STANDARDIZATION OF LI-FI IN IEEE 802.15.13

Volker Jungnickel

Content

- Introduction
- Use-cases
- Scope of 802.15.13
- MAC and PHYs
- Other activities (ITU-T G.vlc, 802.11bb)
- Timelines
- Summary

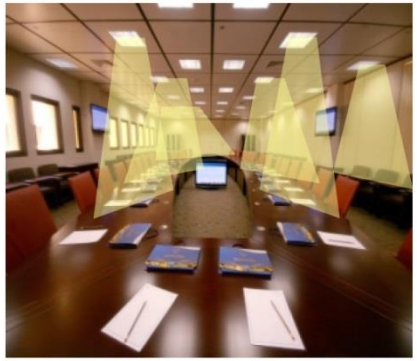
History of OWC in IEEE 802.15

- 802.15.7-2011
  - Non-directed, P2MP using white light and multiple colors
  - MAC based on 802.15.4, a.k.a. ZigBee
  - Support for dimming, optical bandplan, multiple cells
- 3 PHYs
  - 11-266 kb/s (PHY1) , OOK and VPPM
  - 1.25-96 Mb/s (PHY2), OOK and VPPM
  - 12-96 Mb/s (PHY3) using Color Shift Keying (CSK)
- Limited market penetration only within Korea

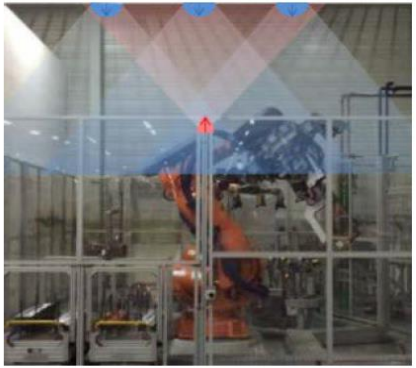
History of OWC in IEEE 802.15

- 802.15.7r1
  - Intended as revision to include Optical Camera Communication
  - Low-speed communications , broadcast topology only
  - 802.15.7r1 = 802.15.7 + OCC today
- 802.15.13
  - In 2015 and 2016, Li-Fi was part of 802.15.7r1
  - OCC and Li-Fi led to intractable document size
  - OCC needs less and Li-Fi more MAC functionality
- New Li-Fi standard
  - Since May 2017, Li-Fi is developed as IEEE P802.15.13

