Extend IMMW scope to include optical bands

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Abstract

This contribution highlights use cases, where light communication (LC) can complement RF and leverage obvious synergies. For industrial and residential use cases, 802.11 should support seamless mobility with RF, enable high area capacity and precise positioning. Integration of LC within MLO and, support of higher bandwidth are obviously required. Due to the overlap of new LC features with mm-wave, 802.11 WG should consider optical bands in the scope defined by IMMW SG.

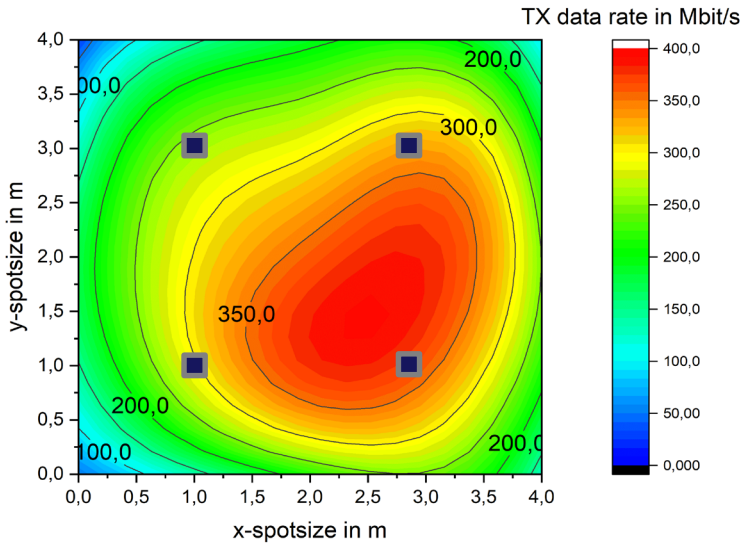
Outline

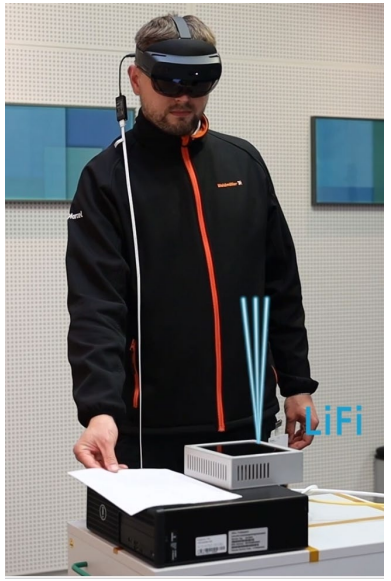
- **Light Communication**
  - use cases and requirements
- **LC features**
  - integration into MLO
  - higher bandwidth operation
  - some other interesting points
- **Summary**

LC as complement where RF has limitations

Defence & Environment	Data & Industrial	Office & Commercial	Retail & Financial	Smart City & Transport	Consumer & Lifestyle
					
Secure commun., Harsh environm., Underwater	Data centres, Industry 4.0 and Future IoT	Secure office: Dense network for Offloading	Shop analytics: Precise positioning for Payments and Back office	Connected street-lights as backhaul for public Wi-Fi	Smart home: Reuse light infrastructure, Mobile devices for Entertainment

Use cases and requirements





- **Industrial communication:** For reliability, multiple optical frontends are used to cover a hotspot area and, overcome blockage. Outside that area, a parallel RF link is available.
- **Current solution:** 4 ms latency for RF/LC handover when implemented at the network layer [3]. Apps like XR require lower latency → Seamless mobility between LC and RF is required
- **Future solution:** Integrate LC into MLO

