IEEE 802 Standards on Light Communications

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Abstract

IEEE 802 recently finished new standards for optical wireless communications. 802.15.13 introduced a new MAC and two PHY layers enabling high reliability, low latency, and low power transmission for industrial wireless applications, and 802.11bb defines how to reuse the 802.11 MAC and OFDM-based PHYs over optical links, aiming at large-volume applications e.g., in enterprise and home scenarios. The tutorial presents major use cases, technical solutions, and recent technology demos in a variety of applications.

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Outline

- **Introduction**
- **IEEE P802.15.13**
- **IEEE P802.11bb**
- **Technology Demos**
- **Summary and Outlook**

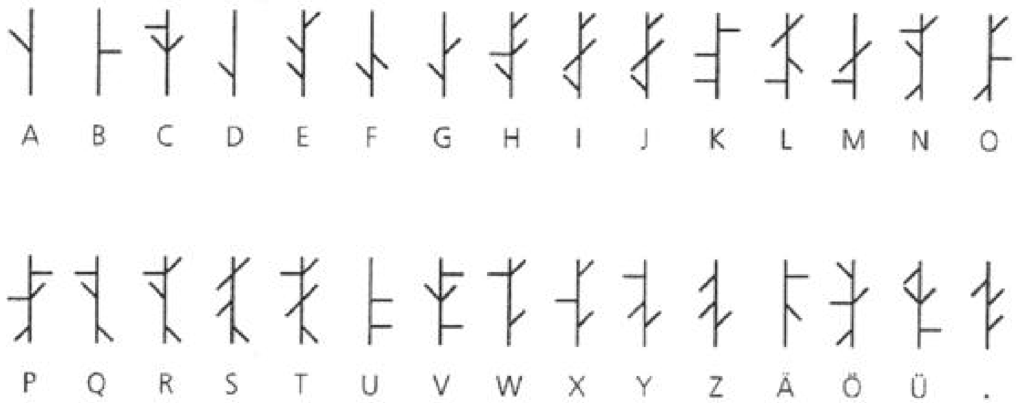
Introduction

- **What is Light Communications?**
  - LC basics
- **Other OWC standards**
  - IrDA
  - IEEE Std 802.15.7
  - ITU-T G.9991

Light Communications history

- **Since ever, people used light to communicate *without wires***

  - Example: Optical telegraph in Cologne, Germany, from 1834

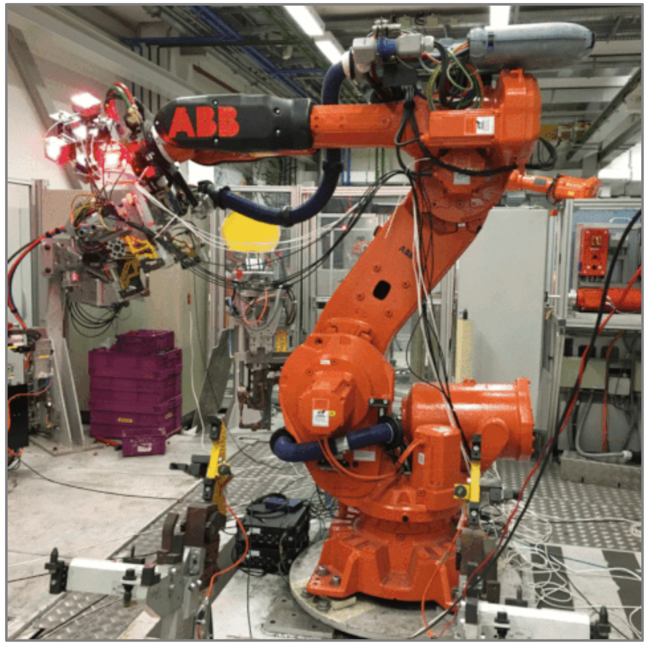


- **Today, visible and invisible light is used**
- **Less photons per bit and, much higher speed**

Light Communications today

Key facts

- **Mobile communication using light**
- **Mobile, bidirectional, high-speed data**
- **Useful complement to RF**



Unique selling points

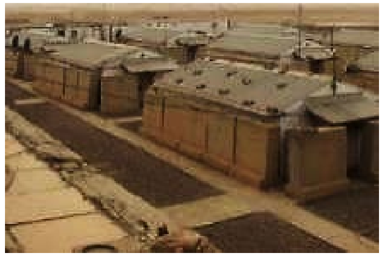
- **Higher capacity/area in small "hotspots"**
  - 1…10 Mbps/m² (Wi-Fi 6…7), >100 Mbps/m² (LC)
- **High service quality: guaranteed delivery at low latency**
  - robust against jamming
  - enhanced privacy

Complement RF by LC

- **Radio is already mature and well established**
  - has issues in dense deployment scenarios
- **Light adds new value**
  - important synergies, both indoors and outdoors
- **New opportunities through LC**

LC use-cases have requirements where RF has limitations

Defence & Environment




Field command
Secure comms
Harsh enviro
Underwater

Data & Industrial


Data centres
Industry 4.0
IoT sensors
Safe enviro

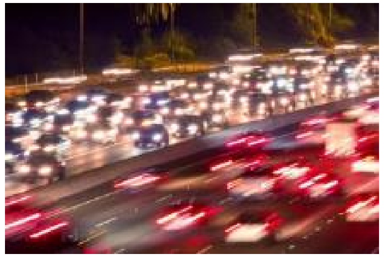
Office & Commercial


Smart building
Secure comms
Dense network
Net offload

Retail & Financial

Indoor location
Shop analytics
Payments
Back office

Smart City & Transport

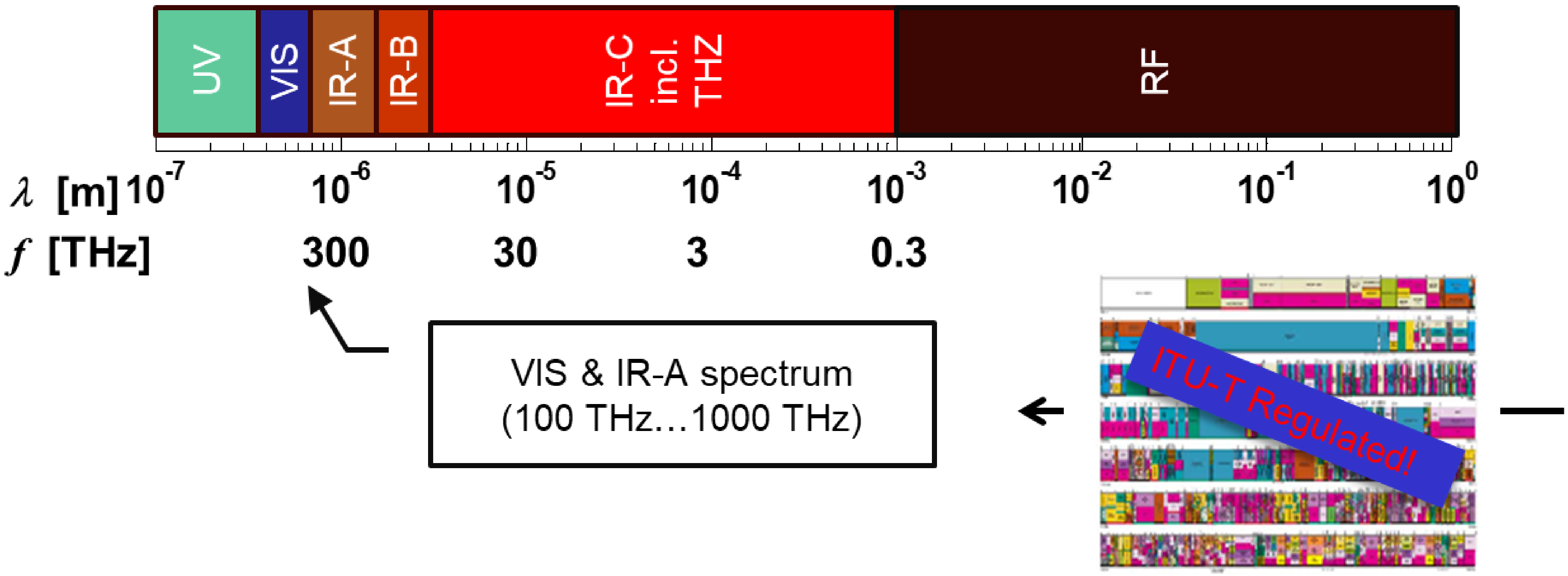
Smart city
Smart transport
Streetlights
Backhaul

Consumer & Lifestyle


Mobile devices
Smart home
Entertainment
Lighting

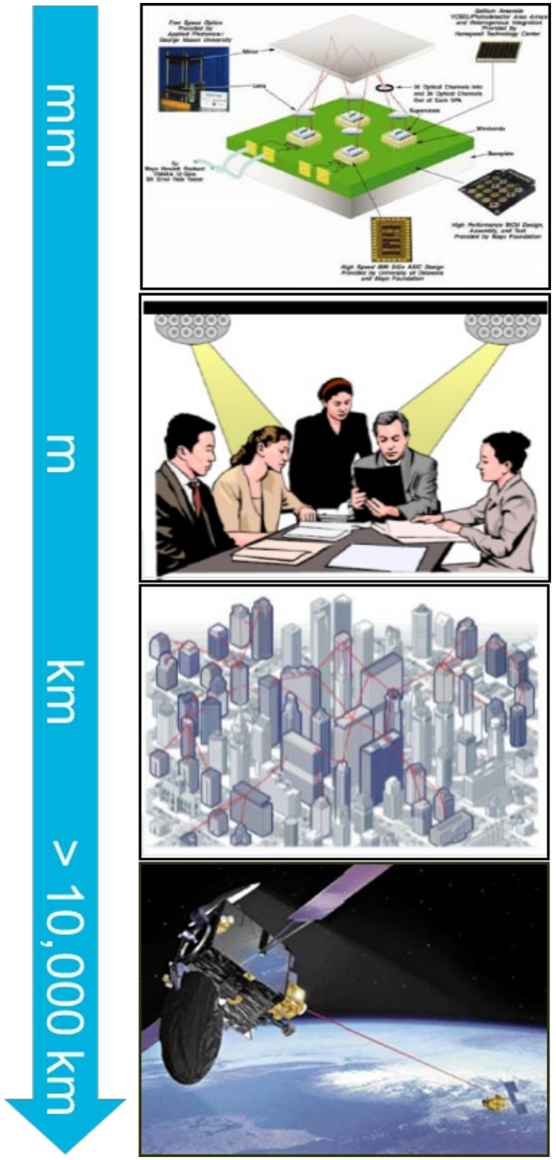
Light offers free wireless spectrum besides RF

- Optical spectrum is unregulated, similar to radio in ISM bands

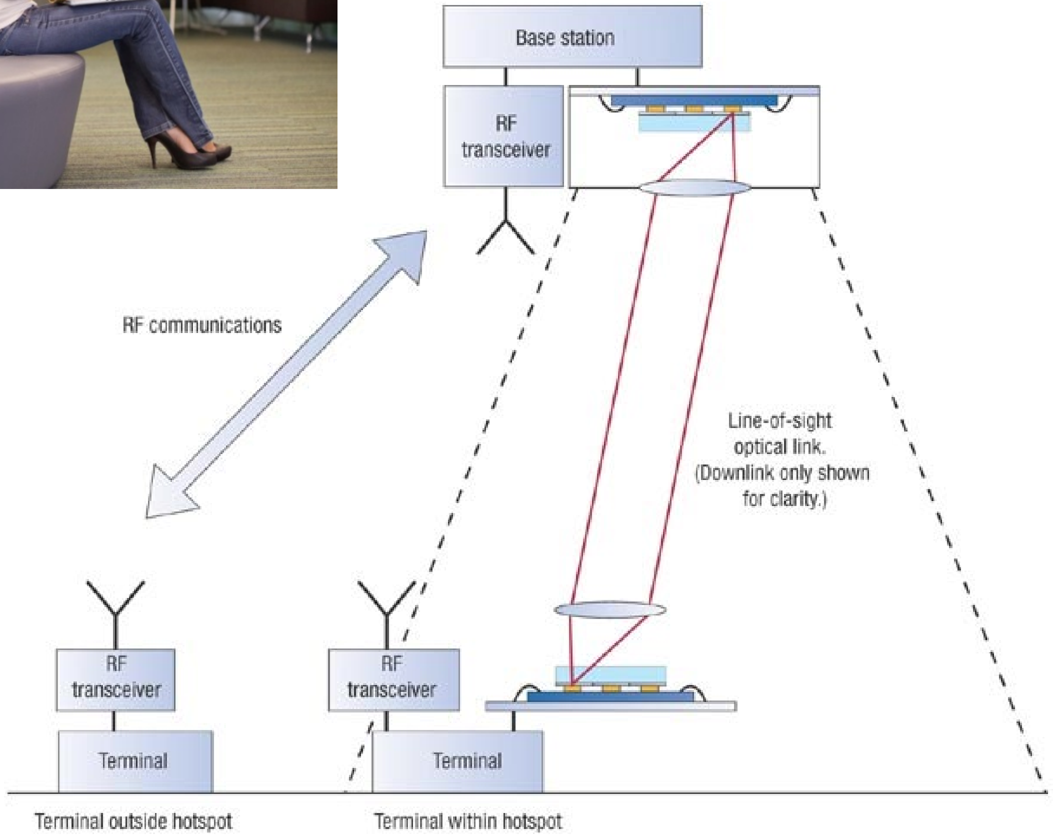


LC domains

- **Light allows connectivity over various distances**
- **Ultra short range**
  - inter-chip interconnects, in-body networks
- **Short-range**
  - optical WLAN, in-flight, car-to-X, indoor positioning, industrial wireless
- **Medium-/long range**
  - inter-building, mobile backhaul, underwater
- **Ultra-long range**
  - satellite feeder links, satellite-to-satellite



Hybrid RF/LC for short range, high rate



- **Optical small cells**
  - densify radio-based WLAN
  - using infrared or visible light
  - 10 Mbit/s … 10 Gbit/s per link
  - eventually integrated into lighting
- **Low-cost off-the-shelf components**
  - LEDs, laser diodes
  - silicon photodiodes
  - digital signal processing

Dominic O'Brien, Gareth Parry & Paul Stavrinou **Optical hot spots speed up wireless communications** Nature Photonics 1, 245 - 247 (2007)

The Taxonomy of Light Communications

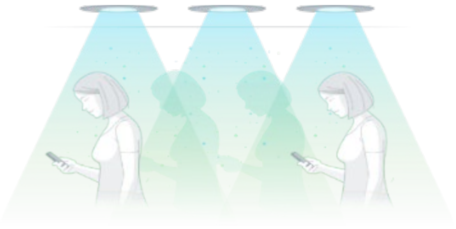
Not all light communications is LiFi. It's is important to understand the differences between these types of communications, as they all have different applications.

