OPTICAL WIRELESS COMMUNICATION FOR THE NETWORKING OF THINGS

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Make Your Light Smarter – Turn It Into Data

Contents

Introduction

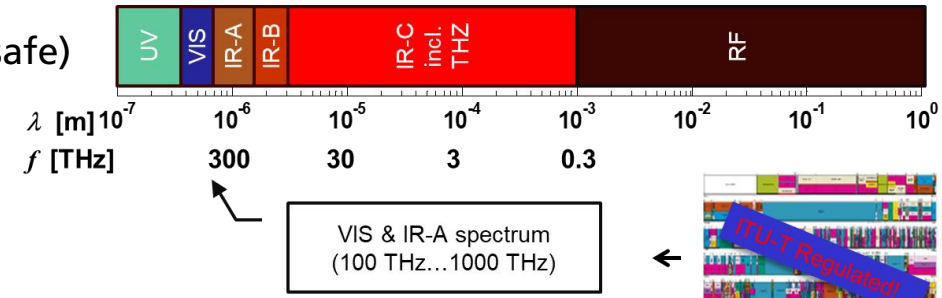
- **Me**
  - Researcher at Fraunhofer HHI
  - M. Sc. Computer Engineering
  - Work on OWC and standardization (mostly IEEE)
  - 1st time RIPE attendee
- **Fraunhofer Society:**
  - 76 institutes for applied research worldwide (mostly in Germany)
- **Heinrich Hertz Institute (HHI)** in Berlin
  - (Wireless) telecommunications, photonic networks and components, video coding, AI, more

Optical Wireless Communication (OWC) & IoT

- Machine-to-machine (M2M) as a subset of IoT
- New/future M2M may require different networking than classical IoT
  - High data rates
  - High densities
  - Low latencies
  - Additional services such as positioning
- Optical wireless communication (OWC) as a new medium (OSI layers 1 & 2) for dense networks
- Goal of this talk: To inform about technology and development

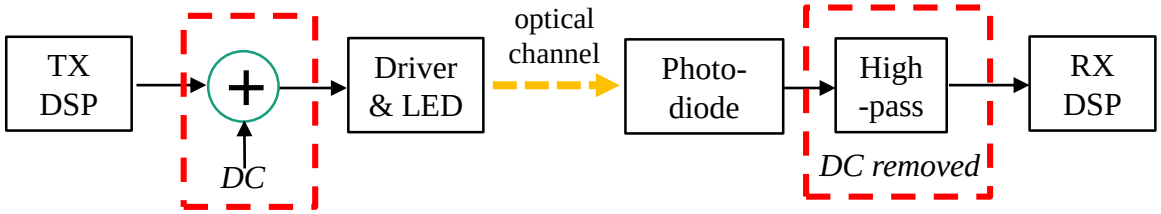
Optical Wireless Communication (OWC) Fundamentals

- Use **light for wireless communication**
  - Untapped spectrum
  - No regulation (it just needs to be eye-safe)
- **Directional** and easily **contained**
  - High density achievable
  - "Data goes where the light goes"
- OWC is the general term
  - LiFi: „brand name" for OWC networks
  - VLC: Visible light communication