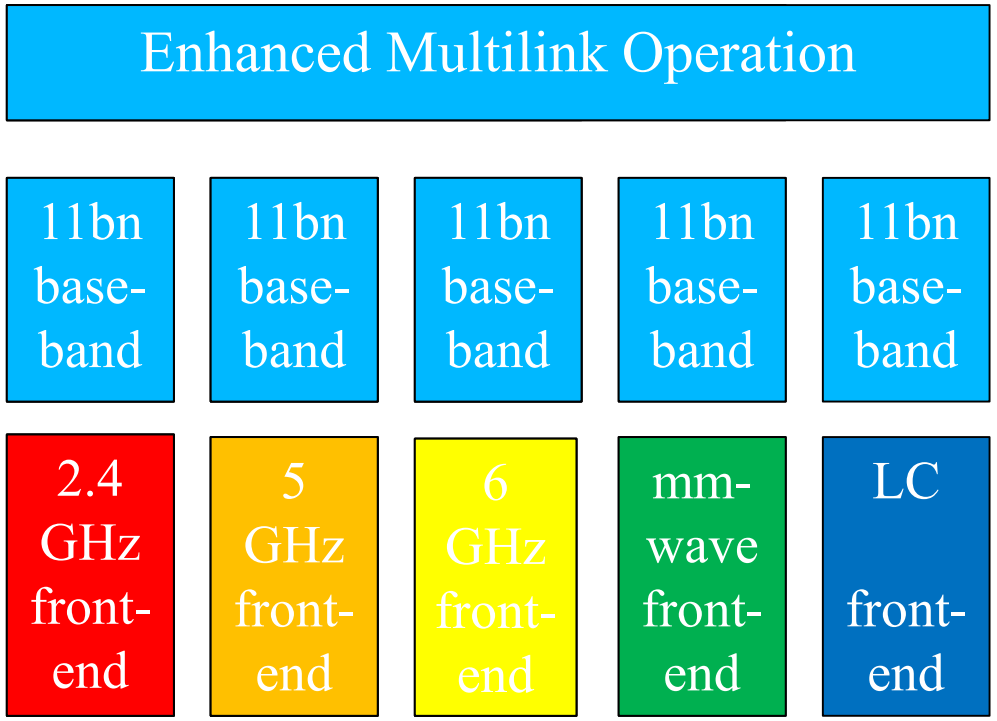
Use cases and requirements

- **Classroom**
  - multiple frontends at the ceiling
  - mobile devices on the tables
- **Current solution**
  - 80 MHz, single spatial stream
  - transmit and receive same signal through multiple optical frontends
- **Future solutions**
  - high area capacity
    - more bandwidth
    - multiple spatial streams

Use cases and requirements

- **Industrial positioning**
  - automated guided vehicle transports spare parts in the shop floor
  - requires cm precision
- **Current solution**
  - SoA uses camera and stripes on the floor, not easily reconfigurable
- **Future solution**
  - LC is promising: Few centimeters precision shown in research [6, 7]
    - due to LOS-based propagation
  - optimize FTM via LC

Why mm-wave and LC in one project?



- **MLO becomes available in 11be**
  - further optimized mechanism in 11bn
- **Reusing the baseband**
  - ability to scale through parallel operation
  - different frontends are used
- **Initial scope**
  - baseband is reused again
  - mm-wave frontend is added
- **Extended scope**
  - baseband is reused again
  - LC optical frontend is added

mm-wave and LC

- Both are expected to sell in low volumes, initially → max. HW/SW reuse is important
- Both have limited range/coverage, do not pass through walls → no interference, higher spatial reuse
- Both are interesting as an underlay for 2.4/5/6 GHz BSS → offload traffic near the AP
- Both are high power and benefit from parallel operation of lower bands → maintain association, save power, seamless mobility, etc.

Features for IMMW

- **Required**
  - integration into MLO
  - higher bandwidth operation
- **Some other interesting points**
  - unified IF interface for mm-wave and LC
  - consistent channel models for all bands
  - MIMO and FTM adapted to LC

Summary

This contribution has reviewed use cases, requirements and corresponding features for the evolution of LC.

- higher bandwidth and MLO integration are required, same as for mm-wave
- some other interesting points have been mentioned

Due to overlaps, it is proposed to extend the scope of IMMW SG beyond mm-wave and include optical bands.

Integration into MLO [4]