Optical Camera Communications

OCC

Low Speed
Geo Location
Advertisements
Notifications

Light Fidelity



LiFi

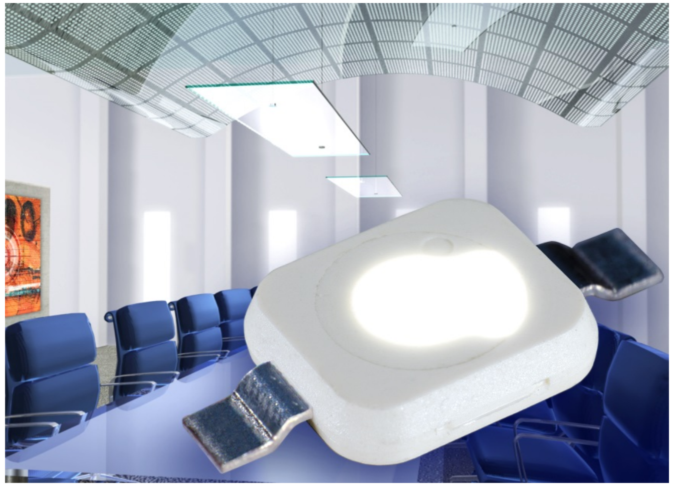
Secure high-speed
mobile wireless
communications

Free Space Optics

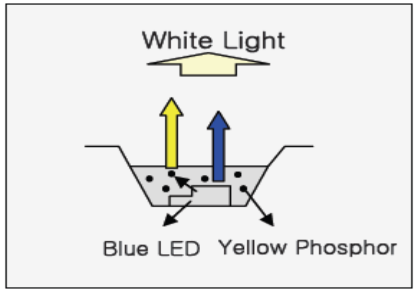
FSO

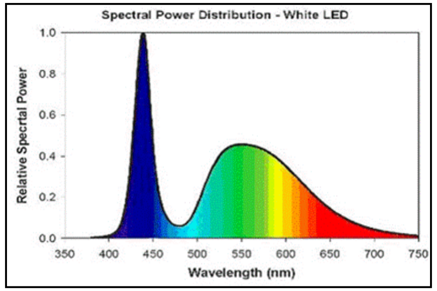
Backhaul
Long-distance
communications

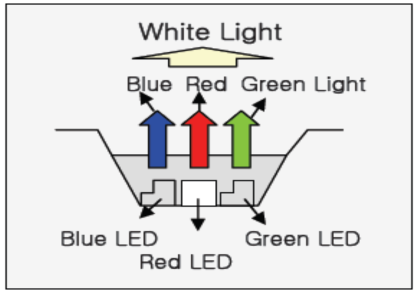
TX: LEDs

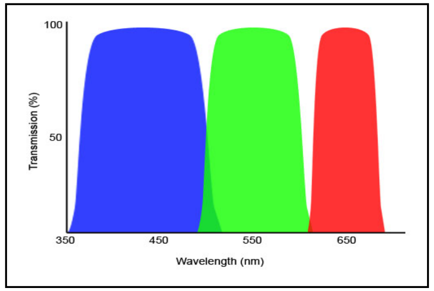


- **Low-cost high-power LEDs became available, e.g. for lighting**
- **For data transmission, LED can be modulated at high speed**
- **Flicker is invisible for the human eye**
- **Blue LED + phosphor**
  - blue LED is fast (~20 MHz)
  - phosphor is slow (1-2 MHz)
- **R+G+B type**
  - wavelength-division multiplexing (WDM → 802.11bb)
  - ~20 MHz per color
  - higher cost



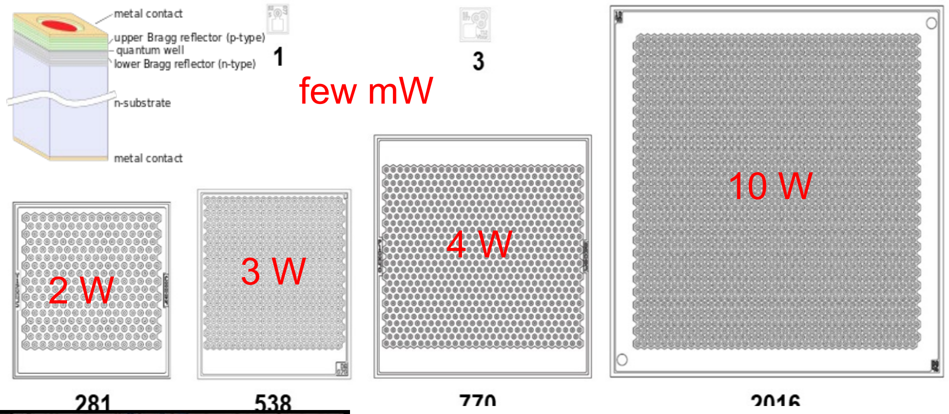


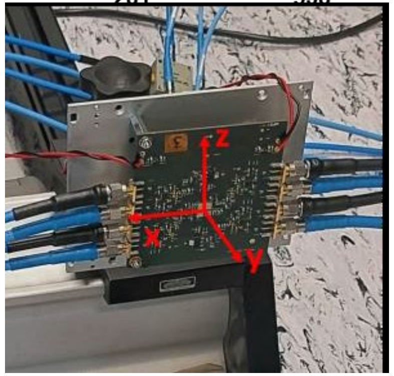


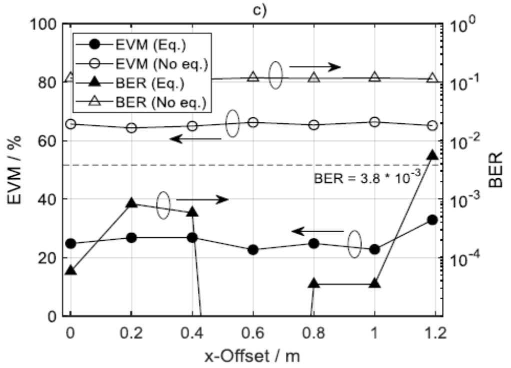


VCSEL arrays have similar bandwidth like mm-wave

- **Vertical cavity surface emitting laser (VCSEL)**
  - circular beam shape, few mW per VSEL
  - 20-30 GHz bandwidth for single VCSELs
- **VCSEL arrays**
  - 100s of VCSELs combined, parasitic L/C
  - similar area and beam shape like LED
- **Available for mass-market**
  - developed for LIDAR, also useful die LC
  - large VCSEL arrays still have few GHz BW
  - 2.5 Gbaud demonstrated in large coverage area

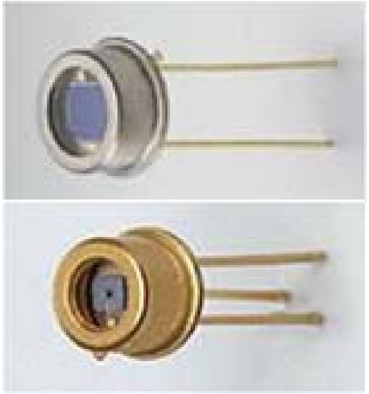


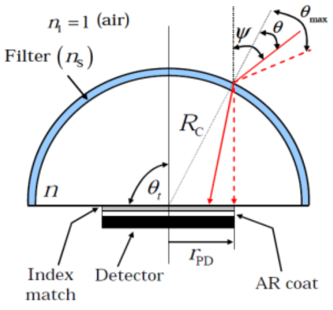


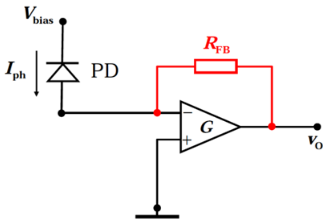


M. Hinrichs et al. Demonstration of 1.75 Gbit/s VCSEL-based Non-Directed Optical Wireless Communications with OOK and FDE ECOC 2022, paper We5.52

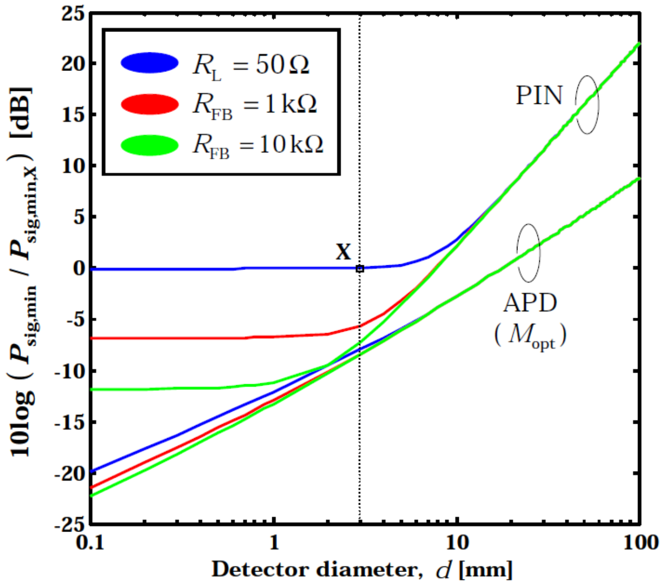
RX: PIN vs. APD





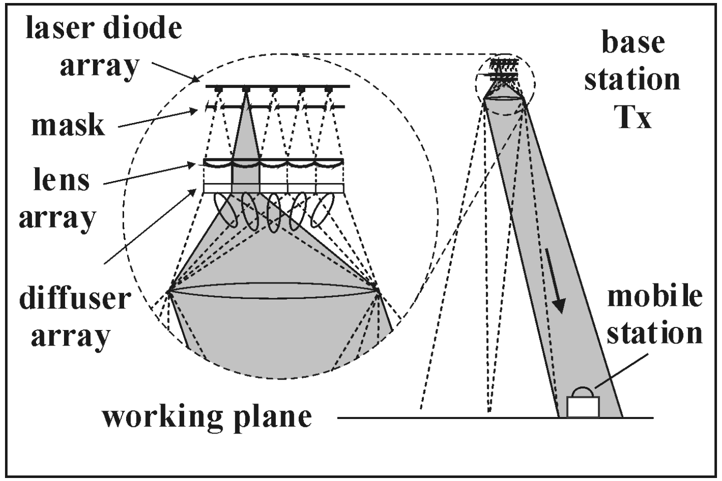


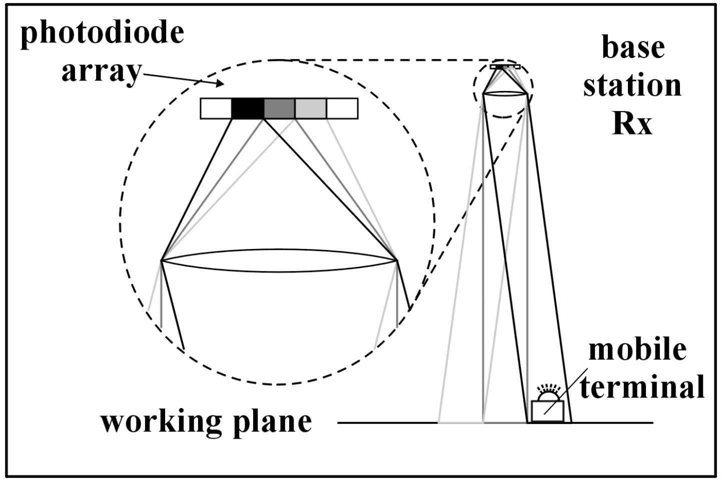
- **PIN photodiode**
  - large area, limited sensitivity, low cost
- **Avalanche photodiode (APD)**
  - smaller area, higher sensitivity, higher cost
- **Optical concentrator (OC)**
  - increased effective area, reduced field-of-view
- **Proprietary bootstrapping (BS)**
  - increases bandwidth, more noise
- **Transimpedance amplifier (TIA)**
  - small photocurrent (µA) into useful voltage (V)
- **Most practical LC frontends use PIN+OC+BS+TIA**



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

Future: Individually addressable TX/RX arrays



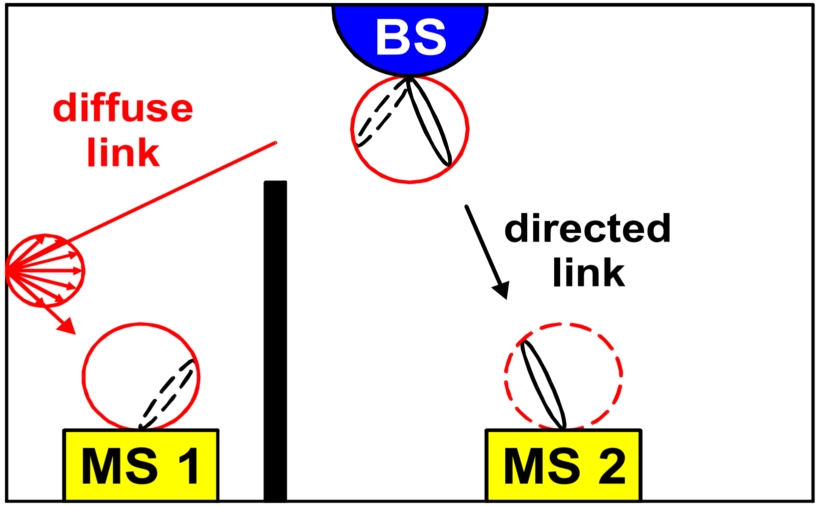


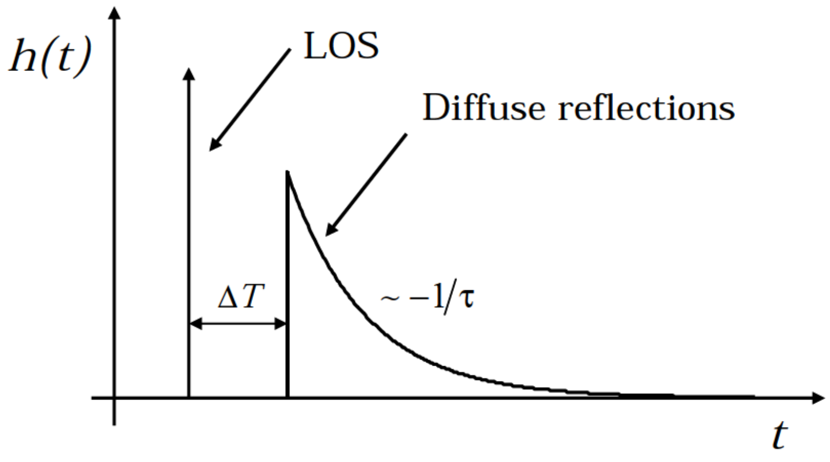
- **Select pixels in the TX array**
  - illuminate only the sector where the Rx is located
  - pixel groups: complexity vs. energy savings
  - higher bandwidth, use of drivers from fiber optics
- **Select pixels in the RX array**
  - smaller PD area = higher bandwidth
  - bootstrapping becomes obsolete → lower noise
  - spatially selective RX to suppress unwanted interference
  - from ambient light or other mobile devices
  - spatial multiplexing