Use Cases for Li-Fi



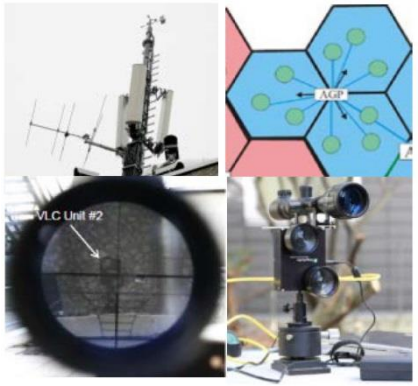
1. Indoor, Office, Home



2. Data Center, Industrial, Secure Wireless

Use Cases for Li-Fi

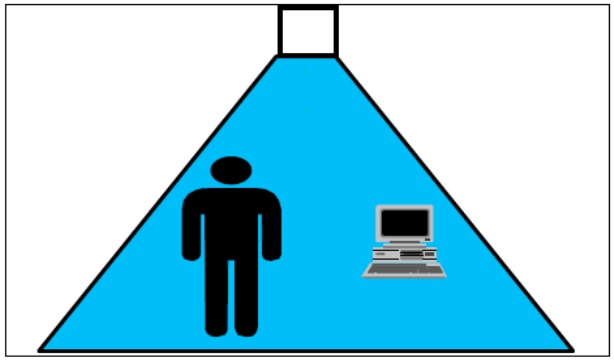
3. Vehicular Communications

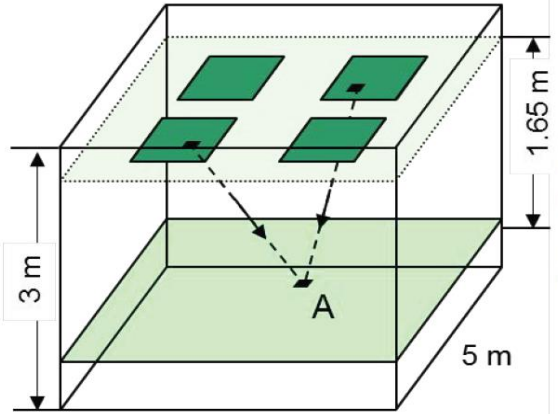


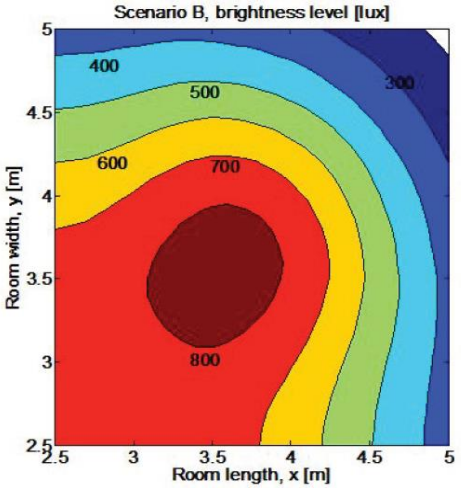
4. Wireless Backhaul, e.g. for small radio cells, video surveillance, LAN bridging

Technologies

- Non-directed LOS

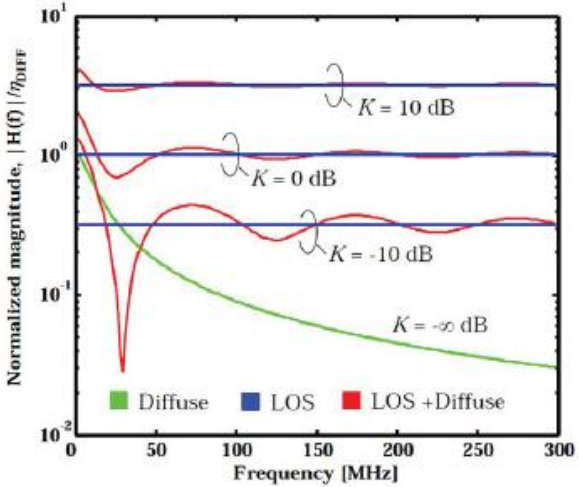


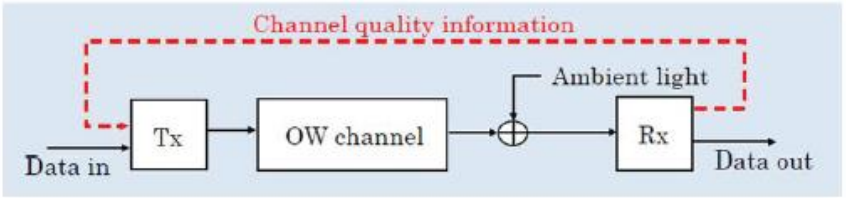




- Limited bandwidth of LED (10-20 MHz, 200 MHz with adv. drivers / TIAs)
- Indoor lighting is bright → rather high SNR
- *High spectral efficiency + high bandwidth enable Gbit/s with LEDs*

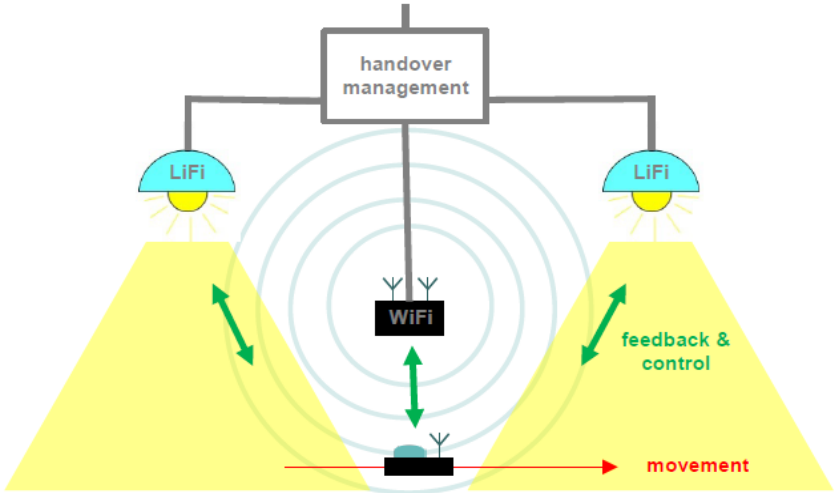
Technologies (2)

