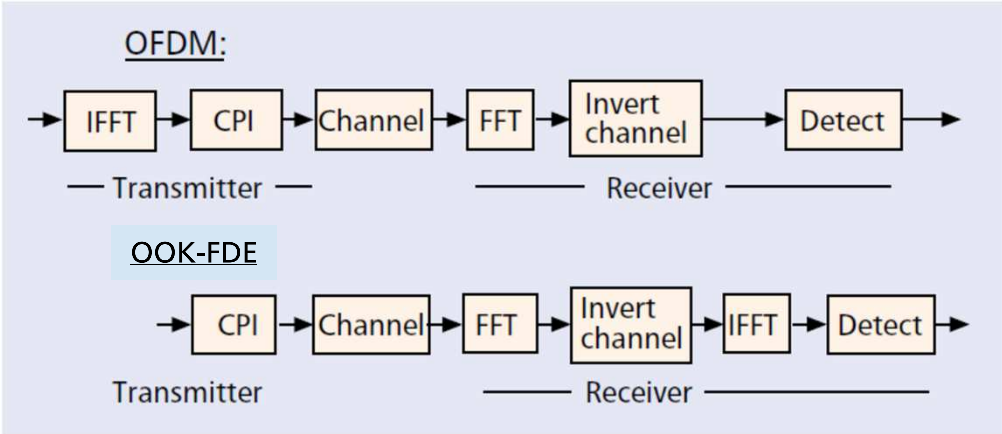
Modulation

OOK/FDE for power efficiency

- OFDM chain can be modified
- Single-carrier (SC) with frequency-domain equalization (FDE)
- Shift IFFT from the TX to the RX
- Works for On-Off-Keying (OOK)



D. Falconer,et al., "Frequency domain equalization for single-carrier broadband wireless systems," in *IEEE Communications Magazine*, vol. 40, no. 4, pp. 58-66, April 2002

Octet 1, LSB left

Bit in the bitmap:	0	1	2	3	4	5	6	7
Clock rate:	12.5 MHz	25 MHz	50 MHz	100 MHz	200 MHz	reserved	reserved	reserved

Figure 49 Clock rate bitmap

IEEE P802.15.13 Draft D6.0, Clause 7.6.19 PM-PHY MCS element

Rate adaptation for OOK

- Mobile scenarios have variable SNR
  - OOK has only two levels, thus limited means to adapt data rate
  - Multi-level would need linear TX frontends (Pulse-Amplitude Modulation, PAM)
  - Variable baud rate works with low-power optical frontends
- MAC layer to adapt the baud rate according to the channel

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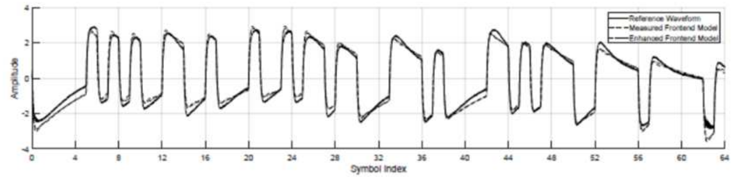
IEEE 802.15.13 PM-PHY

Overcome sloping roofs

a)



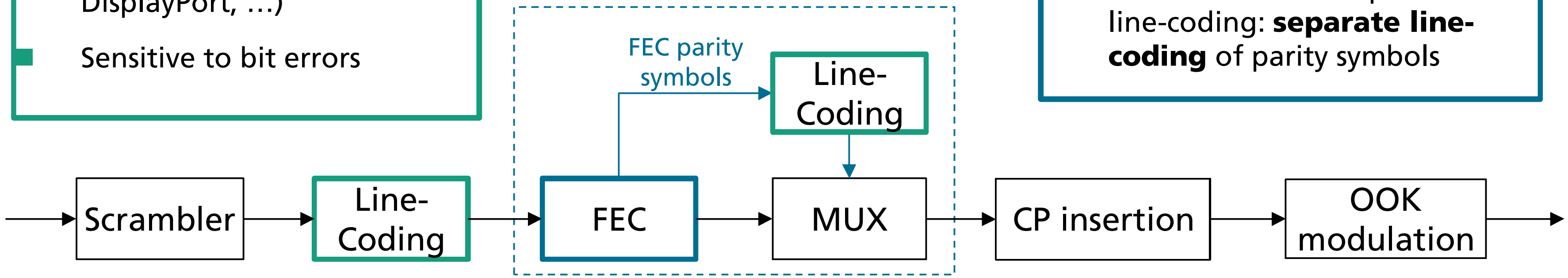
- Combination of OOK with line-coding implies high overhead: alternatives

Line-coding: 8b10b

- Signal balancing to adapt to high-pass characteristic in analog frontends
- Used in various wired technologies (USB 3.0, PCI-E, DisplayPort, …)
- Sensitive to bit errors

FEC: Reed Solomon

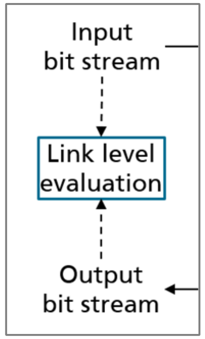
- Code rates: 2/3 (Header), 31/32 (Payload)
- Systematic code: insertion of parity symbols into data stream
- Nested structure to preserve line-coding: **separate line-coding** of parity symbols



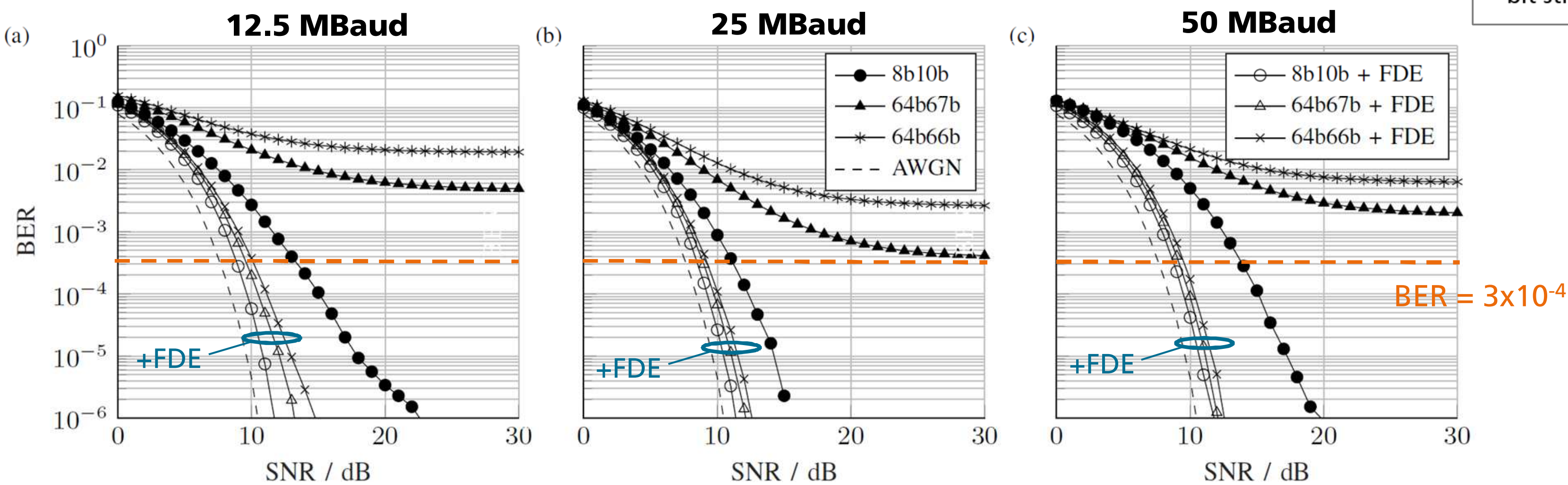
M. Hinrichs et al., "Efficient Line Coding for Low-Power Optical Wireless Communications," *2021 IEEE 94th Vehicular Technology Conference (VTC2021-Fall)*, 2021

Link-Level simulation

Results



- Scrambler-based alternatives do not reach FEC threshold w/o FDE
  - main reason is the high-pass in frontend-model



- **Large effect of FDE**: line coding is no longer needed

M. Hinrichs et al., "Efficient Line Coding for Low-Power Optical Wireless Communications," *2021 IEEE 94th Vehicular Technology Conference (VTC2021-Fall)*, 2021