V. Jungnickel et al., Electronic Tracking for Wireless Infrared Communications, IEEE Trans. Wireless Commun., Vol. 2, No. 5, Sept. 2003

Light propagation

BS: base station, MS: mobile station

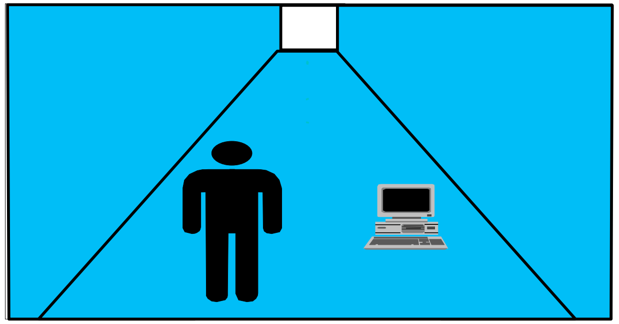


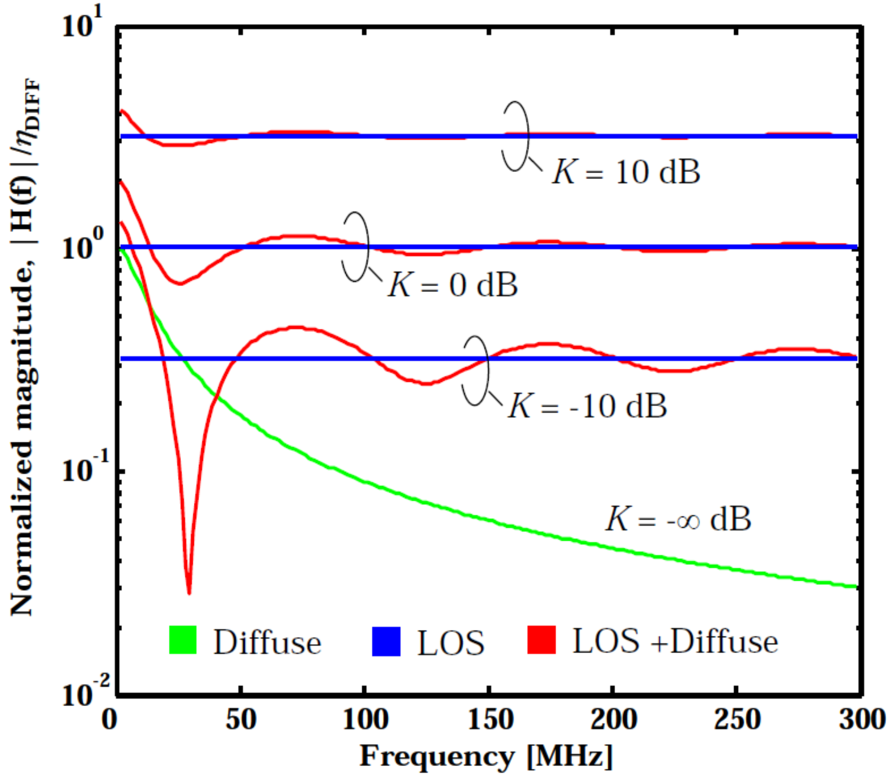


- **Direct link (LOS)**
  - high power
  - blocking is critical
  - no multipath
  - high bandwidth

- **Diffuse link (NLOS)**
  - low power
  - blocking is less relevant
  - inherent support for mobility
  - multipath → 1st order low pass, reduced bandwidth

Directed + diffuse links





- **Channel response depends on**
  - Rice factor

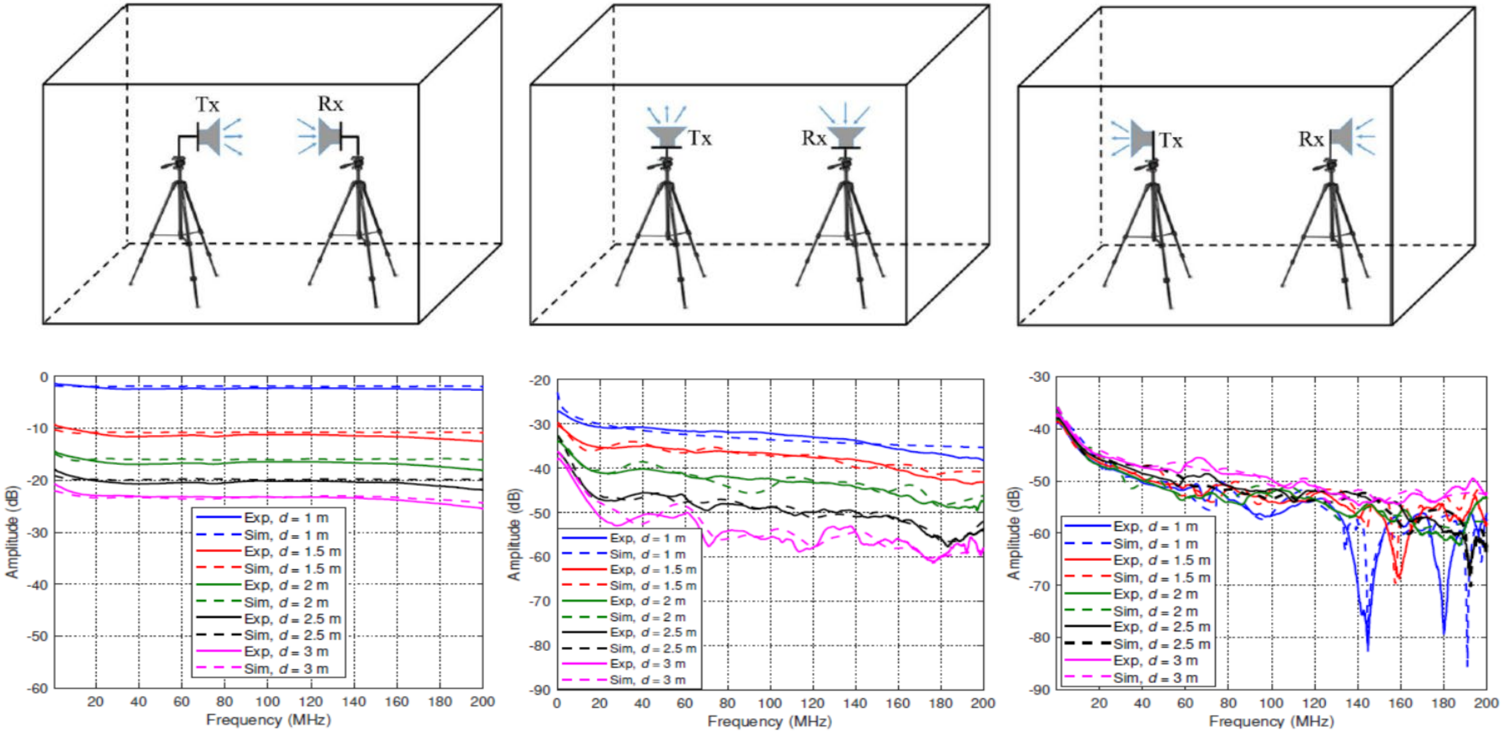
$$K[\mathrm{dB}] = 20 \log \frac{\eta_{\mathrm{LOS}}}{\eta_{\mathrm{DIFF}}}$$

  - delay $\Delta\tau$ between direct and diffuse link

- **Compound channel may be frequency-selective**
  - rare "fading" effects
  - when LOS and NLOS are similarly strong
  - in room corners, or when Tx and/or Rx are tilted

Measured LC channels

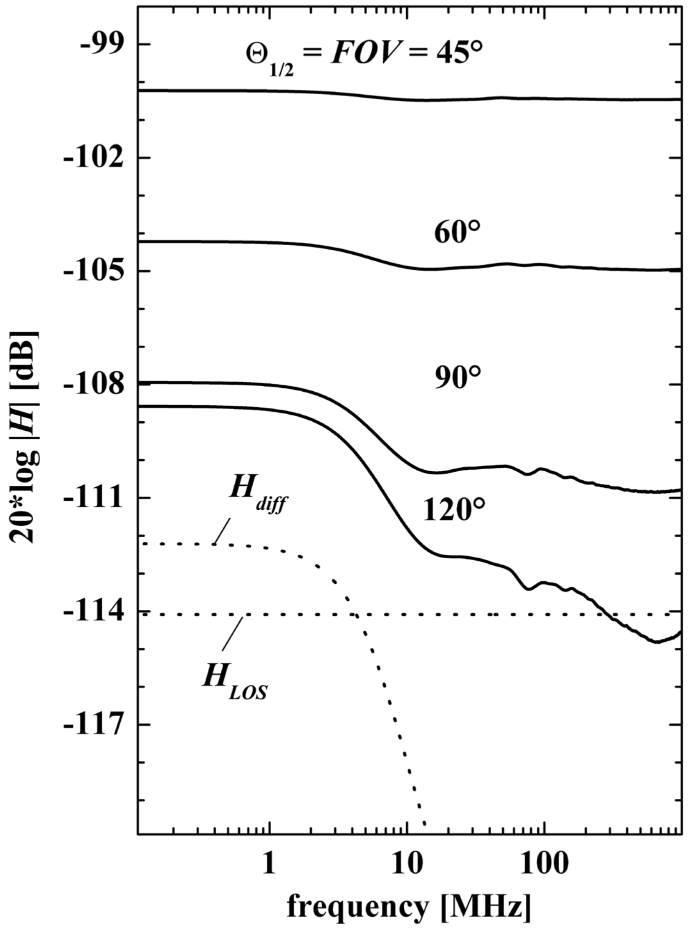
- **Empty room, optical frontends (OFEs) from LC prototypes**
  - line-of-sight (LOS) vs. non-LOS



- **OFE response calibrated out**
  - LOS 20-30 dB stronger than NLOS, very wide bandwidth
  - 1st diffuse reflection: Wide BW
  - All other diffuse reflections: Very limited BW (10-20 MHz)

H. Eldeeb, S. M.Mana, doc. 11-20/1234r0

Impact of TX + RX arrays



- **Shown results are for critical scenario**
  - LOS signal is increased
  - NLOS signal is reduced
- **RX power and bandwidth are increased**

- **Moderate sector sizes may be enough**

V, Jungnickel et al., Electronic Tracking for Wireless Infrared Communications, IEEE Trans. Wireless Commun., Vol. 2, No. 5, Sept. 2003

Fundamentals of DSP for LC

- **LC is baseband channel, starting from DC up to some upper BW**
- **You and Kahn provided an upper bound on the LC capacity (TMS bound)**

R. You and J. Kahn, „Upper-bounding the capacity of optical IM/DD Channels with multiple-subcarrier modulation and fixed bias using trigonometric moment space method", IEEE Trans. Inf. Theory, Vol. 48, No. 2, Feb. 2002

- **Vucic provided a practical formula for TMS bound in frequency-selective LC channel**

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

$$C\left[\frac{\text{bit}}{\text{s}}\right] \le B_{\text{SC}} \sum_{n=1}^{N_{\text{opt}}} \log_2\left(\underbrace{\left(\frac{\eta^2 P_{\text{O}}^2}{N_{\text{D}}} H_n^2\right)}_{\gamma_n}\left(4N_{\text{opt}}\, 2^{\frac{1}{2N_{\text{opt}}}}\right)^{-1}\right)$$

γ **effective SNR**

B_{SC} **subcarrier bandwidth**

$N_{\text{opt}} \le N-1$ **optimal no. of carriers**

P_O **optical power**

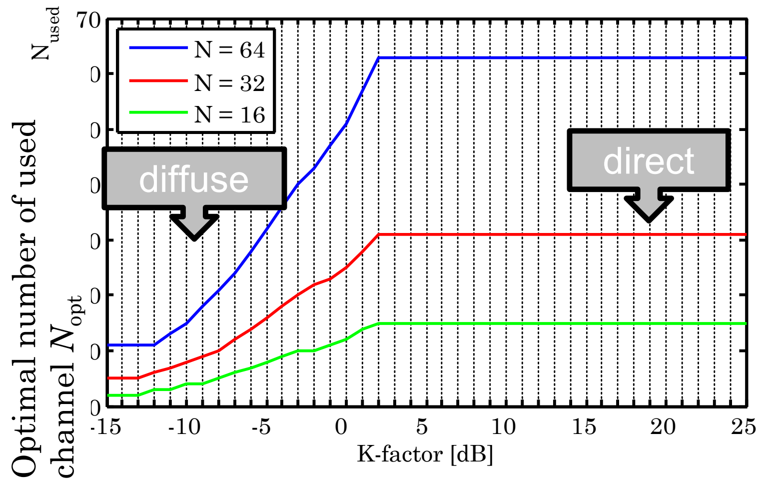
h **optical path gain**

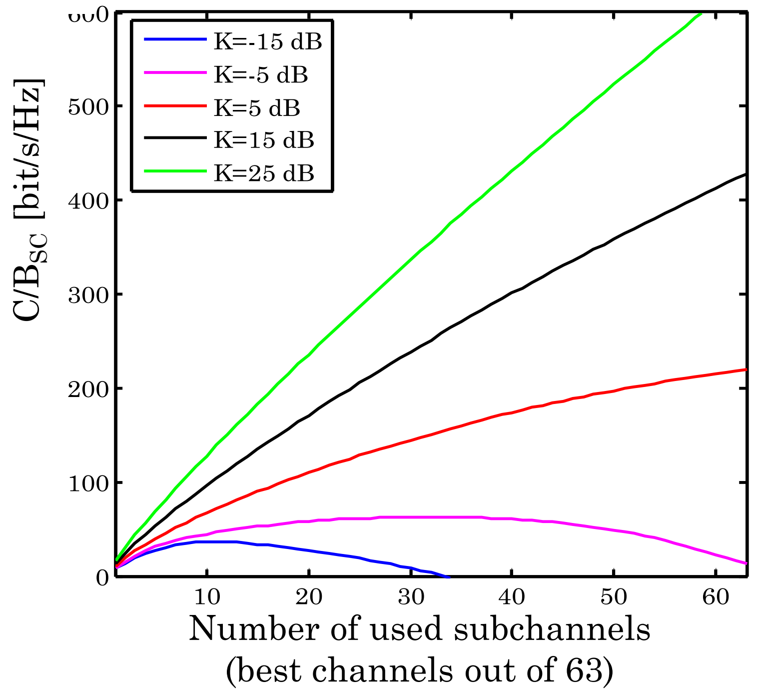
N_D **detector noise**

Optimization of TMS bound

- **Maximize the bound using N_{opt}**
- **Diffused link: low-frequency subcarriers are used**
- **Direct link: all subcarriers are used**