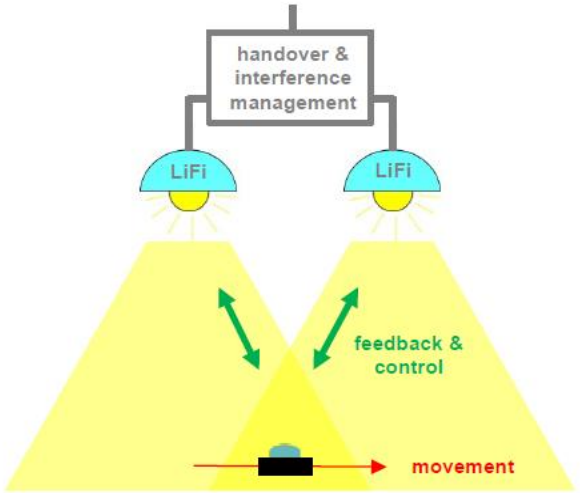




- Superposition of LOS and NLOS at some delay
- Depends on K-factor (ratio betw. LOS and diffuse light) → changes depending on the position
- There are ripples and fades
- Li-Fi channel is both, frequency selective and time-variant
- **OFDM for multi-path**
- **Rate-adaptation for mobility support in one cell**

Technologies (3)





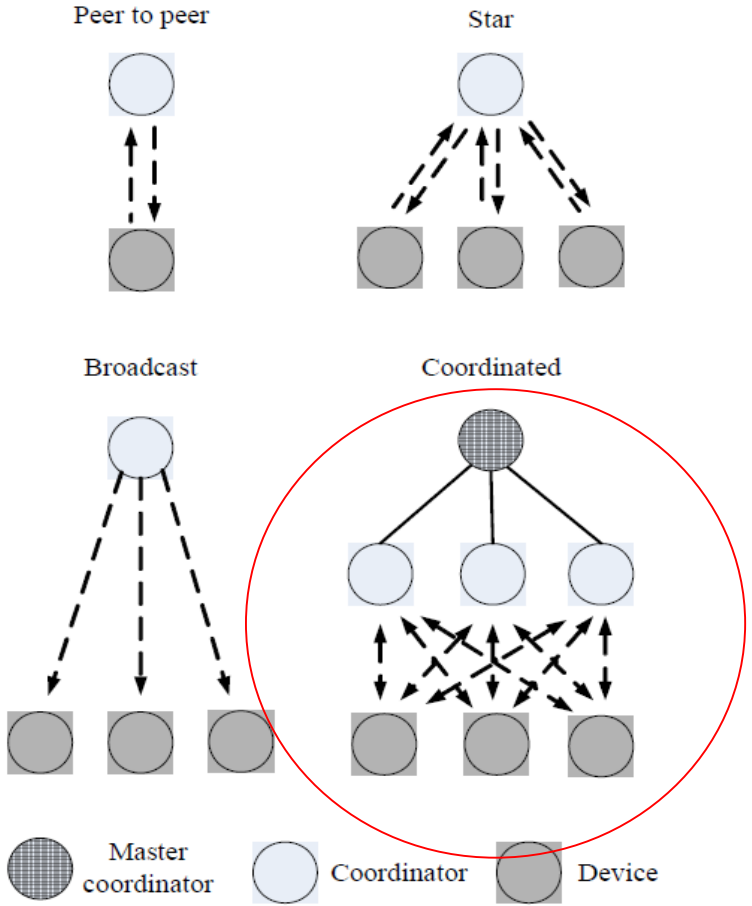
- User can be served by multiple luminaries
- Non-overlapping Li-Fi: Vertical handover to Wi-Fi
- Overlapping Li-Fi cells: Horizontal handover + interference management
- **Mobility support for optical wireless is the key innovation of Li-Fi**