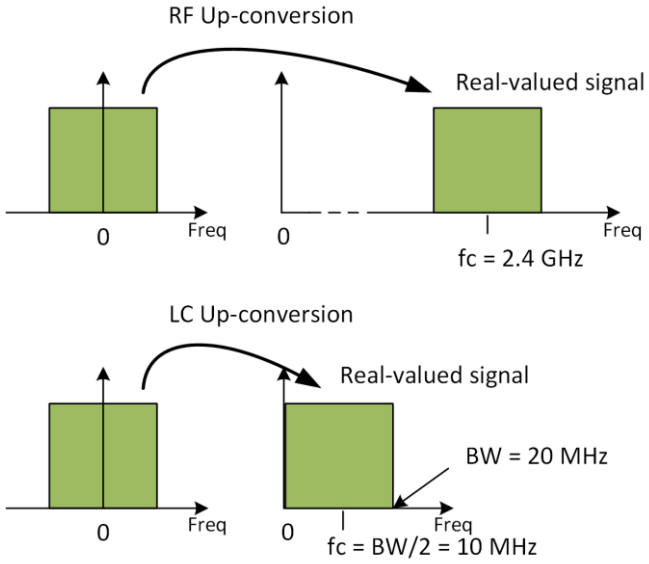


Optical Wireless Signals

- Modulate **light intensity** (“brightness”) of LED or Laser
  - Real-valued, positive signal needed
  - IQ-modulate complex basebands onto low carrier
  - Make the signal positive through a DC-offset at the TX
  - DC and low frequencies are filtered out at the RX

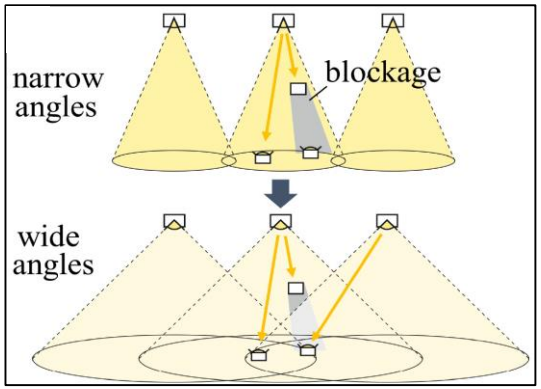


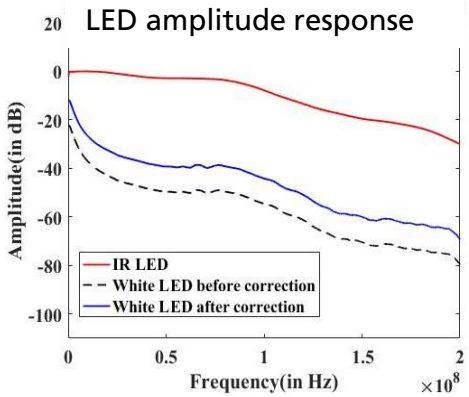
- Use **any wavelength** that works with emitter and receiver
  - Infrared (IR) has beneficial properties
  - Unwanted wavelengths filtered at the RX



Optical Wireless Transmission and Channel

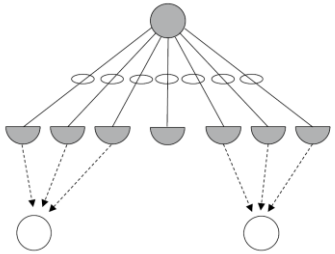
- Frontend limits **Bandwidth**
  - LEDs support up to ~200 MHz
  - Photodiodes have limited bandwidth, too
- Optical **power** is limited
  - Through light source / driver
  - Eye safety requirements
  - High path loss
- Propagation can be **shaped**
  - Lenses for angle of emission
  - Sectorization / imaging