- **LC may use OFDM with adaptive bitloading**





$B = 100$ MHz, $N - 1 = 63$,

$B_{SC} = B / N = \text{const.}$,

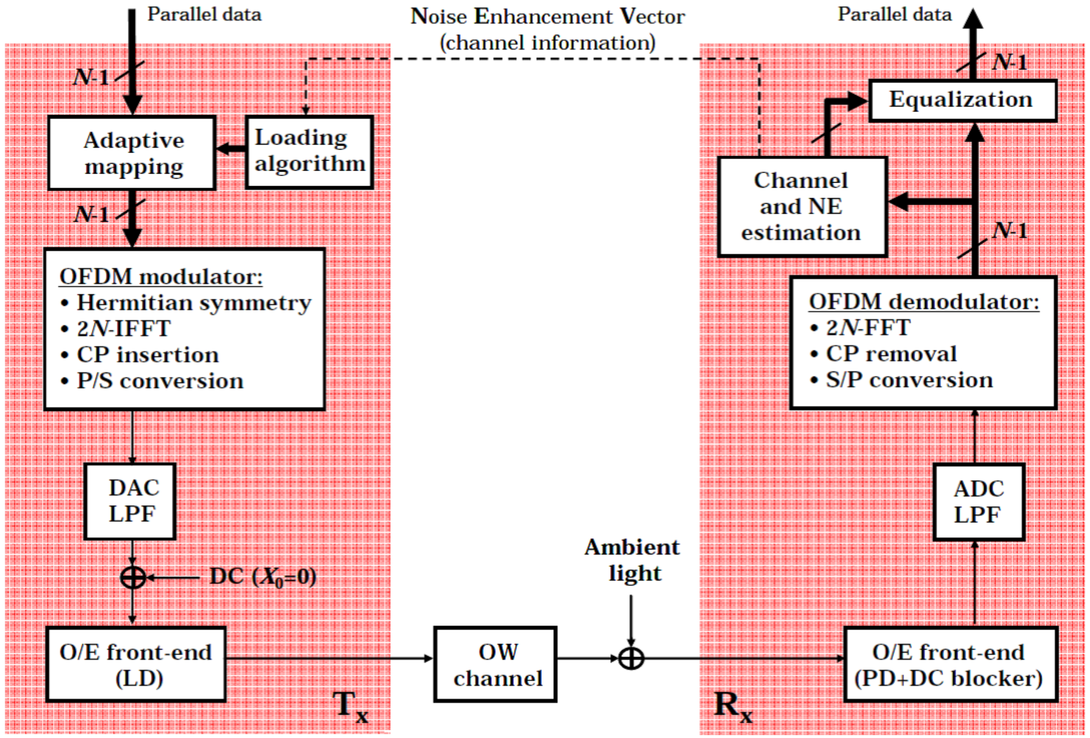
$P_O = 400\,\text{mW}, \ \eta = 1$ A/W

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

Implementation

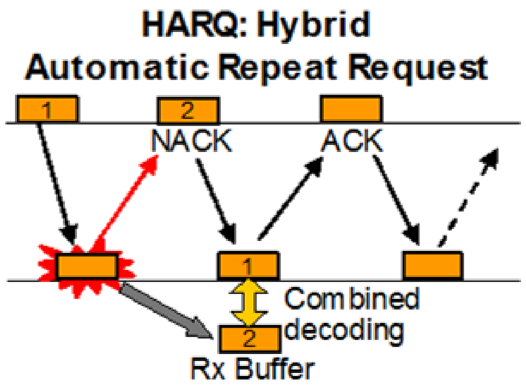
- **DC-biased optical OFDM (DCO-OFDM)**
- **Adaptive bit and power loading on multiple orthogonal sub-carriers**
- **Also known as discrete multitone (DMT)**

J. Grubor, V. Jungnickel, K.-D. Langer, „Capacity Analysis in Wireless Infrared Communication using Adaptive Multiple Subcarrier Transmission, ICTON We C2.7, 2005.

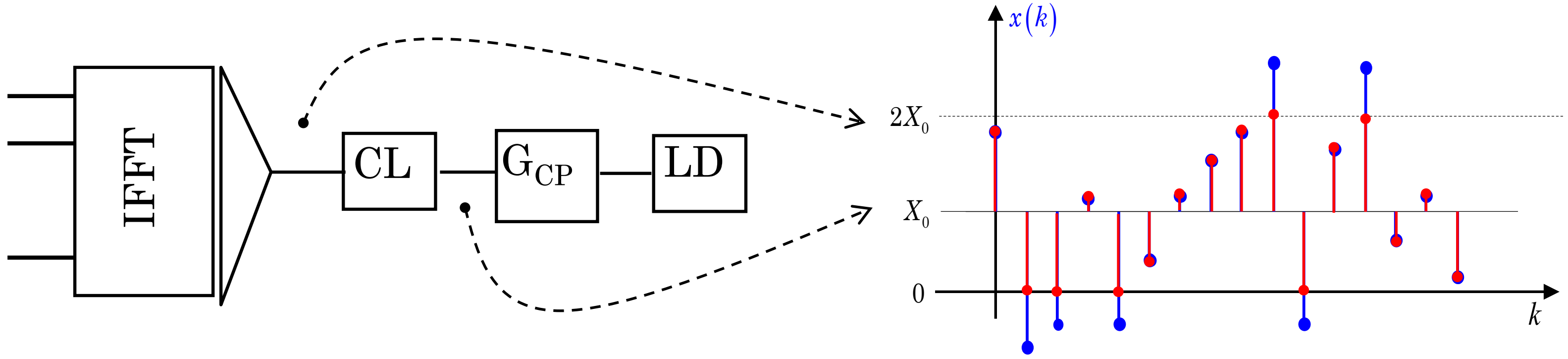


Controlled clipping

- **Clipping is tolerated while errors are corrected**
  - needs powerful forward error correction (FEC)
  - retransmissions (selective repeat, HARQ)
- **Waveform is clipped below zero in the digital domain**

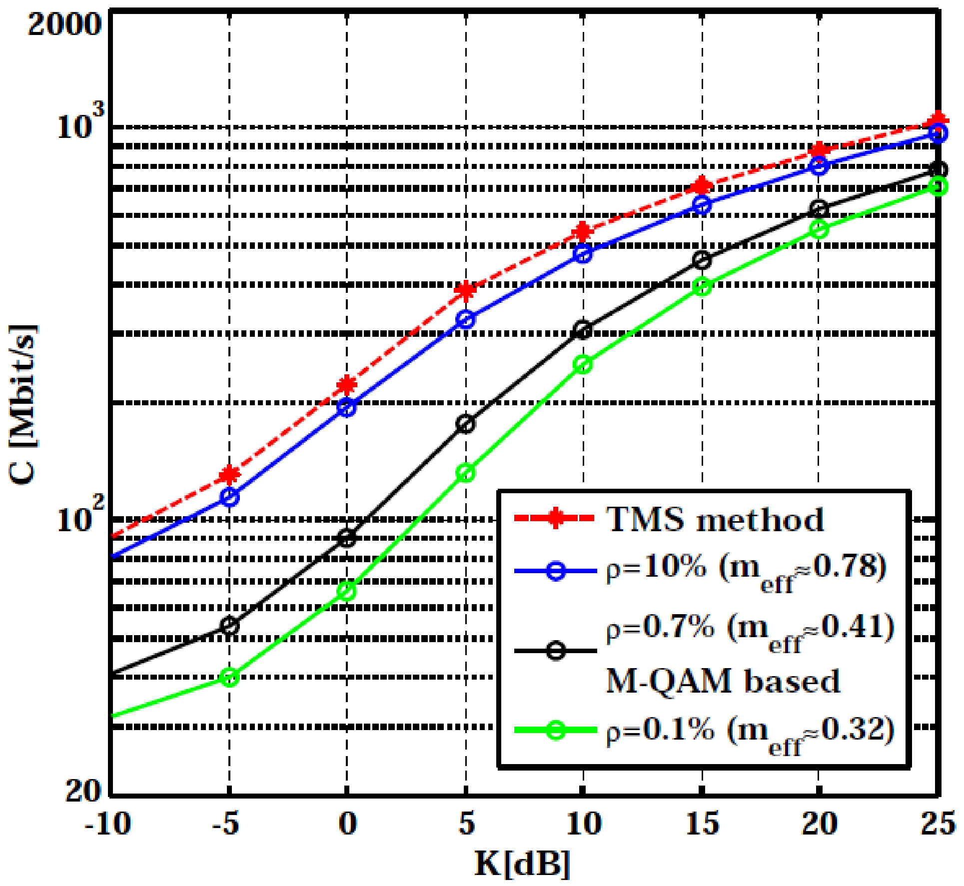


Graph from NSN



- **Link adaptation with controlled clipping**
  - inner loop: bit-loading using fixed thresholds
  - outer-loop: adapt all bit-loading thresholds so that desired error rate is reached

Main insight



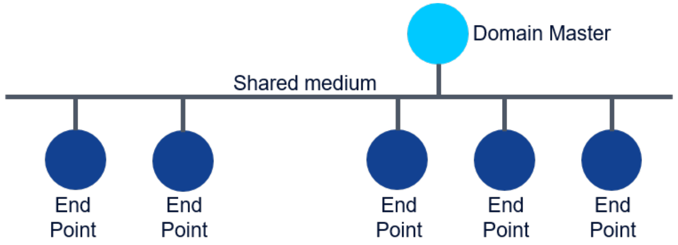
P_{opt}=400 mW, h=1A/W, B=100 MHz, N=64

- **Red is the upper bound using TMS**
- **DCO-OFDM with waterfilling**
  - Green: Clipping is nearly avoided
  - Blue: 10% clipping probability
- **Gap to the TMS bound is very small**

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

- **Adaptive OFDM with controlled clipping comes close to the TMS bound**

Other LC standard: ITU-T G.9991



- **Based on home networking standard G.996x (G.hn coax mode)**
  - chipsets from multiple vendors are available
- **Developed by ITU-T Q18/SG15: In-premises networking**
  - started 2015, first approval April 2019, latest update in April 2021
- **2 PHYs on common MAC (TDMA or Polling)**
  - PHY 1: DCO-OFDM, (DC biased Optical OFDM based on G.9960), performance oriented, up to 2 Gbps
  - PHY 2: ACO-OFDM (Asymmetrically-Clipped Optical OFDM), more flexible, e.g. in case of dimming
- **MAC allows for Quality-of-Service through reservation of the medium for transmissions.**
- **G.9991 network is master/slave architecture with synchronized media access.**
  - domain master (DM) defines the network domain, manages security, and manages communication through assignment of slots for DM/EP interactions.
  - end point (EP) is the communication device that follows the allocations of the Domain Master and transfers data to/from the DM.

IEEE 802 has 3 standards using the light medium

IEEE 802.15.7-2019

- Optical Camera Communications

IEEE 802.15.13

- Speciality networks in industrial / medical scenarios

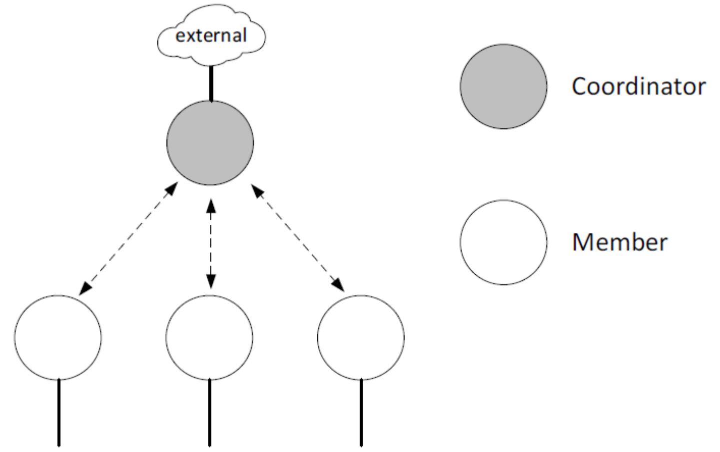
IEEE 802.11bb

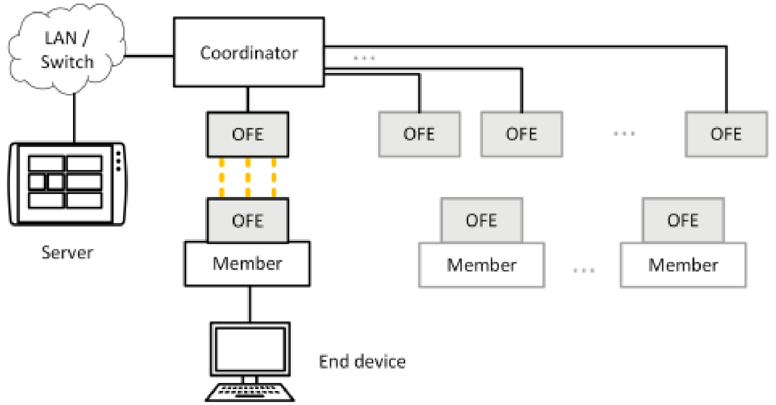
- Mass-market complementing Wi-Fi

- **IEEE P802.15.13**
- Architecture & Service
- PHYs
- MAC
- Status

IEEE P802.15.13 - Overview

- **New standard**
  - originated in P802.15.7, but rebuild entirely
  - only OWC, no OCC
- **Goals: Simplicity, low implementation barrier**
  - Reworked / simplified MAC
  - Basic data transmission w/o security supported
  - Two new PHYs
- **Star topology Network**
  - Coordinator manages the network
  - Members associate with the network
  - Allows P2MP or P2P communication
- **Interconnection with 802 LANs**





- IEEE P802.15.13
- **Architecture & Service**
- PHYs
- MAC
- Status

Architecture and Service of 802.15.13

- **Data transmission always between Coordinator and members**
  - Coordinator bridges data between two members
  - Only exception are relays
- **MAC Data interface**
  - EUI-48 addresses
  - Supports 802.1 MAC service
  - Shim not yet in 802.1AC

Table 13 Parameters of the MD-DATA.request primitive.