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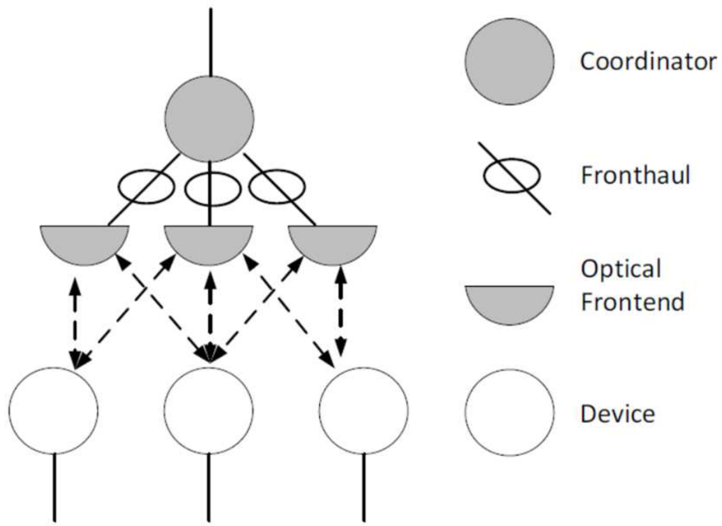
Distributed MIMO
Mobility support

- Hard handover
  - user is covered just by one access point (AP)
  - disconnect from one AP, reconnect to AP
  - processed in higher layers, complex, error-prone
  - latency is compromised
- Soft handover
  - devices are covered by multiple opt. frontends (OFEs)
  - OFEs are connected to coordinator via fronthaul
  - dynamic selection of OFEs serving the device
  - processed in PHY and lower MAC layer → <u>low latency</u>
- Reuse of ideas from Cloud-RAN



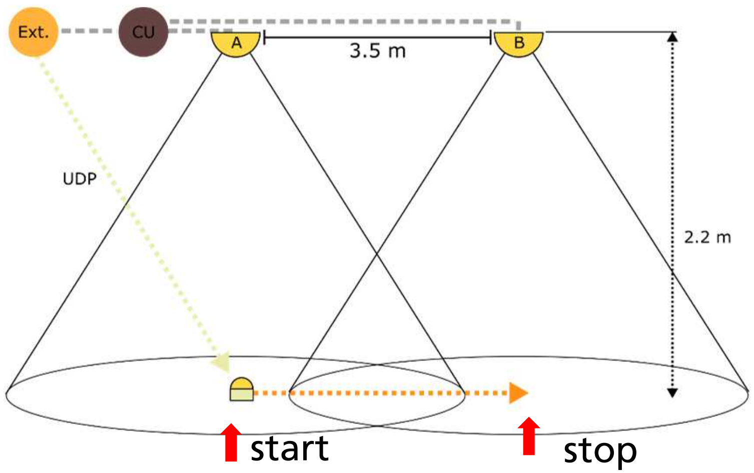
Source: IEEE P802.15.13 draft D2

V. Jungnickel, "LiFi for Industrial Wireless Applications"
OFC 2020, San Diego, paper M3I.1 - Invited

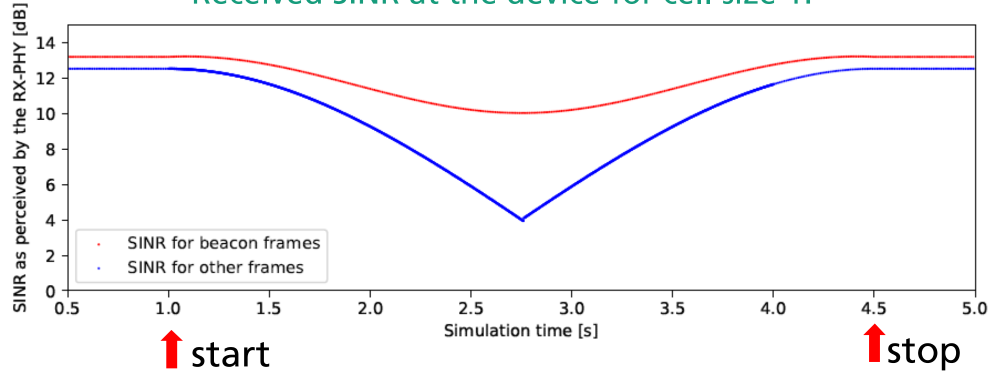
Hard handover creates blind spots

K.L. Bober, Masterthesis, TU Berlin 2018
also in: V. Jungnickel et al., GLC 2019

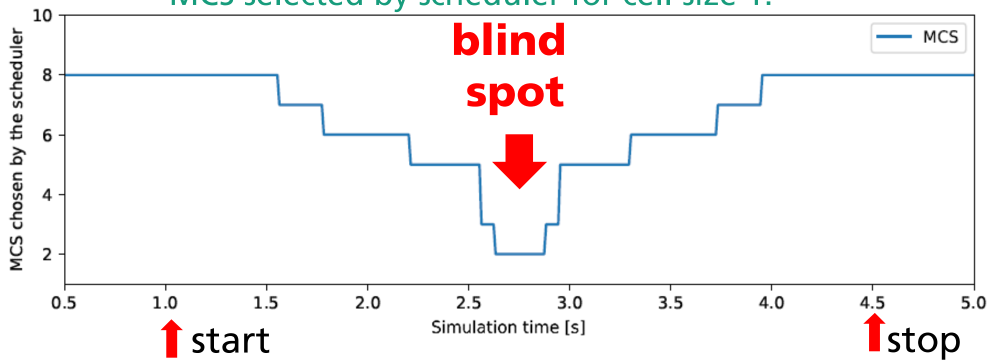
- NS3 based MAC simulation
  - Device moves from cell A to cell B
  - **Max. cell size = 1**
  - SISO, hard handover



Received SINR at the device for cell size 1:



MCS selected by scheduler for cell size 1:



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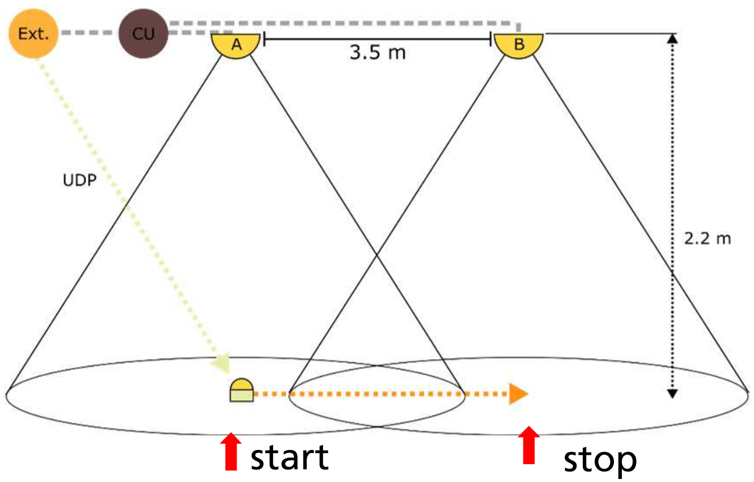
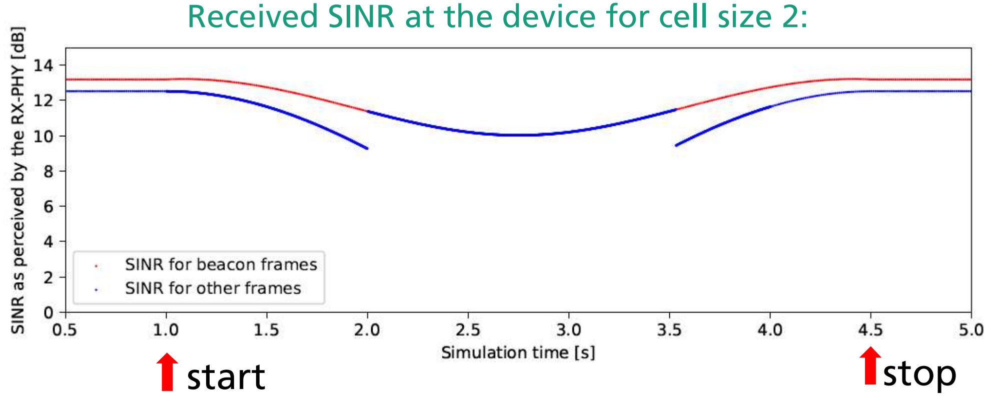
Soft handover removes blind spots