Scope of 802.15.13

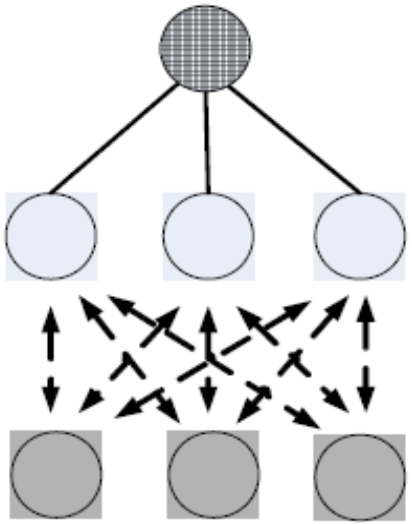
- This standard defines a Physical (PHY) and Media Access Control (MAC) layer using light wavelengths from 10,000 nm to 190 nm in optically transparent media for optical wireless communications.
- The standard is capable of delivering **data rates up to 10 Gbit/s at distances in the range of 200 meters unrestricted line of sight**.
- It is designed for point-to-point and point-to-multi point communications in both non-coordinated and coordinated topologies.
- For coordinated topologies with more than one peer coordinator there will be a master coordinator.
- The standard includes **adaptation to varying channel conditions** and **maintaining connectivity while moving** within the range of a single coordinator or moving between coordinators.

MAC

- Topologies
  - P2P, Star, Broadcast
  - **Coordinated** (new)
- General trend is to simplify 15.7 MAC while adding new features
- Guideline for MAC is 802.15.4



Coordinated topology



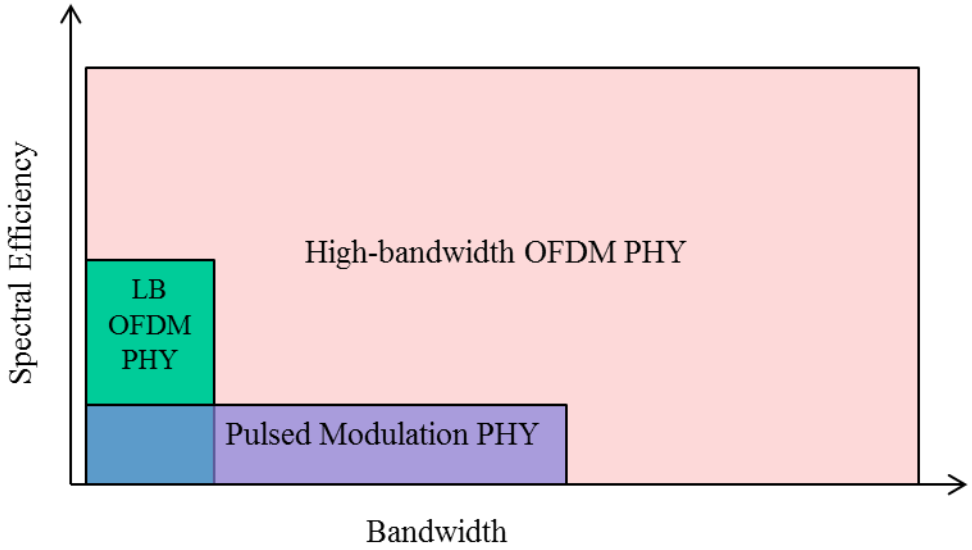
- Consensus to support coordinated topology as **distributed multiuser MIMO** in PHY+MAC
  - Needs new tools in each PHY
  - Explicit pilots for MIMO channel sounding
  - Implicit pilots for data transport
  - Corresponding PHY frames (probe, transport)

Physical layers

1. Low-bandwidth OFDM PHY
   - low rate applications for mobile devices, e.g. Internet, email
   - 5…20 MHz bandwidth
   - moderate spectral efficiency
   - 5 bps/Hz: <100 Mbit/s
2. High-bandwidth OFDM PHY
   - high-rate applications for mobile devices, e.g. downlink, AR/VR
   - 25 MHz…1 GHz, high spectral efficiency <10 bps/Hz, 10 Gbit/s
   - Support for distributed MIMO