Name	Range	Description
DestinationAddress	MAC address	The destination address of the MSDU.
SourceAddress	MAC address	The source address of the MSDU.
Msdu	Octet Sequence	The MSDU in EtherType format, i.e., starting with the Length/Type field and ending with the MAC Client Data field as defined in IEEE Std 802.3™.
Priority	[0, 7]	The priority of the MSDU, as detailed in IEEE Std 802.1AC.
Acknowledged	TRUE, FALSE	Whether the associated MSDU is transmitted with acknowledgment request.

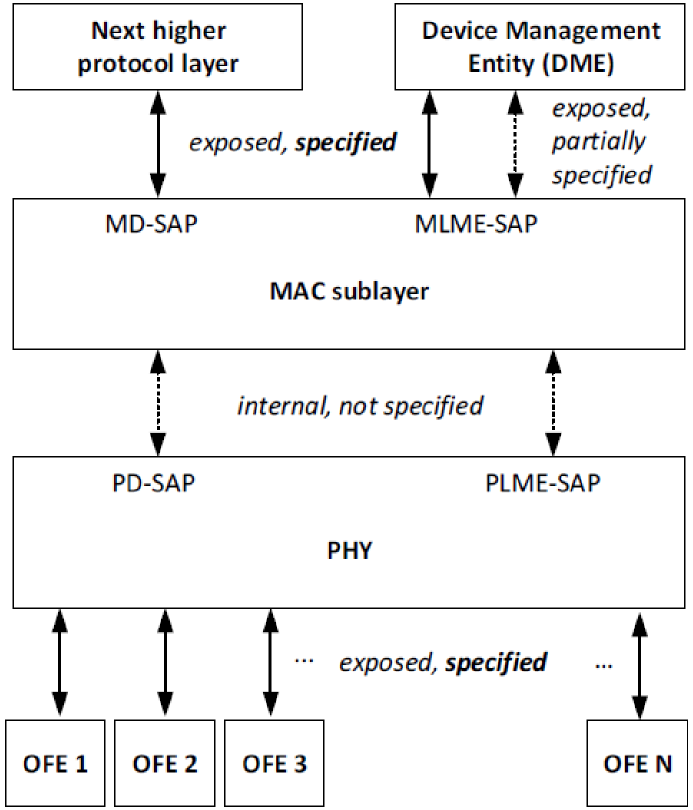


Figure 8 OWPAN device architecture.

- IEEE P802.15.13
- Architecture & Service
- **PHYs**
- MAC
- Status

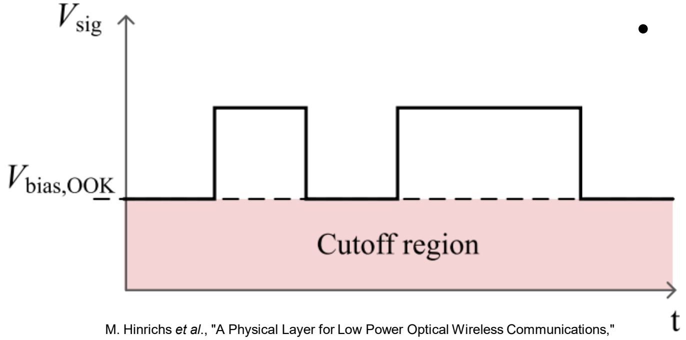
Physical Layers (PHYs)

- **Two physical layers (PHYs) with distinct properties**
  - OOK → Energy efficiency
  - OFDM → Spectral efficiency
- **Both support important features for LC:**
  - Bandwidth and rate adaptation to OFE and channel properties
  - MIMO pilots for channel estimation between multiple TX and RX
  - Cyclic prefix for frequency domain equalization
- **Both have similar Physical layer protocol data unit (PPDU) format:**
  - Preamble: for frame detection and channel estimation
  - Header: information about further PPDU structure
  - Optional pilots: for MIMO channel estimation
  - Payload: contains MAC data

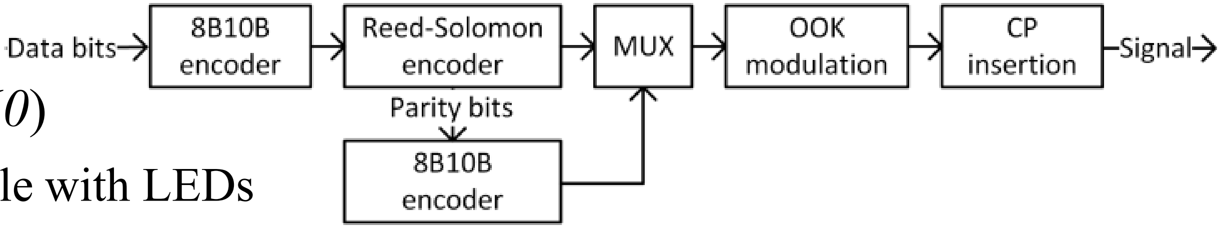
- IEEE P802.15.13
- Architecture & Service
- **PHYs**
- MAC
- Status

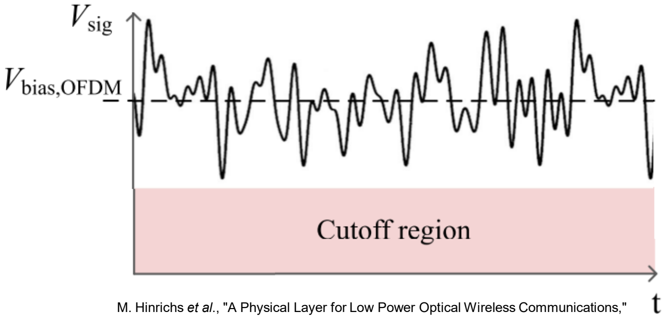
OOK & OFDM PHY

- **OOK: „PM-PHY“**
  - Clock (symbol) rates 12.5 … 200 MHz
  - Reed-Solomon error coding
  - Cyclic prefix for FDE at RX
  - 8b10b line coding removes DC
  - Cyclic prefix 160 or 1280 ns
- **OFDM: „HB-PHY“** (*inspired by ITU-T G.9960*)
  - Bandwidths 50, 100 and 200 MHz → Achievable with LEDs
  - Bitloading → use LED spectrum efficiently
  - LDPC encoding for high performance
  - Cyclic prefix between 160 and 1280 ns

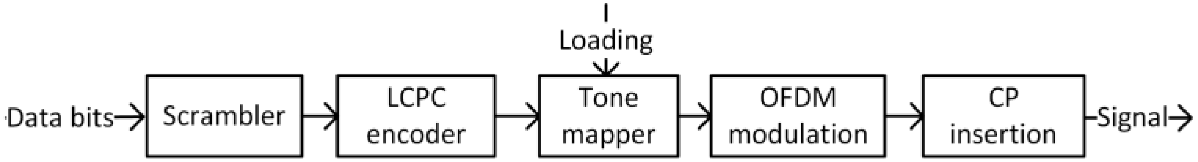


M. Hinrichs *et al.*, "A Physical Layer for Low Power Optical Wireless Communications," in *IEEE Transactions on Green Communications and Networking*, vol. 5, no. 1, pp. 4-17, March 2021





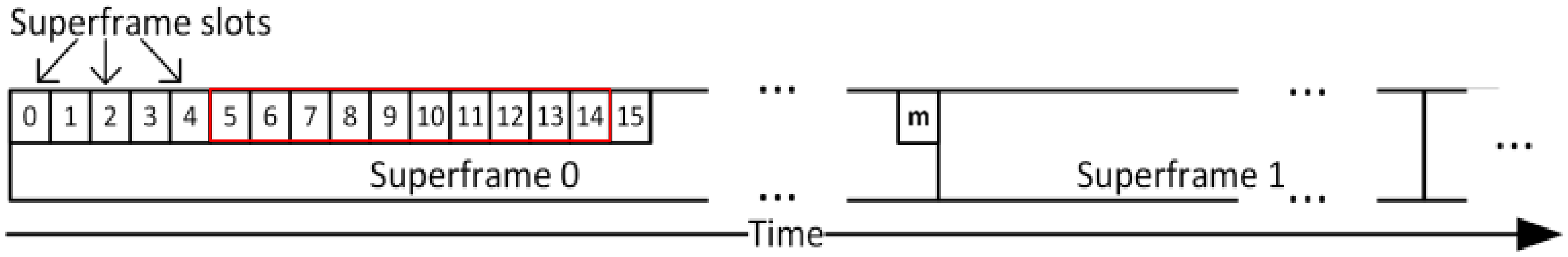
M. Hinrichs *et al.*, "A Physical Layer for Low Power Optical Wireless Communications," in *IEEE Transactions on Green Communications and Networking*, vol. 5, no. 1, pp. 4-17, March 2021



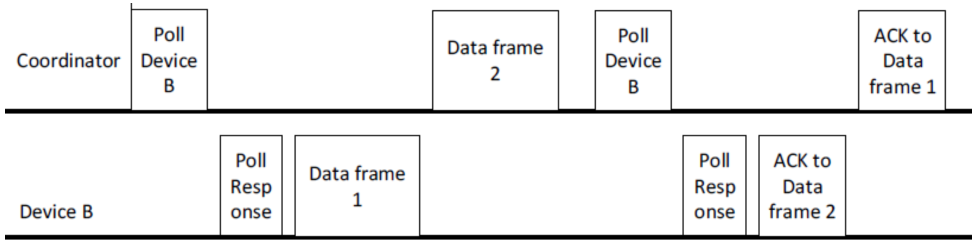
- IEEE P802.15.13
- Architecture & Service
- PHYs
- **MAC**
- Status

Channel Access in 802.15.13

- **Two channel access mechanisms: Scheduled & polled**
- **Scheduled medium access – TDMA reservations without carrier sensing**
  - Random access & "guaranteed" access in random time slices (RTS) and guaranteed time slices (GTS)
  - Coordinator transmits control frames for synchronization and slice distribution regularly but in variable slot
  - Members transmit in allocated slices



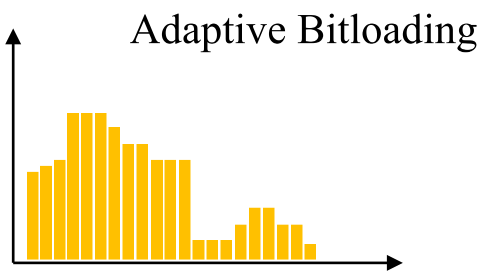
- **Polled medium access - based on IEEE 802.11 PCF**
  - Coordinator polls for random and dedicated transmissions
  - One (dedicated) or more (random) members transmit after receiving a poll frame



- IEEE P802.15.13
- Architecture & Service
- PHYs
- **MAC**
- Status

More MAC Features in 802.15.13

- **Acknowledgment & Retransmission**
  - Single, Block ACK
  - Both <u>not</u> immediate due to possibly fronthaul delay
- **PHY rate adaptation feedback**
  - MCS selection for PM-PHY
  - Adaptive Bitloading for HB-PHY
- **Fragmentation & Aggregation**
  - For efficient use of available resources
- **Relaying**
  - Better throughput for members with bad channel
- **One general frame format (MPDU)**
  - Three frame types – *data*, *control*, *management*
  - Protocol information exchanged in „elements”, that reside in MPDU payload



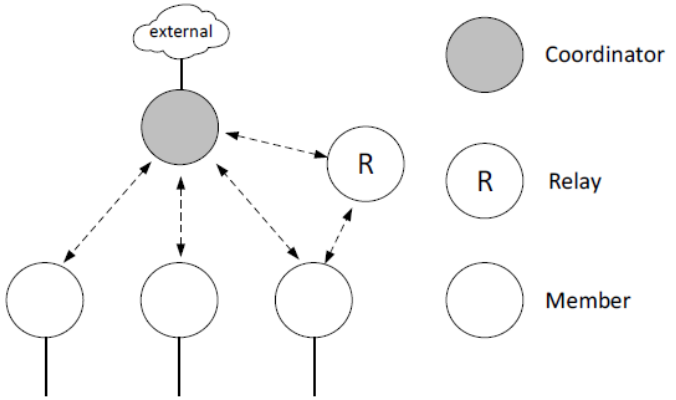


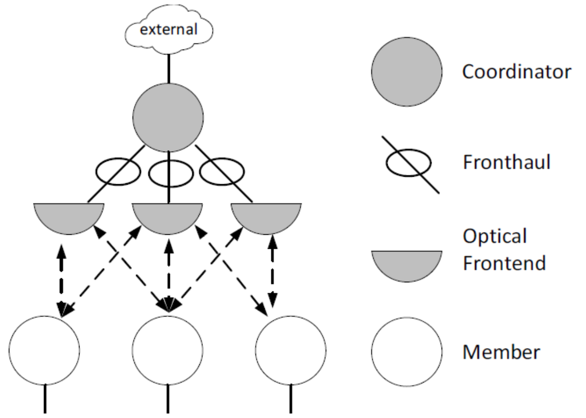
Figure 7 Relay topology.