K.L. Bober, Masterthesis, TU Berlin 2018
also in: V. Jungnickel et al., GLC 2019

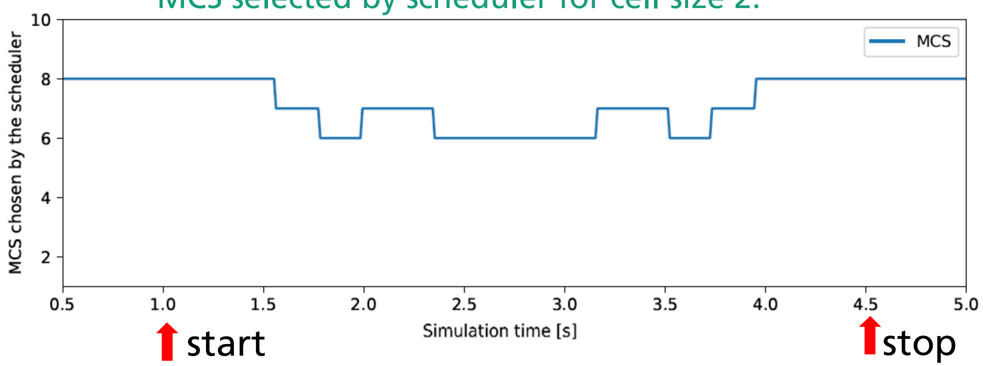
- NS3 based MAC simulation
  - Device moves from cell A to cell B
  - **Max. cell size = 2**
  - MIMO, soft handover



Received SINR at the device for cell size 2:



MCS selected by scheduler for cell size 2:



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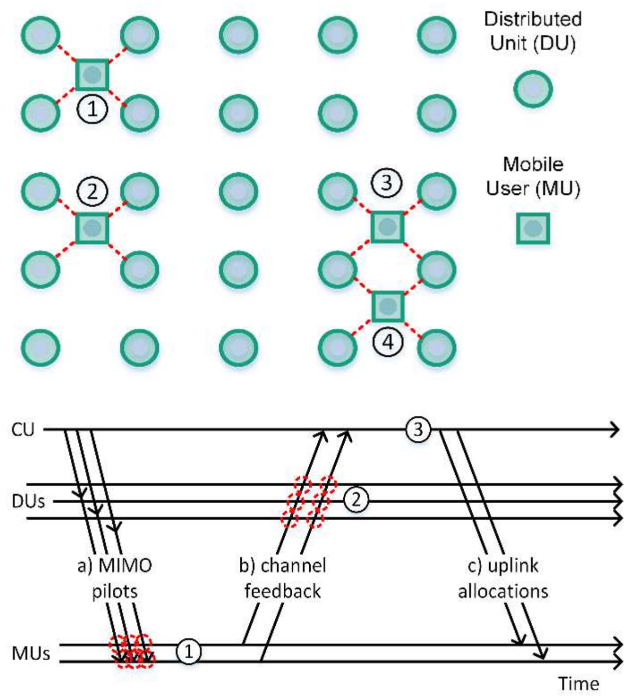
Distributed MIMO

SDMA concept

K.L. Bober *et al*., "Distributed Multiuser MIMO for LiFi in Industrial Wireless Applications" (invited paper), IEEE Journal of Lightwave Technology, March 2021.

- MUs are served by multiple DUs (clusters)
  - enhanced robustness against blockage
- Clusters use space-division multiple access (SDMA)
  - optical modulation spectrum is reused in space
- Overlapping clusters are separated by
  - TDMA / OFDMA, depending on the standard
  - joint transmission / detection (MIMO) betw. clusters
- Elementary feedback-and-control loops
  - defined in new IEEE P802.15.13
  - supported by beacon-enabled MAC and 2 PHYs



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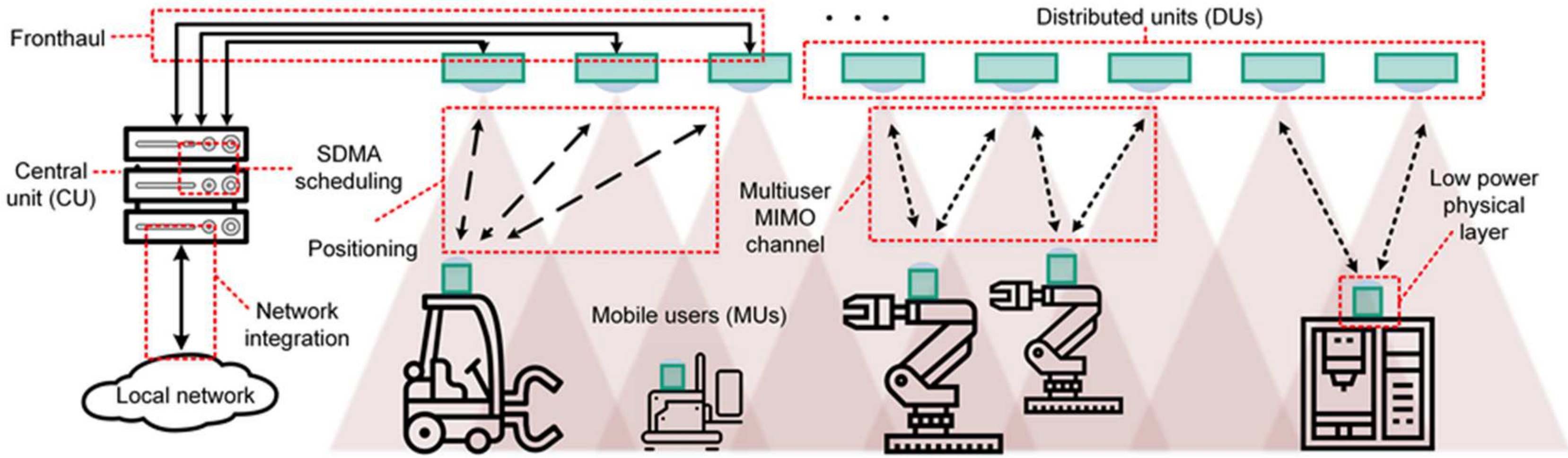
Application: Industrial LiFi

Distributed MIMO

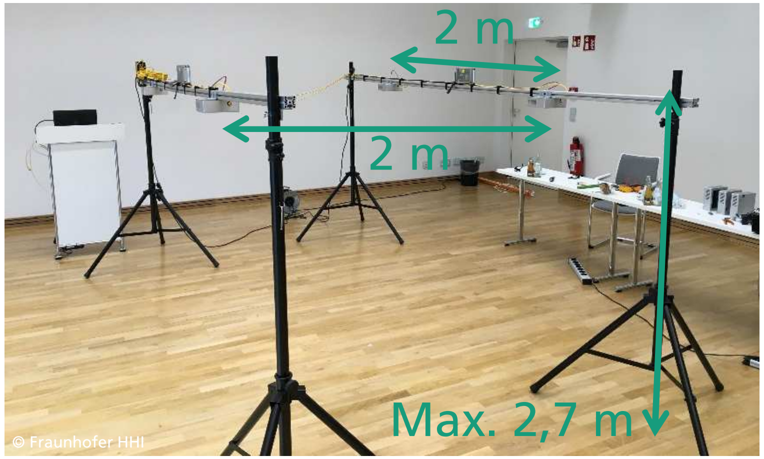
K.L. Bober *et al*., "Distributed Multiuser MIMO for LiFi in Industrial Wireless Applications" (invited paper), IEEE Journal of Lightwave Technology, March 2021.



- Grid of distributed optical frontends with centralized control
- Central unit (**CU**), fronthaul (**F**), distributed units (**DU**)
- Overlapping coverage areas, parallel transmissions to multiple mobile units (**MU**)

D-MIMO Tests
Initial Setup at HHI

- Two LiFi cells with access points (APs) and one central unit
- Each LiFi cell with four optical frontends and one equal gain combiner