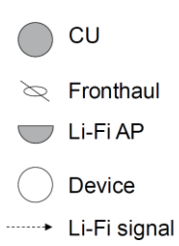


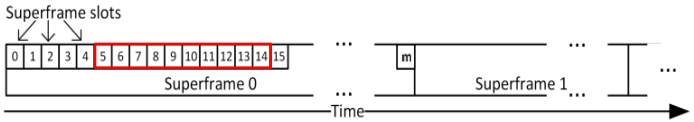


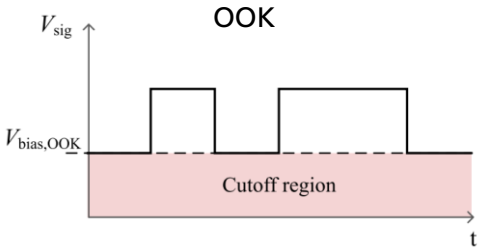
Key Techniques for modern OWC

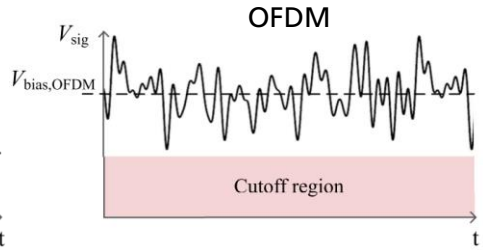
- Distributed-MIMO
  - No handovers
  - Spatial diversity against shadowing
- Reservation-based medium access
  - Counter the “hidden-terminal problem” due to directivity
- On-Off-Keying (OOK)
  - High power efficiency and long reach
  - Low complexity transmitters
- OFDM modulation + bitloading
  - Efficient use of power per bandwidth
- VCSEL (vertical-cavity surface emitting lasers)
  - Higher bandwidth, power efficiency





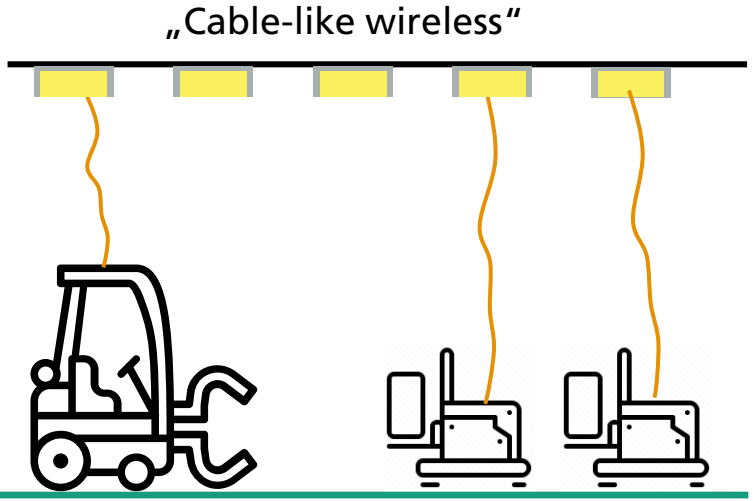






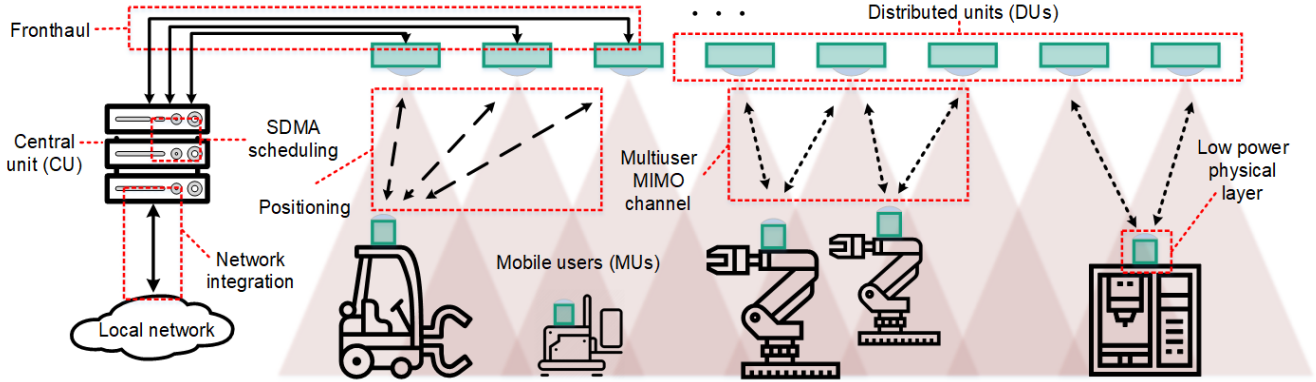
General Use Cases for Light Communication

- Applications leveraging **specific properties of light**
  - Little random interference
  - Strict confinement
  - Very high density of users
  - High positioning accuracy
  - Confidentiality, jamming-resistance
  - Electromagnetic sensitive environments
- **Traffic offloading** from radio to a new band
  - Dedicated OWC „Hot-Spots“
  - 1…10 Mbps/m² (Wi-Fi 6, 7)
  - > 100 Mbps/m² (OWC)
- **“Dissimilar redundancy”** via OWC and RF