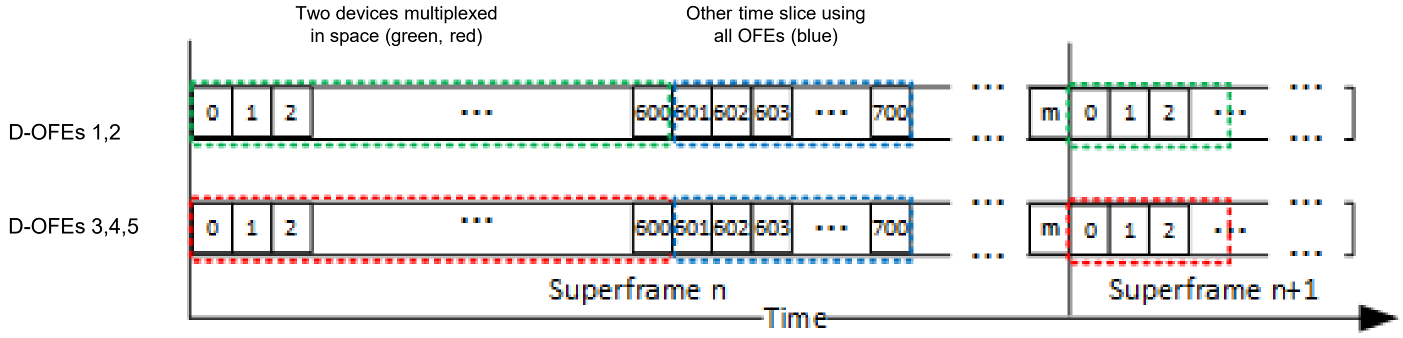
2 Octets	6 Octets	6 Octets	2 Octets	0/2 Octets	0/2 Octets	0/8 Octets	variable	4 Octets
Frame Control	Receiver Address	Transmitter Address	Payload Element ID	Sequence Control	Fragmentation Control	Relay Control	**Payload**	**FCS**
MAC header								

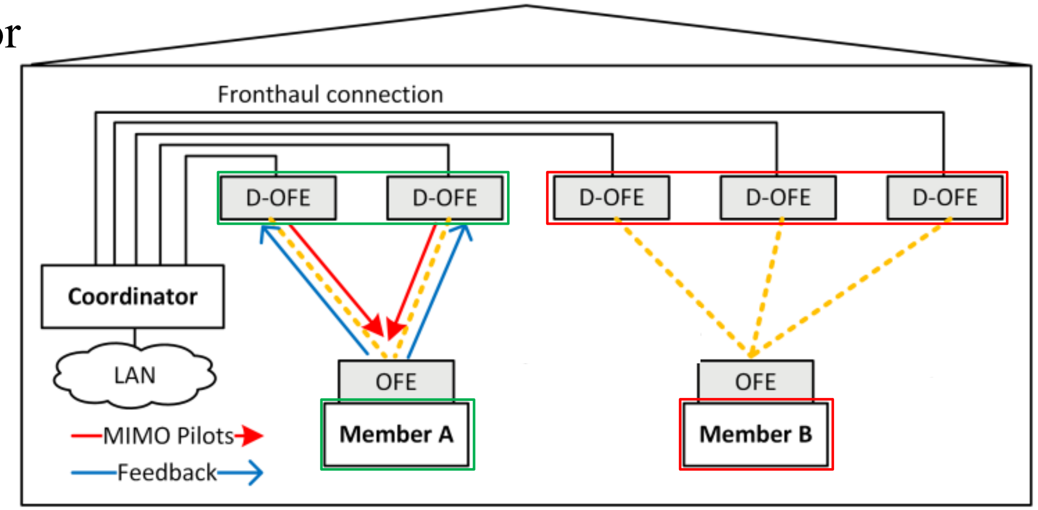
- IEEE P802.15.13
- Architecture & Service
- PHYs
- **MAC**
- Status

MAC for Distributed MIMO

- **Multiple optical frontends (OFEs) can serve one device**
  - Spatially distributed OFEs (D-OFE) connectd via "fronthaul"
  - Fronthaul details are implementation-specific
  - Spatial multiplexing & diversity through MISO TX
- **MIMO Feedback routine for OFE selection**
  - Parallel transmission of orthogonal pilots from OFEs
  - CSI feedback of member's observed OFEs to coordinator
  - Coordinator schedules medium access based on CSI



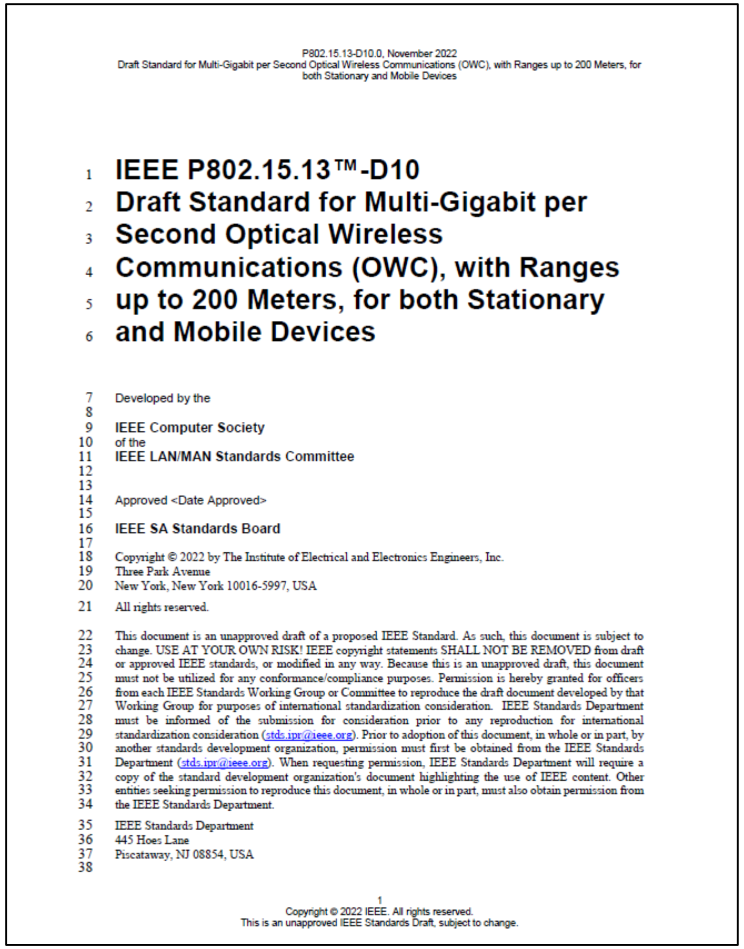




- IEEE P802.15.13
- Architecture & Service
- PHYs
- MAC
- **Status**

Current Status

- **802.15.13 D10.0 is approved by 802.11 WG, 802 LMSC, RecComand IEEE SA board**
  - Over 98% approval rate
  - D10.0 is available in IEEEXplore: https://ieeexplore.ieee.org/document/9963940
- **Awaiting publication Q2-3/2023**
  - publication process / editing starts soon
- **Next steps: System and market development**
- **Possibly, future revisions & amendments**
  - Bug-fixing
  - Security specification
  - Positioning
  - Further features towards enabling TSN bridging



P802.15.13-D10.0, November 2022
Draft Standard for Multi-Gigabit per Second Optical Wireless Communications (OWC), with Ranges up to 200 Meters, for both Stationary and Mobile Devices

IEEE P802.15.13™-D10
Draft Standard for Multi-Gigabit per Second Optical Wireless Communications (OWC), with Ranges up to 200 Meters, for both Stationary and Mobile Devices

Developed by the

IEEE Computer Society
of the
IEEE LAN/MAN Standards Committee

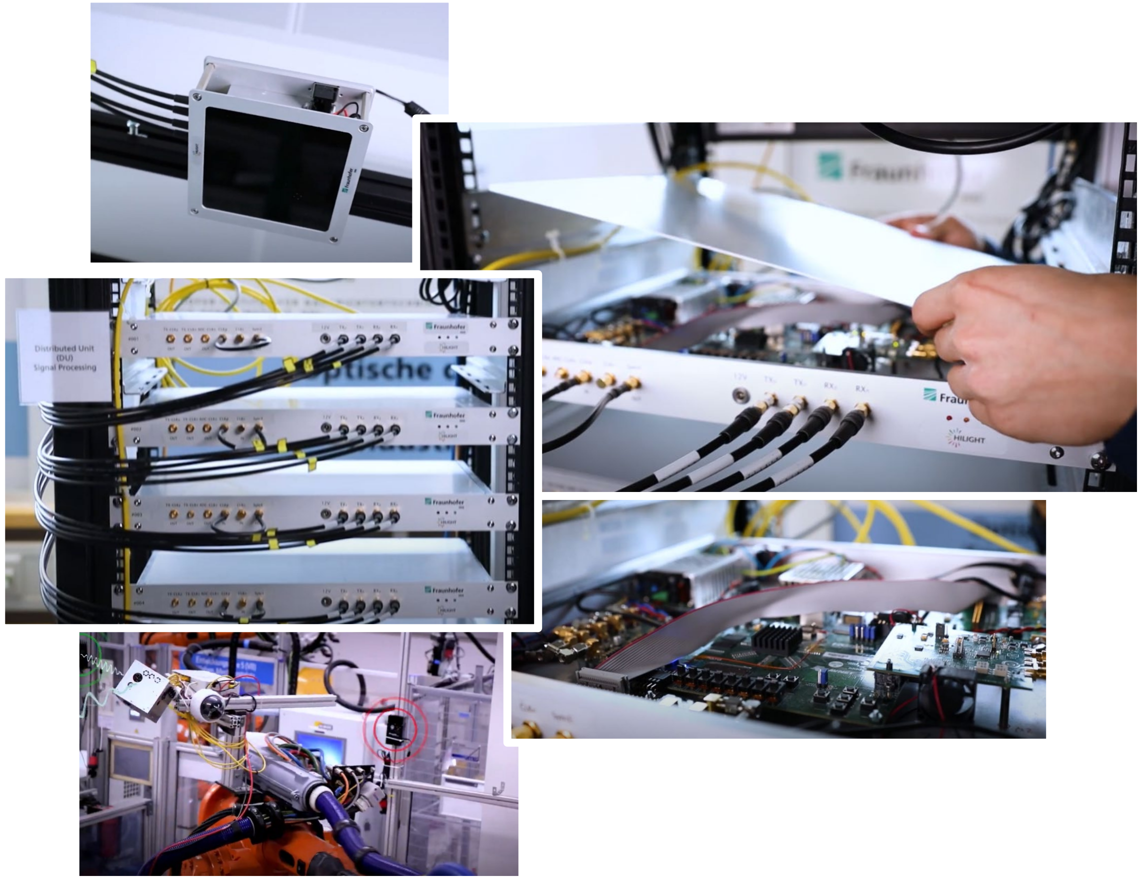
Approved <Date Approved>

IEEE SA Standards Board

- IEEE P802.15.13
- Architecture & Service
- PHYs
- MAC
- **Status**

Implementation

- **Validation through prototyping**
  - D-MIMO over Ethernet Fronthaul
  - FPGA-Based PHY implementation
- **Bugs were found and fixed in the spec**
  - Possibly more to come?
- **Test deployments in industrial environments**
  - In progress
- **Development of new features in the future**
  - Improved PHYs
  - Integrated positioning support
  - Security
  - …



Timings

- **802.15.13 D10.0 is approved by 802.11 WG, 802 LMSC, RevCom and IEEE SA board**
  - 98% approval rate
  - awaiting publication in Q2/2023
- **D10.0 is available in IEEEXplore**
  - https://ieeexplore.ieee.org/document/9963940

IEEE 802.11bb Overview

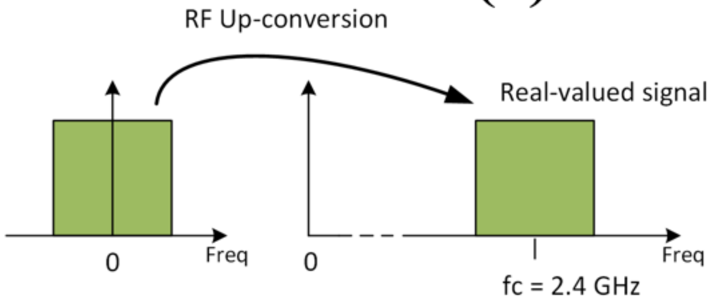
- **802.11bb aims at LC for the mass market**
- **IEEE 802.11 is the world's most common communications standard**
  - Over 3.8 billion Wi-Fi chipsets were shipped globally in 2021 in everything from smartphones, TVs, CCTV cameras, baby monitors, etc.
  - The large established market and open standards have created a highly competitive, vibrant ecosystem of devices, testing facilities, etc.
- **Deploying LC on a global scale requires reducing the barrier to entry for anyone looking to produce interoperable systems**
- **IEEE 802.11bb offers the simplest integration route with the highest number of possible device integration options**

Operational concept

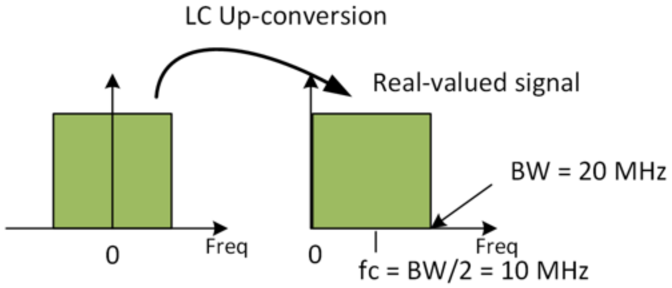
March 2019 doc.: IEEE 802.11-19/0388r0

Using existing 802.11 PHYs for LC (2)

- RF frontend up-converts baseband signals onto e.g. f_c=2.4 GHz.



- LC frontend up-converts baseband onto low IF e.g. f_c=BW/2 + Δ.
  - Δ is to be agreed depending on signal mask design.



- This way, any complex-valued baseband signal (i.e. any existing IEEE 802.11 PHY) can be used to facilitate LC.