- Mobile unit can move freely inside LiFi cell
- Measurement of data rate

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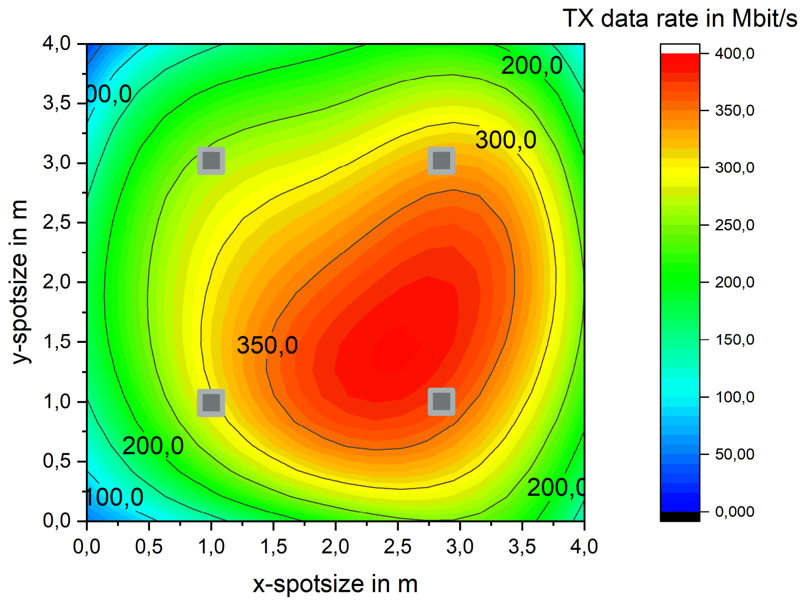
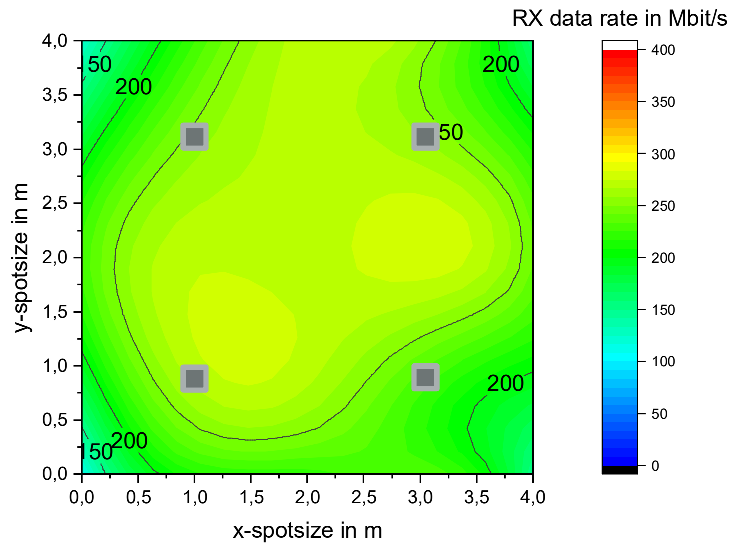
Measured Data Rates

Downlink and uplink





- LiFi cell is able to cover an area of ~ 20 m²
- Gross date rates up to 380 Mbit/s downlink, 280 Mbit/s uplink

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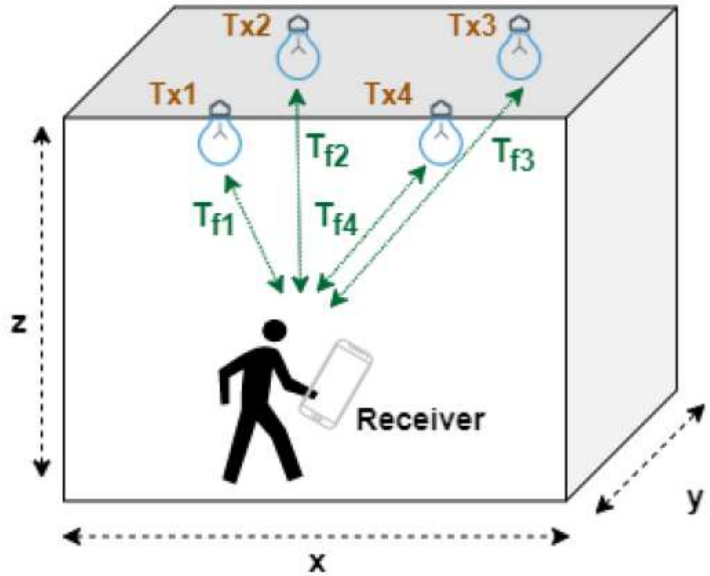
Positioning integrated with communications

Time-of-flight measurement

- Hot topic in RF community
- GPS is not available in buildings
- Indoor positioning can be integrated with wireless communication for future IoT
- Wi-Fi suffers from multipath and penetration through walls
- LiFi travels via LOS and remains in same room
- Good candidate for indoor localization

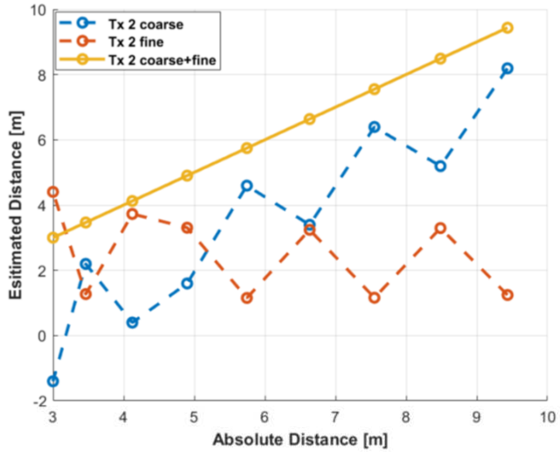


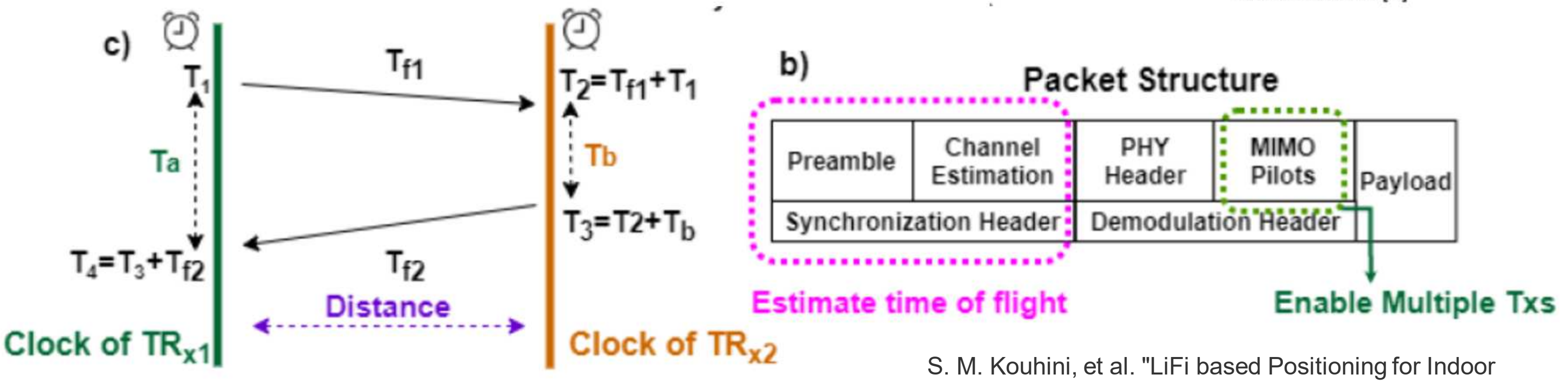
S. M. Kouhini, et al. "LiFi based Positioning for Indoor Scenarios," *17th ISWCS*, 2021

Integrated positioning concept

OFDM Frame Structure

- Reuse tools in **PHY frame structure**
- Framing Sequence: Coarse timing
- Training Sequence: fine timing
- Allows cm accuracy





S. M. Kouhini, et al. "LiFi based Positioning for Indoor Scenarios," *17th ISWCS*, 2021

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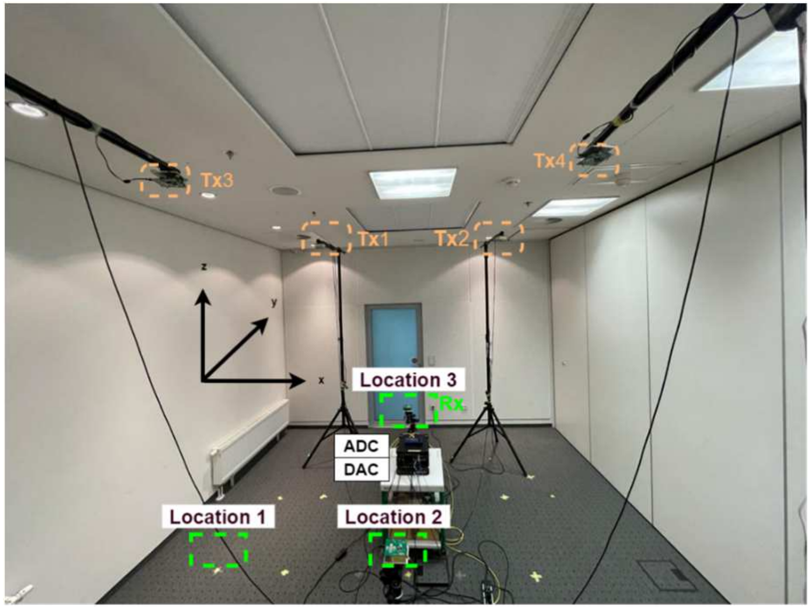
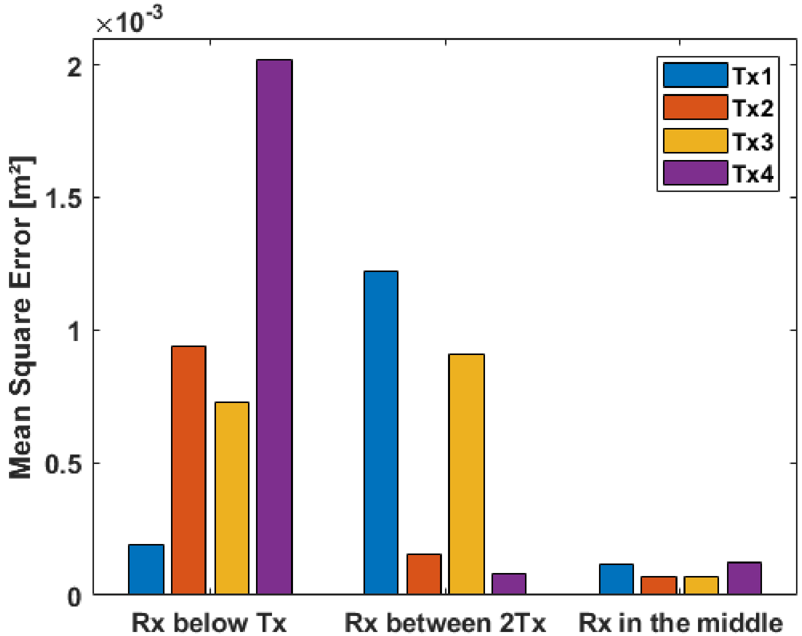
Measurement Setup
Positioning in a Conference Room