Example: Industrial Communication

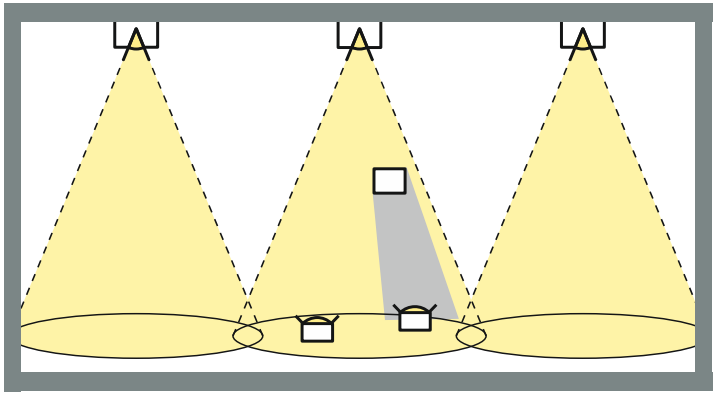
- Point-to-point communication
- Access network for shop floor machines
- Potential for positioning with below 3 cm accuracy [1]



[1] S. M. Kouhini *et al.*, "LiFi Positioning for Industry 4.0," in *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 27, no. 6, pp. 1-15, Nov.-Dec. 2021, Art no. 7701215, doi: 10.1109/JSTQE.2021.3095364.

Example: Secure Communication

- Information security / confidentiality
  - Safety authorities
  - Medical patient data
- Robustness against denial-of-service-attacks
  - Medical devices
  - Critical backhaul links
  - Factories
- OWC as part of a comprehensive security concept
  - Alternative to RF + shielding
  - Simpler measures to prevent leakage



Optical Wireless Technologies and Standards

- Introduction
- OWC Fundamentals
- **Applications, Technologies, Standards**
- Current Status
- Conclusion & Outlook

- Not considered OWC here:
  - Remote controls ☺
  - IrDA (e.g. in Early smart phones)
  - Free space optics (FSO)
- OWC technologies (layer 2):
  - Proprietary OWC / LC solutions
  - ITU-T G.9991 (“G.vlc”)
  - (IEEE Std 802.15.7-2018: optical camera comm.)
  - IEEE Std 802.15.13-2023: specialty applications
  - IEEE P802.11bb: mass market

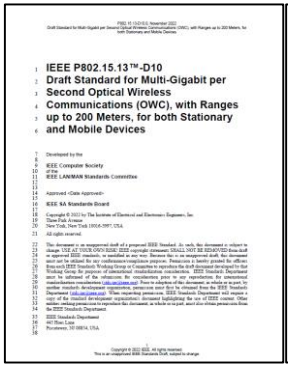

ITU-T G.9991 (03/2019)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Access networks – In premises networks

High-speed indoor visible light communication transceiver – System architecture, physical layer and data link layer specification

Recommendation ITU-T G.9991


IEEE P802.15.13™-D10

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


IEEE P802.11bb™/D7.0 March 2023

P802.11bb™/D7.0

Draft Standard for Information technology—Telecommunications and information exchange between systems Local and metropolitan area networks—Specific requirements

Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

Amendment 7: Light Communications

ITU-T G.9991 (a.k.a. G.vlc)

- Developed by ITU-T Q18/SG15 (In-premises networking)
  - Available: https://www.itu.int/rec/T-REC-G.9991/en
- Extends ITU-T G.hn (G.9960/9961)
  - Originally for power line, phone line, coax, POF, …
  - G.9991 adds mobility, light medium, enterprise security
- Chipsets available