Submission Slide 6 Volker Jungnickel (Fraunhofer HHI)

Non-negative real-valued OFDM

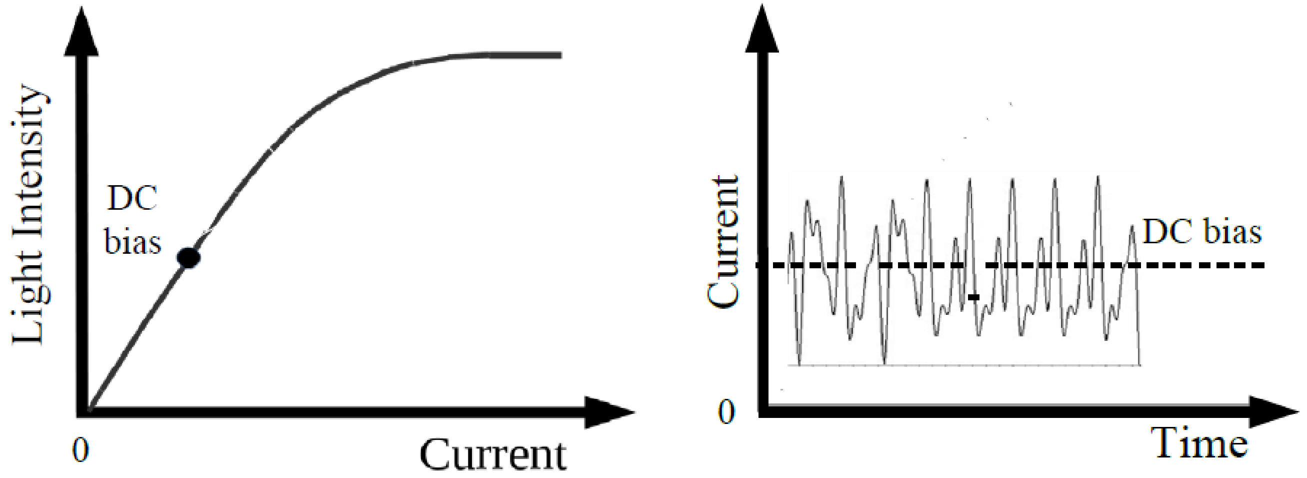
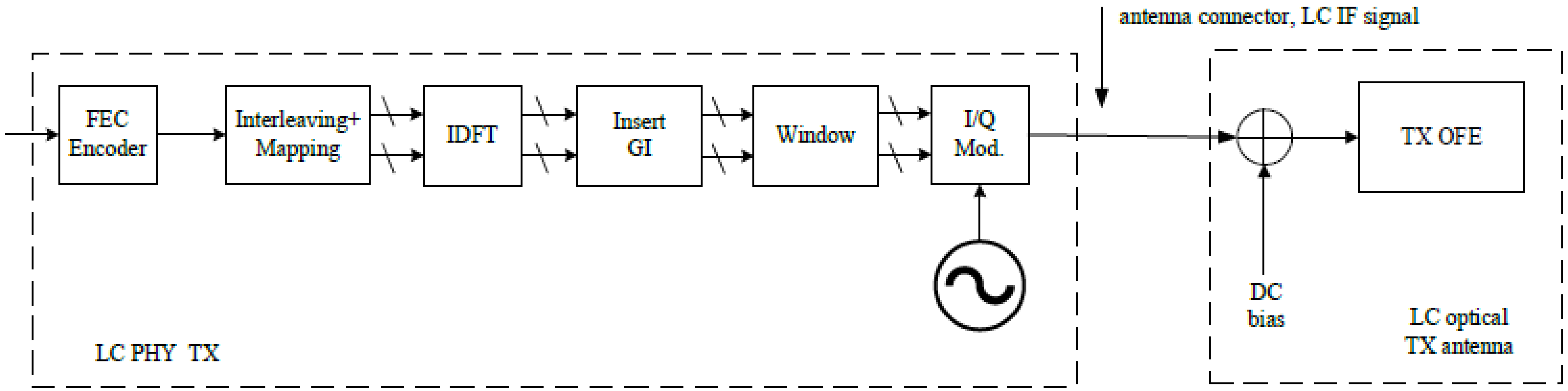


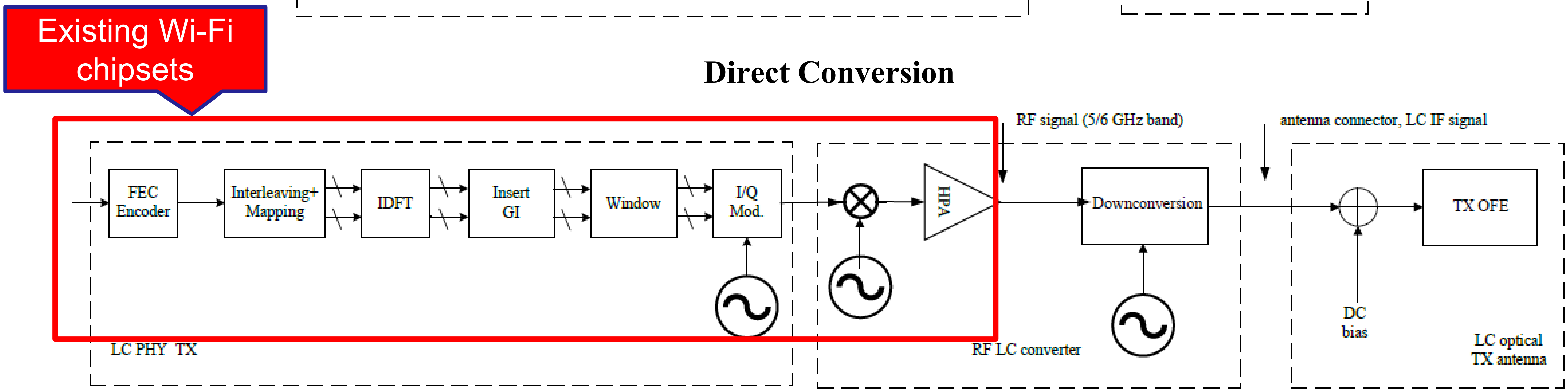
Figure 31-3—Operation of an SSL device with DC bias

- **Add the bias and OFDM signal on IF carrier with limited RMS amplitude**
- **LC channel can be regarded as real-valued AWGN**

Implementation options



Direct Conversion



Up/Down Conversion from RF

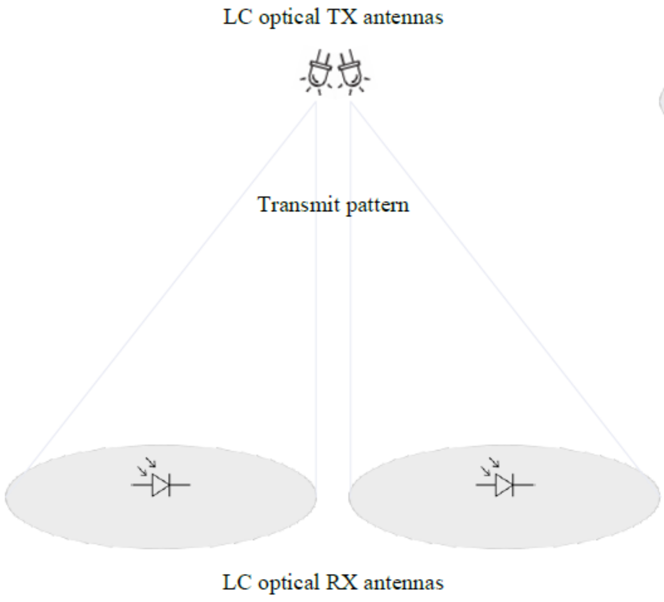
LC IF mappings from 5 and 6 GHz

Table 31-1— RF to LC IF Mapping for channels in the 5 GHz and 6 GHz bands

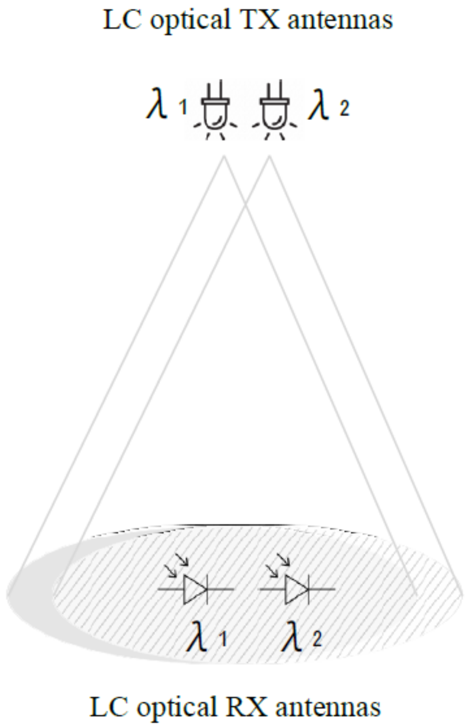
Channel number	RF frequency band	RF center frequency (MHz)	LC IF center frequency (MHz)	Channel width: 20 MHz	40 MHz PrimaryChannel LowerBehaviour	40 MHz PrimaryChannel UpperBehaviour	40 MHz	80 MHz / 80+80 MHz	160 MHz
34		5170	16						
36		5180	26	Channel number 36 16 MHz-36 MHz					
38		5190	36		Channel number 36 16 MHz-56 MHz	Channel number 40 16 MHz-56 MHz			
40		5200	46	Channel number 40 36 MHz-56 MHz				Channel center frequency index 42 16 MHz-96 MHz	
42		5210	56						
44		5220	66	Channel number 44 56 MHz-76 MHz					
46		5230	76		Channel number 44 56 MHz-96 MHz	Channel number 48 56 MHz-96 MHz			
48		5240	86	Channel number 48 76 MHz-96 MHz					Channel center frequency index 50 16 MHz-176 MHz
50	5 GHz	5250	96				N.A.		
52		5260	106	Channel number 52 96 MHz-106 MHz					
54		5270	116		Channel number 52 96 MHz-136 MHz	Channel number 56 96 MHz-136 MHz			
56		5280	126	Channel number 56 116 MHz-136 MHz					
58		5290	136					Channel center frequency index 58 96 MHz-176 MHz	
60		5300	146	Channel number 60 136 MHz-156 MHz					
62		5310	156		Channel number 60 136 MHz-176 MHz	Channel number 64 136 MHz-176 MHz			
64		5320	166	Channel number 64 156 MHz-176 MHz					
			176						
1		5955	186	Channel number 1 176 MHz-196 MHz			Channel center frequency index 3 176 MHz-216 MHz		
3		5965	196						

- **802.11bb channel mapping**
  - RF channels 1-64 with centre frequencies from 5.19-5.32 GHz "en block" to LC IF centre frequencies 26-166 MHz
  - RF channels 1-64 with centre frequencies from 5.955-6.095 GHz "en block" to LC IF centre frequencies 206-326 MHz

Spatial multiplexing, Wavelength-division multiplexing



Spatial Multiplexing



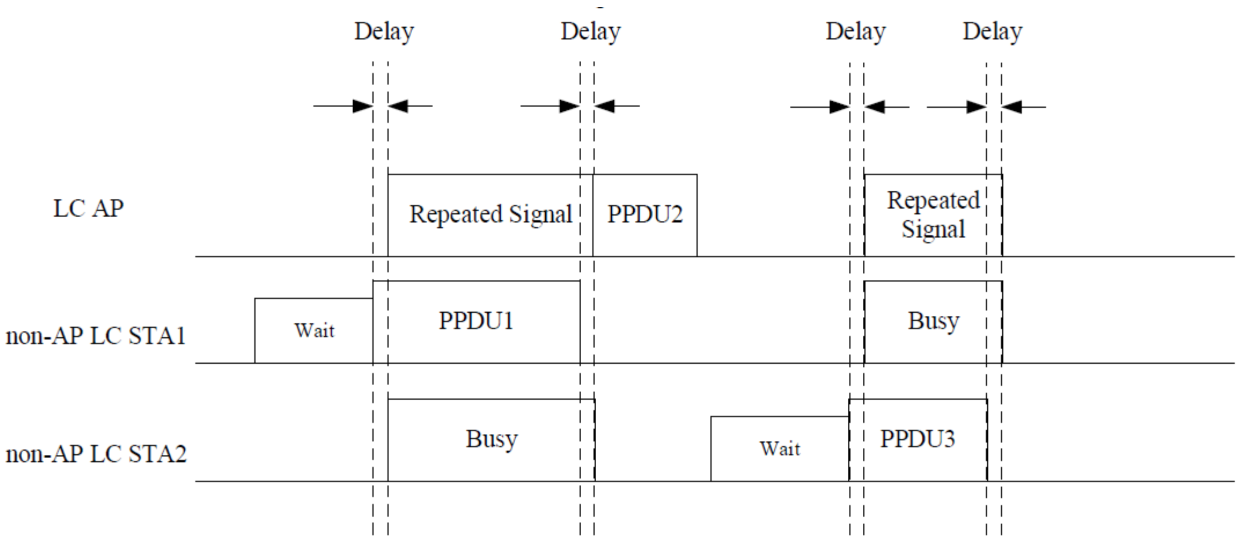
Wavelength Division Multiplexing

1) 800nm – 900nm
2) 900nm – 1000nm

CCA and LC repetition

- **802.11bb systems shall have the same requirements for Clear Channel Assessment (CCA) as those for existing Wi-Fi 4, Wi-Fi 5 and Wi-Fi 6 chipsets**

- **802.11bb suggests an LC repetition approach where the LC AP immediately retransmits the received signal from a STA using amplify-and-forward as an example**



Timings

- **802.11bb Draft 7.0 is currently in the IEEE Standards Association recirculation ballot – ballot closes on 14 Mar.**
  - Over 95% approval rate and all comments resolved from D6.0

- **802.11bb Draft D6.0 is available in IEEExplore**
  - https://ieeexplore.ieee.org/document/10042199

- **Expected final 802.11 Working Group approval in Mar. 2023**
- **Expected final 802 Executive Committee Approval in Mar. 2023**
- **Expected RevCom & Standards Board Final Approval by Jul. 2023**

802.11bb next steps

- **Support for continued education on the benefits of LC**
  - Consider joining the Light Communications Alliance
  - http://lightcommunications.org/

- **Enable Wi-Fi 7 support for LC**
- **Identify certification body for LC**
- **Define certification process and test specifications**

Light Communications Alliance (LCA) in a nutshell

Formed in 2018

10

OUR FOCUS TECHNOLOGIES

- LiFi
- OCC
- FSO

MOTIVATION

Delivering the benefits of ubiquitous Light Communications to serve people & technologies, requires a far-reaching & coherent ecosystem working at a determined pace

MISSION

Driving a consistent, focused & concise approach to market education that will highlight the benefits, use cases & timelines for Light Communications

HOW

Aligning leaders across every industry to develop or envisage business models using Light Communication systems & technologies by defining a standard of education in an efficient communication & co-operation frame.