- Precise positioning needs well-overlapping LiFi cells

S. M. Kouhini, et al. "LiFi based Positioning for Indoor Scenarios," *17th ISWCS*, 2021

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LiFi for Smart Buildings

Mobile Communication by Light

- Use cases
  - Conference Room / Classroom
  - Smart Home / Smart Lighting
  - Smart Hospital
- Current work
  - Pilot installations in class rooms
  - Channel measurements in surgery room
  - LiFi enabled medical devices

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Pilot Installation in Class Room

Valuable Feedback from Users

- Installation in a classroom
  - LiFi in Hegel Gymnasium Stuttgart
  - One AP serves multiple users
  - Seamless mobility through simplified MIMO
- Valuable user feedback
  - Application-driven technology development
  - One users does not need 200 Gbit/s
- Required features
  - <100 Mbit/s per user, full coverage, seamless mobility
  - Enhanced usability, low-power for integration into mobile devices

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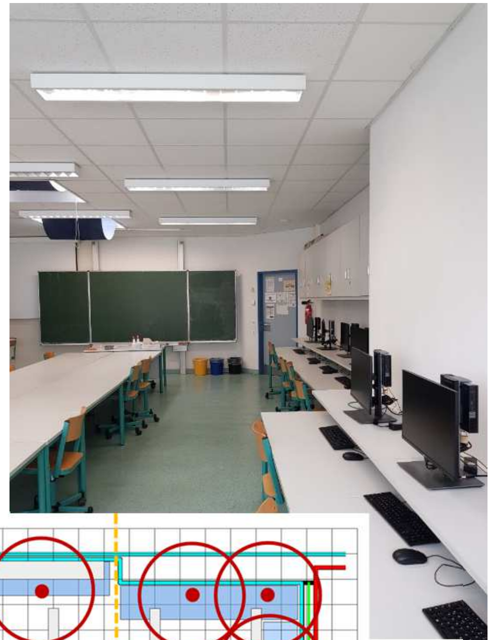
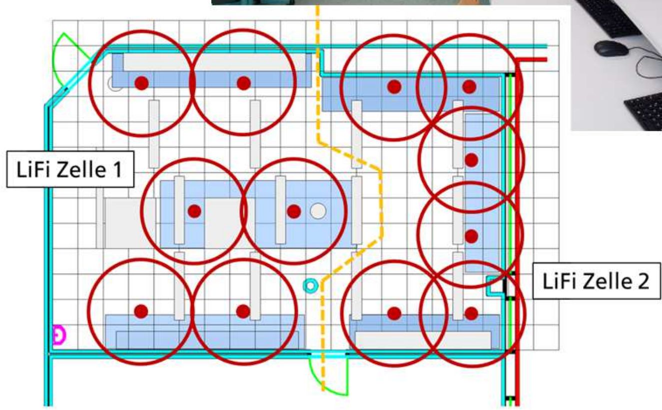
Residential LiFi
Further Development

- Next gen. LiFi installation a classroom March 2021
  - Main-Kinzig-Kreis, Hessen, Germany
- Central unit to connect up to 8 LiFi access points
- Seamless mobility, further reduced cost



DU



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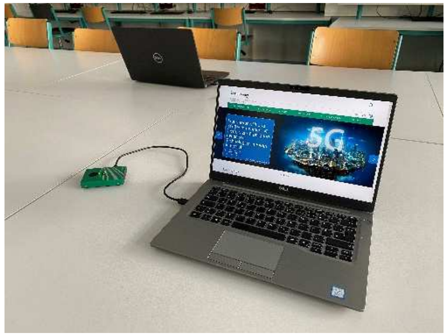
LiFi Installation in Hessen

Networked small cells using LiFi

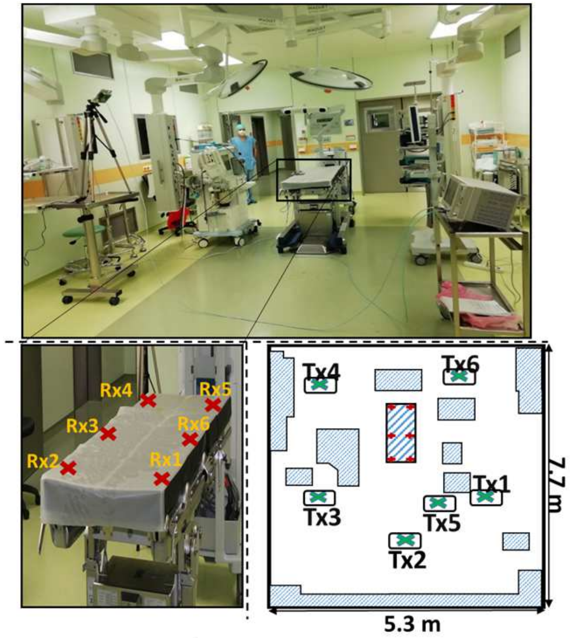


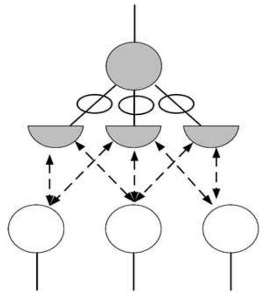
Measurements in a Surgery Room

MIMO for Robustness and High Data Rates

- Neurosurgery scenario, University Hospital Prague
  - Tx and Rx at several positions
  - Evaluate the performance
- D-MIMO architecture
  - multiple-input multiple-output (MIMO)
  - coordinator, fronthaul, opical frontends
  - joint processing for all mobile users
- Promising results
  - time-division multiplex is baseline
  - double throughput using D-MIMO (~600 Mbit/s)

Sreelal M. Mana, "LiFi Experiments in a Hospital," in *OFC 2020*, OSA paper M3I.2.





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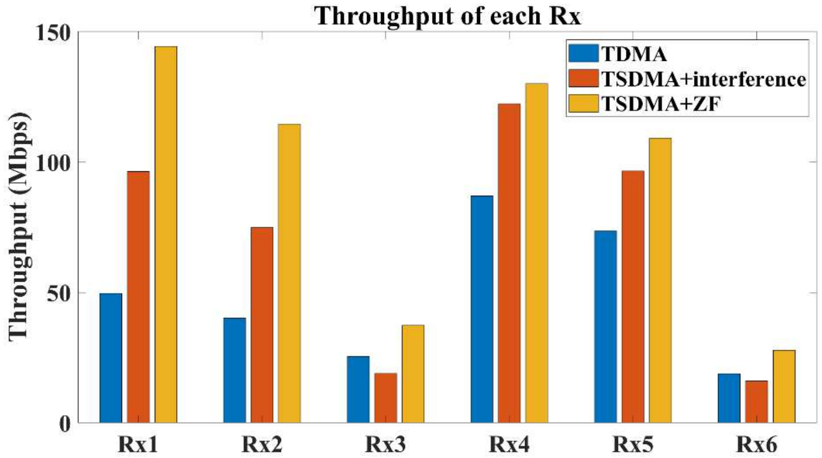
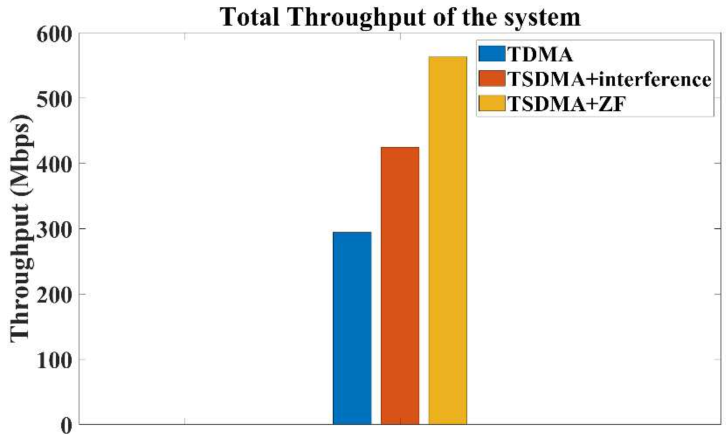
Results in the Hospital

Multiuser MIMO Throughput

- SINR is calculated for each Rx
- Throughput of each individual Rx and total system is calculated
- Various D-MIMO approaches were investigated
- SDMA is the most efficient approach

Sreelal M. Mana, "LiFi Experiments in a Hospital," in *OFC 2020*, OSA paper M3I.2.