Shannon's theorem

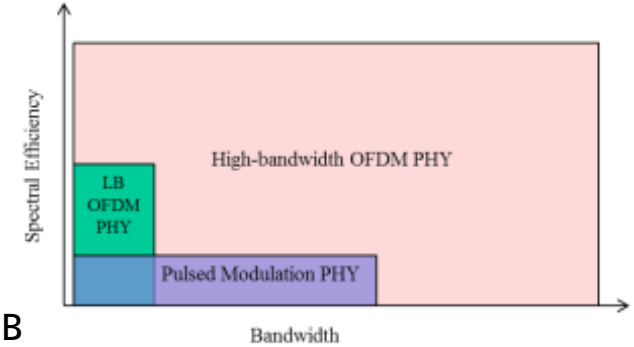
$C=B*\log_2(1+SNR)$



Physical layers

3. Pulsed Modulation PHY

- Low-power applications e.g. uplink, IoT, Industry 4.0



Example

- 100 Mbit/s = 10 MHz * 10 bps/Hz needs a very high SNR ~ 30-40 dB
- 100 Mbit/s = 100 MHz * 1 bps/Hz needs 3dB x 9 = 27 dB less electrical SNR

How?

- Up to 200 MHz bandwidth, low spectral efficiency (0.1…3 bps/Hz): <100 Mbit/s
- **10…100 Mbit/s with low power for industrial coverage**
- Serial modulation with Reed-Solomon Coding, Frequency-domain equalization
- 2-PAM and 8B10B line coding ***or*** M-PAM with Hadamard-Coded Modulation (HCM)
- Rate adaptation through variable M and variable number of HCM codes
- Support for MIMO → spatial diversity, reliability
- Specification is combination of proposals from Fraunhofer HHI, ETRI and vlncomm

Other standardization actitives: ITU-T G.vlc

- Derived from G.hn for (fixed & wired) home networking technologies
  - Well-established ecosystem: Powerline, coax, twisted pair, POF
  - Performant chipsets up to 2 Gbit/s from multiple silicon vendors
  - Rate-adaptive OFDM, LDPC, fast retransmissions, TDMA-based multiuser access
- Li-Fi is considered as 5th medium (but 1st being mobile & wireless)
  - Missing support for mobility (horizontal/vertical handover)
  - Only few power-saving mechanisms are supported so far
- Timeline is similar to TG13 in IEEE 802.15.13
  - Mutual liaision statements in place, 1st joint workshop Febr. 7, 2018 in Geneva
  - Next step is mutual exchange of specifications (at WG LB draft level)
- Ideas in 802.15.13 and G.vlc are useful for early product development!

Other standardization actitives: IEEE 802.11bb

- After its MAC proposal in 802.15, pureLiFi was asked to bring Li-Fi in 802.11
- There was significant opposition from big chipset vendors initially
- A Technical Interest Group produced a report anwering many questions
- A Study Group finished the PAR and CSD recently
- Fraunhofer HHI actively supported the creation of 802.11bb
- **IEEE 802.11 TGbb will take off in July 2018**
- New objective is to address the mass market for Li-Fi (low cost, low energy)
- Limited scope (new PHY, few modifications of 802.11 MAC)
- Goal is to finish the 802.11bb amendment in 2021
- 802.11bb may reuse existing technical work from 802.15.13/G.vlc

Timelines

- **IEEE 802.15.13** shall be ready end of 2018
  - Serves needs in specialty markets, single silicon vendor w/o ecosystem
- **G.vlc** aims at consent in Oct. 2018, chips maybe available end of 2018
  - Serves needs in specialty markets, multiple silicon vendors, ecosystem is in place
- **802.15.13 has advanced ideas, Time-to-market is faster for G.vlc**
- **IEEE 802.11bb** starts in July 2018, standard may be ready 2021
  - PAR/CSD are different from 15.13, now adressing the needs of the mass market
  - Challenges are low power and low cost, but performance may be sacrificed
  - Narrow scope, aggressive time plan, reuse work from 802.15.13 and G.vlc
  - Powerful ecosystem of Wi-Fi Alliance to serve the mass market

Summary

- IEEE 802.15.13/G.vlc is ready end of 2018
  - New technologies for higher performance and improved mobility
  - Standards are designed for specialty markets, adressing near-term needs
  - Combine 802.15.13 ideas with ecosystem of G.vlc → early product development
- 802.11 LC takes off in July 2018 and aims to be ready in 2021
  - Address the future needs of a potential mass market for Li-Fi
  - Support of more big chipset and lighting vendors is t.b.d.
  - Exploring the future mass market needs success in near-term specialty markets
- Li-Fi attracted more interest and became mature through standardization
  - Standardization is essential for future exploitation of promising R&D results
  - Standardization helps to solve „chicken-or-egg“ problem of new wireless technologies