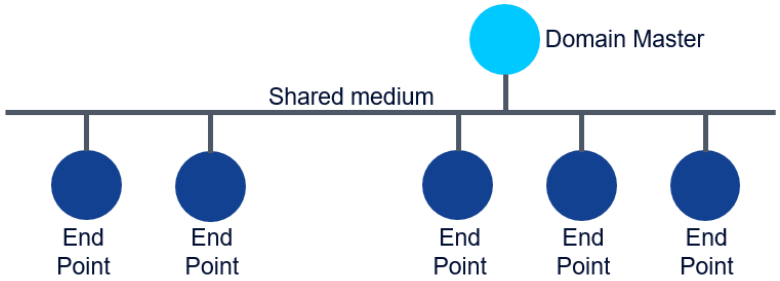
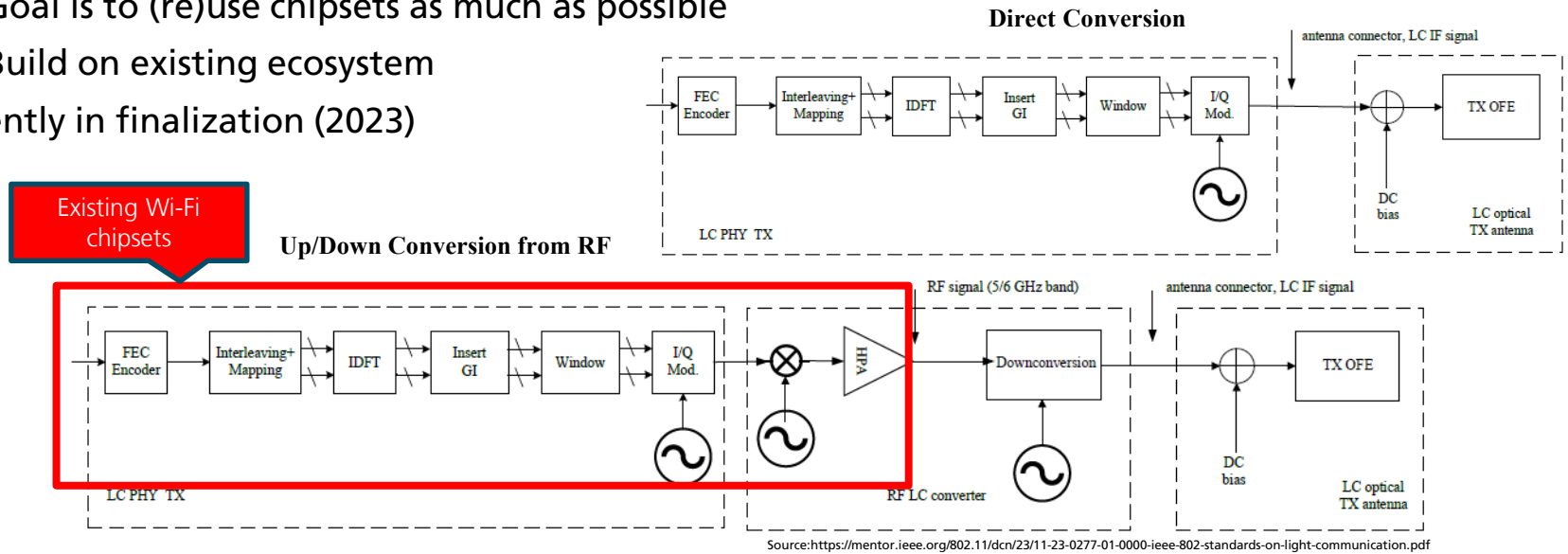


Image Sources:
https://www.signify.com/de-at/innovation/trulifi/
https://lifi-neon.de/

IEEE P802.11bb

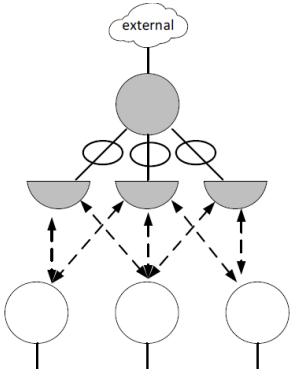
- Adds light medium to Wi-Fi
- Technically based on the IEEE 802.11ax MAC / PHY
  - Goal is to (re)use chipsets as much as possible
  - Build on existing ecosystem
- Currently in finalization (2023)