LiFi for Industrial Applications

Integration of LiFi and 5G

- LiFi-enhanced 5G
  - Use LiFi next to 5G
  - 5G for coverage
  - LiFi for capacity in hot spots
- Vertical handover
  - LiFi attached to 5G core
  - non-3GPP interworking function (N3IWF)
  - 5G core supports LiFi like 5G
- Demo is in progress in EU-funded project ELIoT

N3IWF – Non-3GPP InterWorking Function

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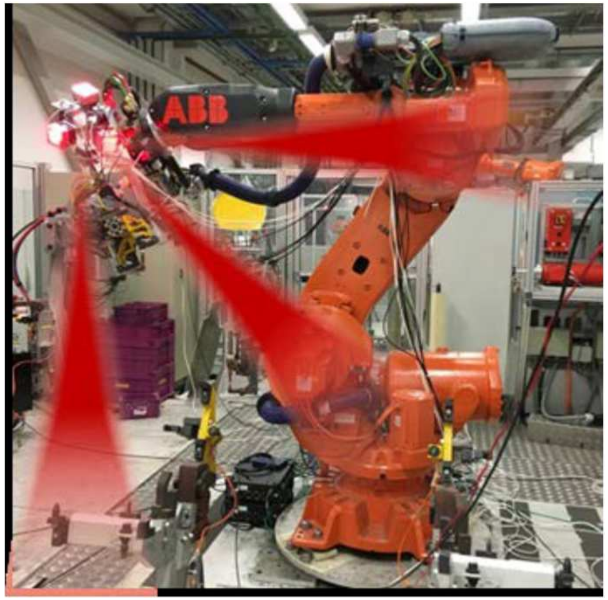
Industrial requirements are tough

Cable-like but wireless

- **Security**
  - propagation is confined inside the room/light beam
  - LiFi is naturally *robust against jamming and EMI*
- **Mobility**
  - wide-beams, 5-6 m high, 100 Mbit/s, eye-safe → *low power*
  - artificial intelligence needs integrated positioning
- **Robustness**
  - overcome LOS blockages, many devices → *distributed MIMO*
  - from diversity (passive combiner) to spatial multiplexing (DSP)
- **Low-latency**
  - TSN support, low jitter → *deterministic medium access*
  - *hot spots covered by D-MIMO islands → fast handover to RF*



LiFi APs

Combiners

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Initial proof-of-concept

BMW robotics lab (OWICELLS project, 2015-2018)

In: 1:10   Out: 2:00

- https://www.youtube.com/watch?v=066jgai1Fbc

P.W. Berenguer et al. IEEE JSAC 36 (1), 185-193, 2017

P.W. Berenguer et al., IPC 2017; P.W. Berenguer et al., ECOC 2018, P.W. Berenguer et al., GLC 2019

P. W. Berenguer et al., JLT, 37 (6), 1638-1646, 2019

Standards development for LiFi

V. Jungnickel *et al.*, "A European view on the next generation optical wireless communication standard," *IEEE CSCN*, 2015, pp. 106-111

- **IEEE 802.15.7-2011/2018**
  - leverage the beauty of visible light for wireless communication
  - sophisticated MAC was borrowed from ZigBee, hardly implementable, no market
- **ITU-T G.9991-2019**
  - legacy of fixed home networking (powerline, coax, twisted pair, POF)
  - very powerful and flexible OFDM PHY, multiple users, limited mobility support
- **IEEE P802.15.13**
  - reduce complexity for industrial applications, handle LiFi like in mobile comms.
  - 3 PHYs (low-power, moderate and high rate), 2 MAC modes: Polling, D-MIMO
- **IEEE P802.11bb**
  - Define new PHY and integrate it into 802.11 MAC → mobility support from Wi-Fi
  - Pave the way into the mass market, reduce costs and power consumption

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IEEE 802.15.13

- **Scope**
  - Multiple Gbit/s
  - adaptation to time varying mobile channels
  - maintain connectivity while moving
- **Industrial applications**
  - control of mobile robots in manufacturing cells and on assembly lines
  - automated guided vehicle systems, small-cell backhaul
  - secure communications in hospitals, nuclear facilities, etc.

Physical layer

1. Pulsed Modulation (PM) PHY

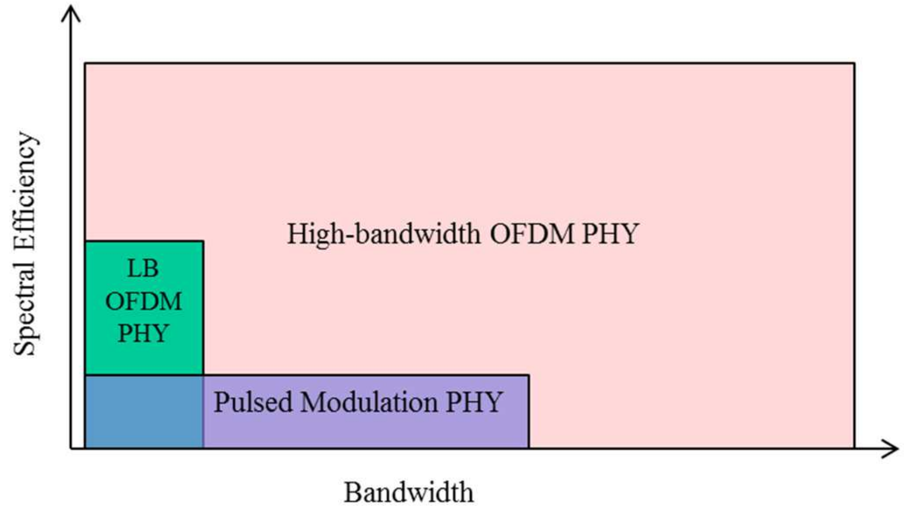
- OOK/FDE: power-efficient
- 12.5…200 MHz bandwidth,
- low spectral efficiency, 1 bps/Hz, 100 Mbit/s

2. Low-bandwidth (LB) PHY

- 5…20 MHz bandwidth
- moderate spectral efficiency
- 5 bps/Hz: <100 Mbit/s

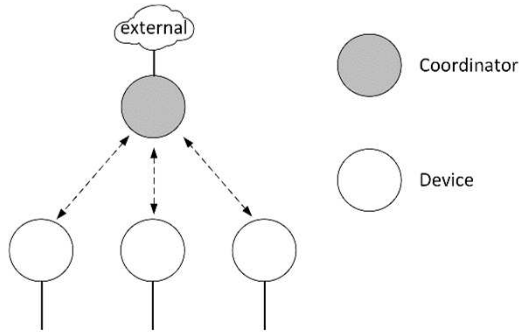
3. High-bandwidth (HB) PHY

- DC-OFDM, spectrally efficient
- 25 …200 MHz bandwidth
- high spectral efficiency: multiple Gbps

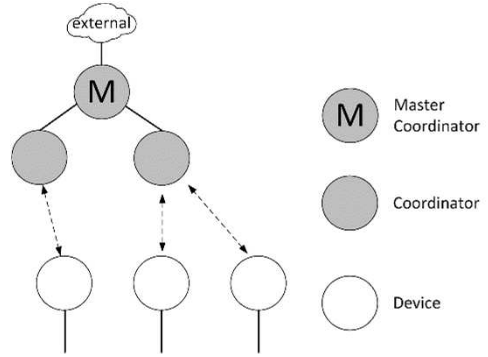


MAC layer

- **Ceiling-mounted "coordinators"**
  - coordinator assists all transmissions of devices
- **Star topology**
  - special cases:
    - P2P (coordinator with a single device)
    - Broadcast (downlink only)
    - Coordinated topology (master coordinator: classical handover)
- **MAC modes**
  - high speed in professional applications
  - polling-based mode for office/home
  - deterministic TDMA for industrial applications
  - support for relaying