LCA

KEY MEMBERS

12

LiFi/OCC key players

pureLiFi
Lucibel
NavTech
OLEDCOMM
Signify
Zero 1

Applications

Crantec
pureLiFi
OLEDCOMM
Signify
Zero1

Operators

Emirates Integrated Telecommunications Company (du)
Liberty Global
Orange
Luxembourg POST

Equipement vendors

pureLiFi
BKS Digital
GETAC
Nokia
Signify
VIAVI

Networking and security

BKS
Crantec
Nokia
QRCrypto

University/Research Institute

CEA
University of Edinburg
University of Strathclyde
Institut Mines Telecom

LCA

Technology Demos

- **Indoor**
  - Industry
  - Medical
  - Secure conference room
  - Classroom
- **Outdoor**
  - Backhaul
  - Platooning

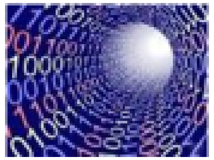
Summary

- …

Acknowledgements

- **Work on 802.15.13 and 802.11bb was funded by several national and European projects.**

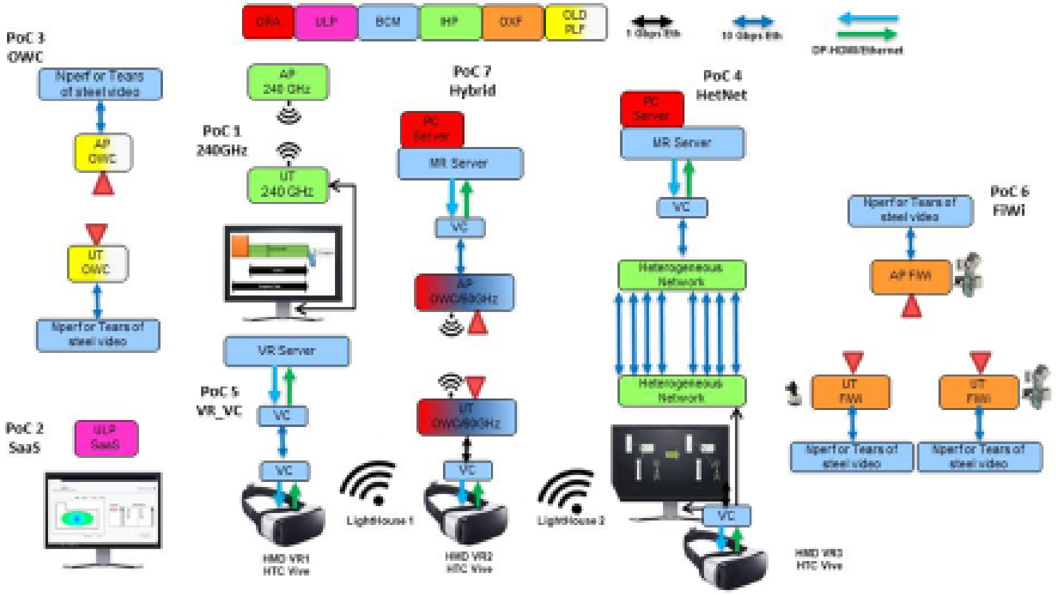
WORTECS



H2020 WORTECS

Wireless Optical/Radio TErabit CommunicationS
https://wortecs.eurestools.eu/

- WORTECS explores Terabit/s capability of above 90GHz spectrum, combining radio and optical wireless technologies.



WORTECS Proof of Concepts (PoCs)

- PoC 1: A wireless transmitter and receiver chips working in the 240 GHz band.
- PoC 2: A channel simulation tool, which models wireless propagation channel for beyond 60 GHz RF and optical spectrum.
- PoC 3: Optical wireless communication (OWC) prototypes based on both G.hn and 802.11
- PoC 4: Implementation of the Heterogeneous Networks (HetNet)
- PoC 5: Prototypes with low latency video compression/decompression for VR use case
- PoC 6: Fiber-Wireless-Fiber (FWF) prototype
- PoC 7: Hybrid RF and optical wireless communication system

ELIoT

H2020 IA Enhance Lighting for the Internet of Things (2018-2022)

https://www.eliot-h2020.eu/

Future IoT

- imaging sensors, video
- reliable transmission
- 100 Mbit/s/device
- high density of devices
- latency/jitter constraints

Great variety of use cases

- potential to create a new mass market
- Use cases actually need networked LC, aka LiFi

Industrial

Office/commercial

Outdoor

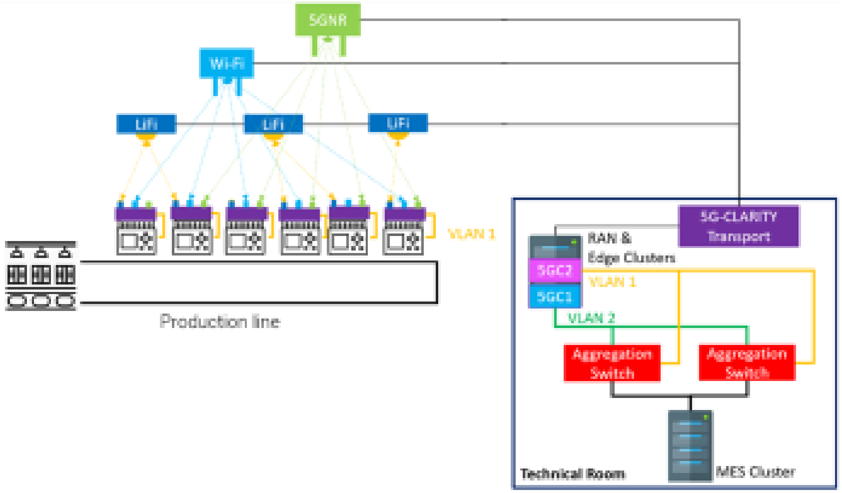
Indoor/consumer

5G-Clarity

H2020 5G-CLARITY

Beyond 5G Multi-Tenant Private Networks Integrating Cellular, Wi-Fi, and LiFi, Powered by Artificial Intelligence and Intent Based Policy
https://www.5gclarity.com/

- 5G-CLARITY designs and demonstrates the integration of 5G, Wi-Fi, and LiFi technologies, and managed through AI-based autonomic networking, in two use cases: BOSCH factory (Aranjuez, Spain), and M-shed museum (Bristol, UK).



Use case: Industry 4.0

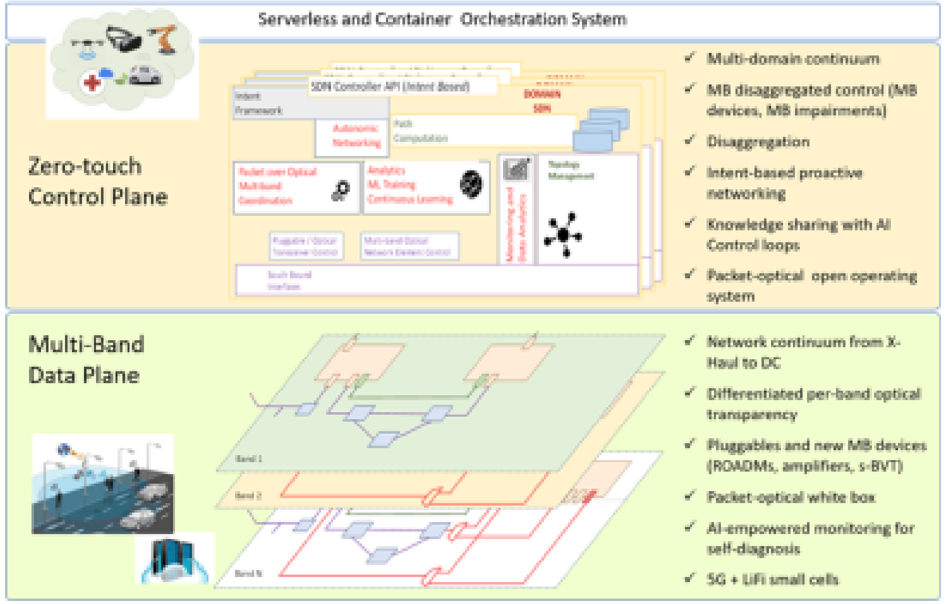
Use case: Smart Tourism

B5G-OPEN

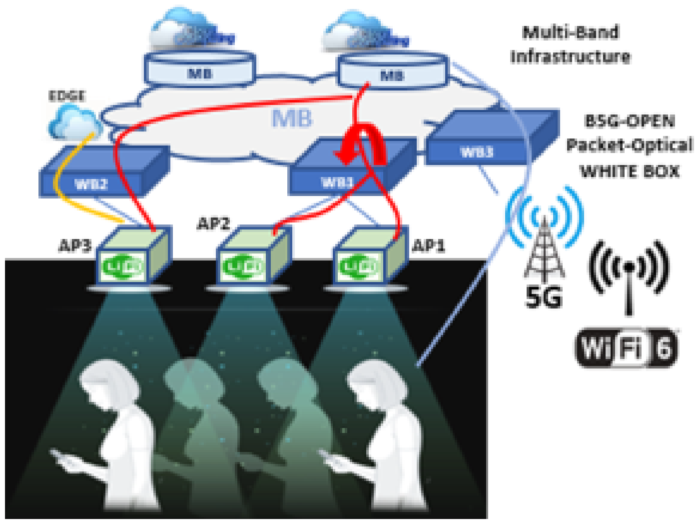
H2020 B5G-OPEN

Beyond 5G – OPtical nEtwork coNtinuum
https://www.b5g-open.eu/

- B5G-OPEN targets the design, prototyping and demonstration of a novel end-to-end integrated packet-optical transport architecture based on MultiBand (MB) optical transmission and switching networks.



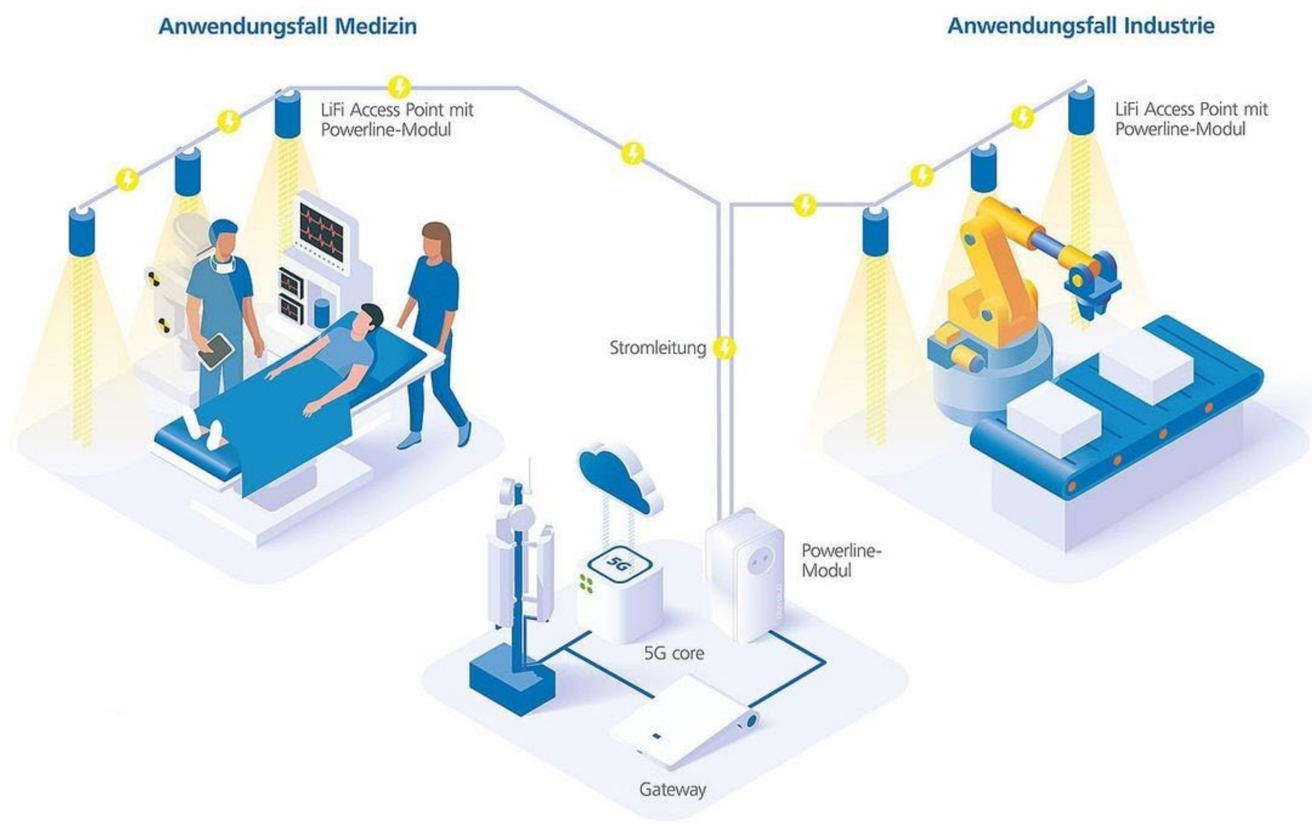
B5G-OPEN key innovations



Demonstration shows QoS-guaranteed connectivity under complex B5G conditions

LINCNET

LiFi-enabled 5G for INdustrial Campus NETworks



devolo, BISDN, IndustrialSolutions Sol – WIR LEBEN NETZWERK, TU berlin, SIEMENS, SMART MOBILE LABS, Fraunhofer HHI, Thiem-Research GmbH, IMF Future Radio Technology, VOLKSWAGEN, DB Systel GmbH, ROHDE&SCHWARZ, MHP A PORSCHE COMPANY, VPIphotonics, Weidmüller

German Federal Ministry of Economics and Climate Action

https://www.lincnet.de/en-gb

Medical and industrial use cases

– Heterogeneous infrastructure
– based on LiFi, PLC and 5G

Reduce barriers for adoption

- powerlines as backbone network
- LiFi relay nodes (surgery lamps) to aid communications between e.g. endoscopes and large screens