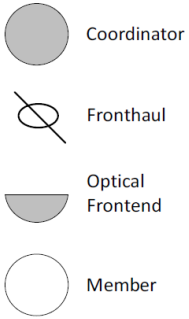


Source:https://mentor.ieee.org/802.11/dcn/23/11-23-0277-01-0000-ieee-802-standards-on-light-communication.pdf

IEEE Std 802.15.13-2023

- New standard for specialty applications
- Advanced OWC features supported
  - Distributed MIMO
  - Physical layer: OOK / OFDM
  - Deterministic MAC
- No chipsets available yet
  - Currently prototype development / evaluation
  - FPGA / Software





Current OWC Market

- Multiple companies have commercial products
  - Signify, PureLiFi, Oledcomm, Fraunhofer HHI, …
  - Mostly based on ITU-T G.9991
- Not a mass market yet
  - Integration into end devices required
  - Cost needs to justify added value
- Special applications are served
  - Industrial
  - Security sensitive
  - Offices / schools

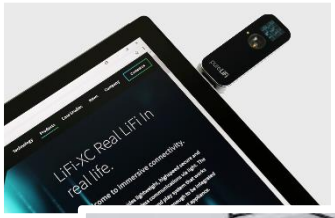
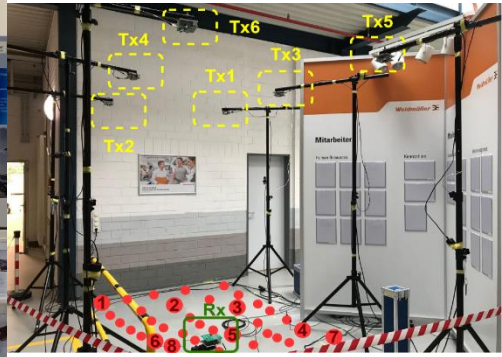
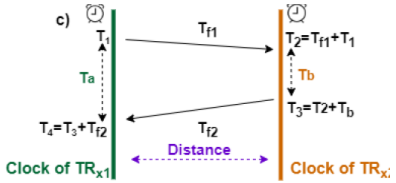


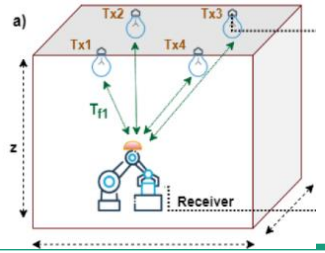
Image Sources:
https://www.oledcomm.net/product-range
https://www.signify.com/de-at/innovation/trulifi/
https://purelifi.com/lifi-products-2/
https://lifi-neon.de/

Current Developments

- Fundamentally working, but potential not yet fully utilized
  - QoS not yet sufficient due to repurposed chips
  - No positioning yet
- Work on Integration with power line communication
  - Reduced setup effort
  - Based on ITU-T G.hn / G.vlc
- „Next generation OWC“ is being developed
  - Realtime protocols / deterministic networking
  - Positioning
  - Lasers and beam-steering







Project 5G-COMPASS: Integrating OWC in Heterogeneous 5G-Networks

- Goal: heterogeneous 5G networks for ubiquitous high data rates
  - 5G RAN outdoors
  - Cheap (W)LAN technologies for indoor coverage
    - Fiber to the room (FttR), powerline communication, WLAN, **OWC / LiFi**
    - Integrate with 5G core
- Smooth handover between all technologies
- Open interfaces and ML-based optimization
- Consortium of 15 partners
- Funded by German Federal Ministry of Transport and Digital Infrastructure

Conclusion

- Light as a new mobile wireless medium
- Support for future IoT with high density M2M communication
- First generation available as layer-2 technology
- New developments for higher performance underway
- Mass market is to be established
  - Increase utility-to-cost ratio in different applications
  - OWC-specific chipsets

Questions?

Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institute, HHI

WE PUT SCIENCE INTO ACTION.

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