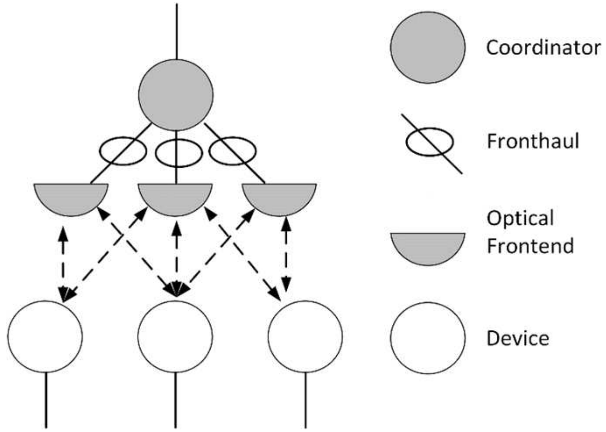
Star topology



Coordinated topology

Distributed MIMO support

- **Multiple LiFi access points**
  - small cells → too many handovers → latency, reliability, overhead are compromised
- **Horizontal handover**
  - between coordinators: fair between adjacent rooms
- **New: Distributed MIMO**
  - between access points in the same room
  - one coordinator controls multiple optical frontends
  - pilots for MIMO sounding and adaptive transmission
  - Supported by the PHY waveform
  - MAC frames + procedures for feedback and control



Draft evolution

- March 2017: started
  - Legacy of 802.15.7
- 2017: Proposals, mergers, technical discussion
  - ideas for distributed MIMO to replace classical handover
- 2018: Spring Cleaning
  - remove old 15.7 text, reintroduce what people understood
- 2019: Minimalistic design
  - initial draft with 150 pages
- 2020: IEEE 802.15 WG letter ballot

  D1.0-D3.0: 815 comments (350 technical, 475 editorial) resolved
- since 2021: IEEE SA ballot

  D4.0: 95% approve, 3 NO, 314 comments (9 G, 112 T, 193 E)

  D5.0: 98% approve, 1 NO, 158 comments (1 G, 96 T, 61 E)

  D6.0: 97% approve, 2 NO, 94 comments (0G, 45 T, 49 E)
- publication expected in 2022

P802.15.13™/D6.0

Draft Standard for Multi-Gigabit per Second Optical Wireless Communications (OWC), with Ranges up to 200 Meters, for both Stationary and Mobile Devices

Developed by the

IEEE Computer Society

of the

IEEE LAN/MAN Standards Committee

Approved <Date Approved>

IEEE SA Standards Board

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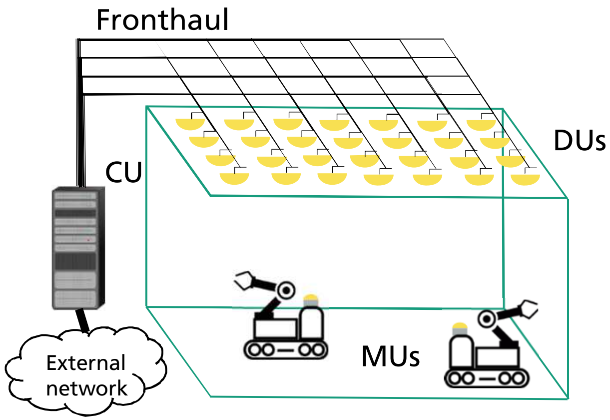
Implementation

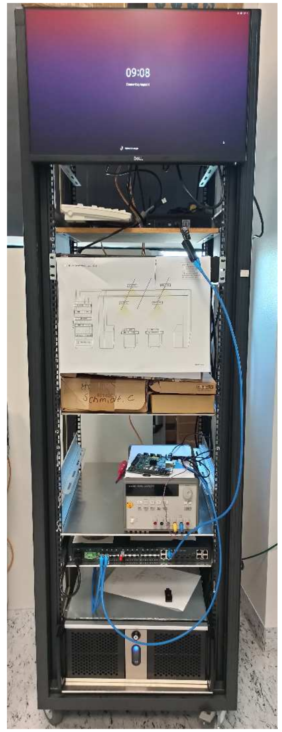
Realtime LiFi system development

- **Goal:** *Scalable distributed MIMO for LiFi in industrial applications*
  - Implementation of 802.15.13 scheduled MAC, 1-2 PHY modes
  - COTS signal processing unit plus HHI optical frontends
  - Goal is D-MIMO in real-time → validation of IEEE 802.15.13



ELIOT SESAM ERIKA AIRBORNE IEEE 802.15

ZYNQ
DPDK DATA PLANE DEVELOPMENT KIT



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HILIGHT Realtime prototype

Realtime demonstration of 802.15.13 standard

- PM-PHY is implemented, HB-PHY is ongoing
- D-MIMO Architecture
  - Central unit, Ethernet fronthaul, distributed units, mobile units are mostly implemented
- Video from first HILIGHT demo is available on Youtube

https://www.youtube.com/watch?v=NEWqi_QHUV8

6G in Buildings

Future IoT creates essential new needs

- 80-90% of traffic demand is indoors, increasingly wireless
- Future IoT (imaging sensors in Cameras, LIDARs, RADARs) will increase demand
- Growing numbers of such devices will connect wireless
- Cable-like quality of service: ultra-reliable, low latency, higher data rates
- New concepts for indoor connectivity are needed in 6G era

What is the role of LiFi and Wi-Fi in 6G to serve these needs?

State-of-the-art

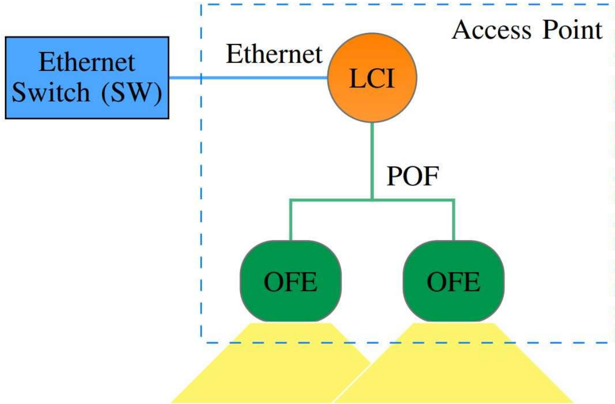
Future IoT creates essential new needs

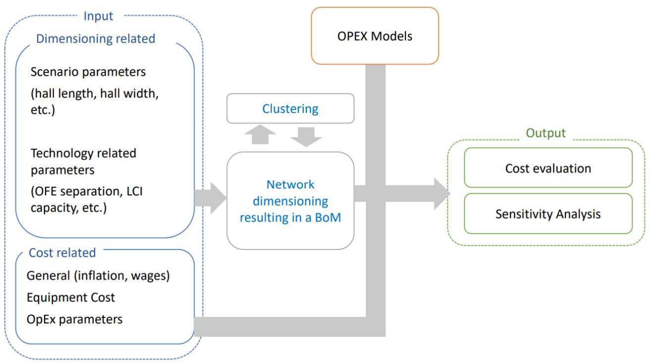
- buidlings are mostly connected by copper
  - DSL or cable, some already use fibre
- also inside in homes, traffic is distributed via copper
  - Ethernet, powerline communications (PLC)
- each home has independent Wi-Fi router
  - Wi-Fi 5…6 is used to connect devices wireless, uplink is DSL
  - few 100 Mbit/s peak rate, 100 m² home → **few Mbit/s/m² area capacity**
- LiFi is an emerging technology, not yet really introduced
  - 1 Gbit/s, 3-5 m² per optical frontend → **few 100 Mbit/s/m² area capacity**
- Major issue related to LiFi is cost

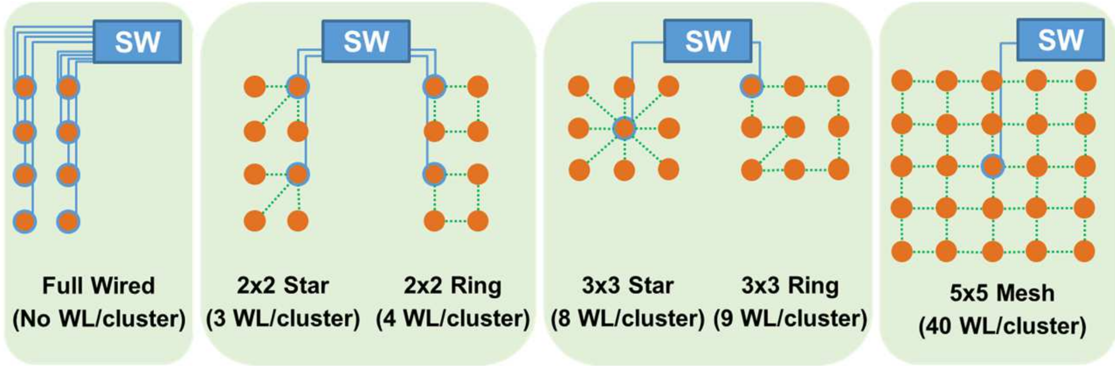
Technoeconomics of small cells

Densification of the network through LiFi

- Model of small cell deployment in a manufacturing hall
- Various cablings were investigated
- Use existing methodology from fixed access networks
- Compute total cost of ownership (CAPEX+OPEX)



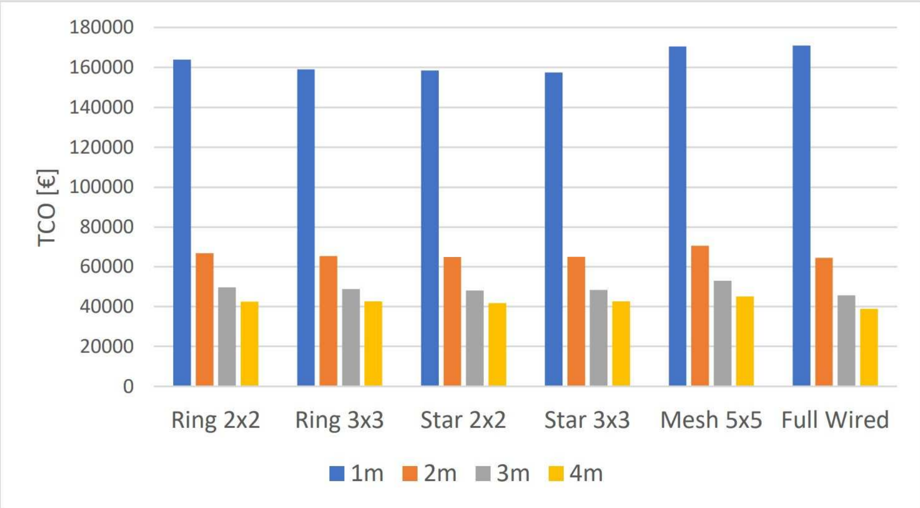


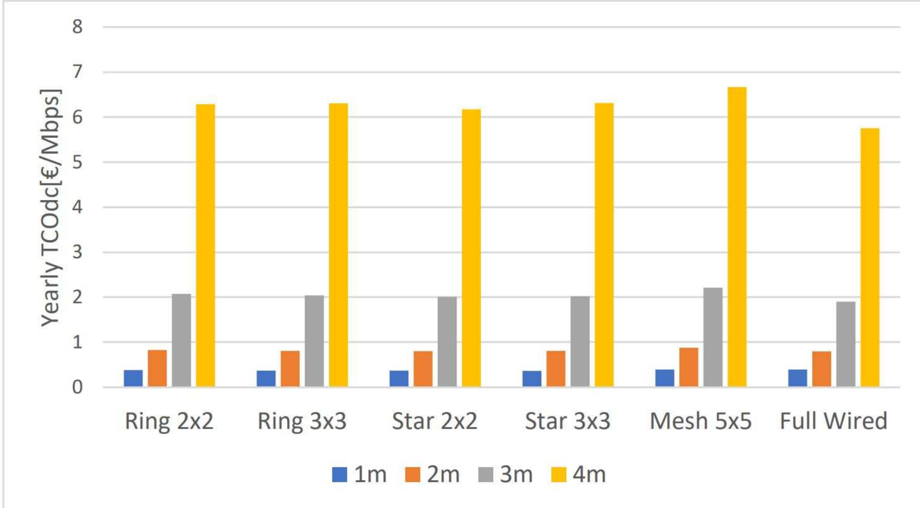


M. Kaufmann et al, „Techno-economics of LiFi in IoT Applications“, ONDM Workshop May 2022

Main result

TCO increases, but TCO-per-Mbit/s reduces, if cells get smaller





- **Wi-Fi** is cheaper if we want **to cover large areas**
- **LiFi** pays out if we want **to upgrade capacity in dense areas**

M. Kaufmann et al, „Techno-economics of LiFi in IoT Applications", ONDM Workshop May 2022

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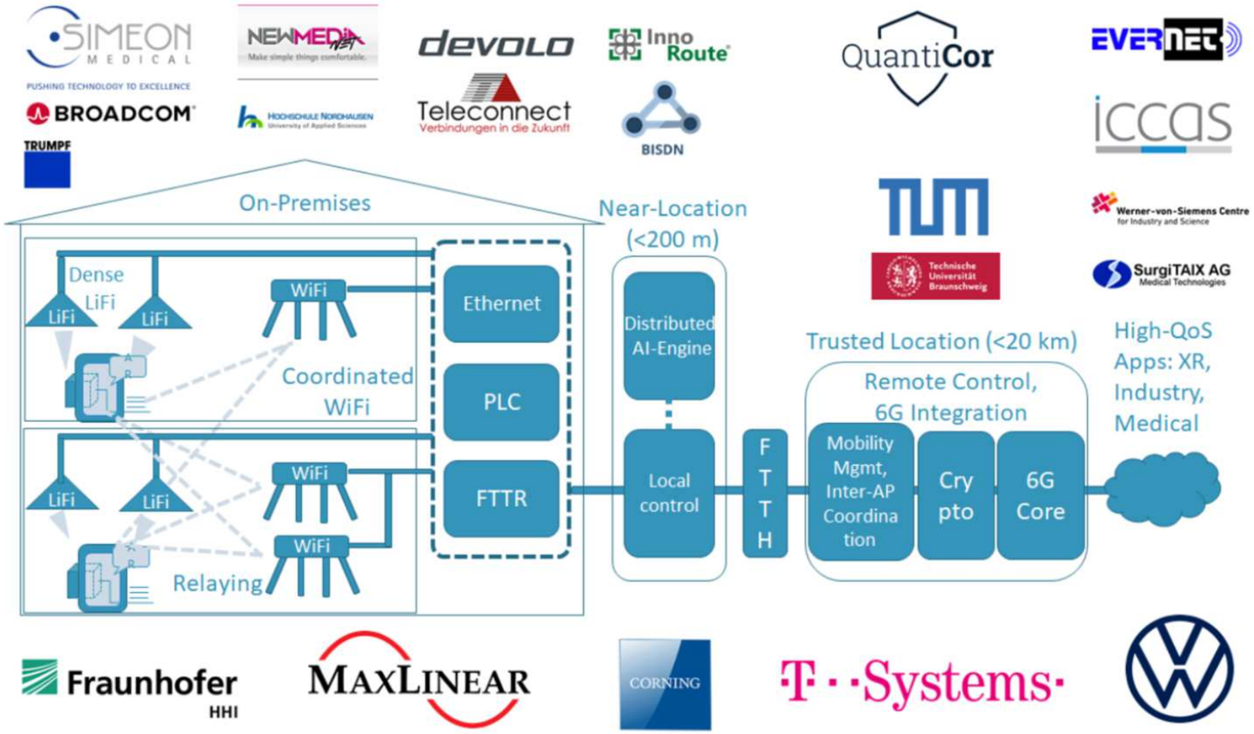
6G inside buildings

Heterogeneous system concept



- FTTH to the buidling
  - Connect building to the 6G core via central office
- Wi-Fi 8 to cover the whole building wireless
  - interference coordination in the central office
- FTTR to each room
  - Mesh WLAN nodes
  - LiFi cells
  - via diverse media (Ethernet, PLC, FTTR)

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Summary

The role of LiFi for 6G in buildings

- LiFi has become increasingly mature in recent years
- Optical frontend technology is mastered by multiple vendors
  - Further potential through VCSEL arrays
- New PHY and MAC layer technologies were introduced
  - DC-OFDM, OOK-FDE, distributed MIMO, integrated positioning
  - First standards are developed, accordingly
- Various applications in different markets have been tested
- Techno-economics: Small cells pay out for higher capacity in dense areas
  - Use optical technologies to move 6G further into the home: FTTR, LiFi
- Challenge is higher performance at very low cost

Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, HHI

WE PUT SCIENCE INTO ACTION.

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