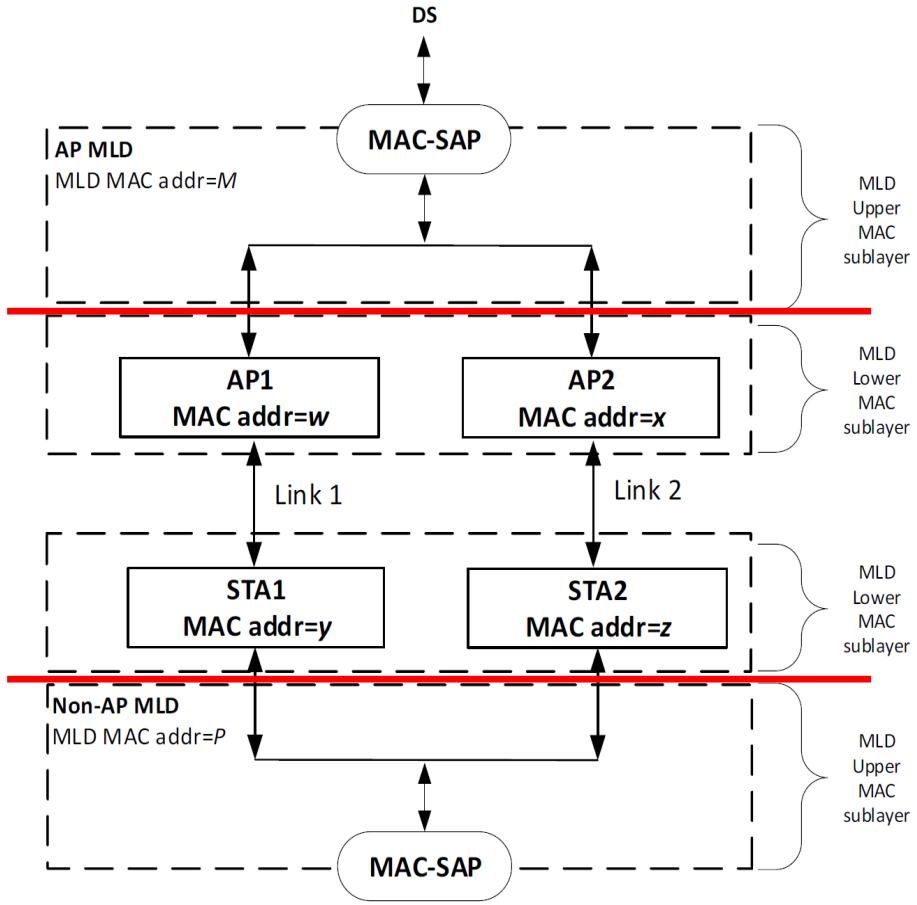


Figure 4-30a—Example MLD and the affiliated STA communication system

- Separation of MAC in MLD Upper and Lower MAC sublayers
- Allows optimized channel access in each band
- MLO interface between U/L MAC could be very similar for all bands

Higher bandwidth

- **LC channel can support 320 MHz and more bandwidths**
  - Same as mm-wave
    - besides 11n/ac/ax, LC can also reuse baseband signals from 11be/bn/…
    - LC optical antennas support 320 MHz and more using VCSEL array instead of LED, slides 12-13 in [5]
  - Other than mm-wave,
    - LC applies frequency shift to LC IF, instead of mm-wave carrier frequency
- **LC channel is less impaired**
  - less frequency-selective
    - LOS is dominant, fading where NLOS is noticeable (room corners, multiple optical antennas) [8, 9]
  - less time-variant
    - LC signal is same as e.g. Equation (19-1) for an LC PHY with HT support, where *fc* is the LC IF
    - Doppler frequency relates to LC IF *fc* = 26…326 MHz, not to RF carrier frequency *fc* = 45/60 GHz
  - less CFO and phase noise

References

[1] IEEE Std 802.11bb-2023, https://standards.ieee.org/ieee/802.11bb/10823/

[2] IEEE 802 Tutorial “IEEE 802 Standards on Light Communication” at March 2023 Plenary Meeting https://mentor.ieee.org/802.11/dcn/23/11-23-0277-01-0000-ieee-802-standards-on-light-communication.pdf

[3] A. Paraskevopoulos *et al.*, "Software-defined LiFi - RF network for Industry 4.0 applications," *IECON 2022,* Brussels, Belgium, https://ieeexplore.ieee.org/document/9969087

[4] 11-23/0221r1 “Hybrid LC and RF in UHR” https://mentor.ieee.org/802.11/dcn/23/11-23-0221-01-0uhr-hybrid-lc-and-rf-in-uhr.pptx

[5] 11-23/0091 “New Light Communication Features” https://mentor.ieee.org/802.11/dcn/23/11-23-0091-00-0wng-light-communication-for-uhr.pptx

[6] S. M. Kouhini *et al.*, "LiFi Positioning for Industry 4.0," in IEEE JSTQE, vol. 27, no. 6, pp. 1-15, 2021 https://ieeexplore.ieee.org/abstract/document/9479791

[7] C. Kottke *et al.*, "In-building Optical Wireless Positioning Using Time of Flight," OFC *2023* San Diego, CA, USA, https://ieeexplore.ieee.org/abstract/document/10117339

[8] S.M. Mana *et al.* “Experiments in Non-Line-of-Sight Li-Fi Channels”, *Global Li-Fi Congress 2019,* Paris, France, https://ieeexplore.ieee.org/abstract/document/8864131

[9] S. M. Mana et al., "LIDAR-Assisted Channel Modelling for LiFi in Realistic Indoor Scenarios," in IEEE Access, vol. 10, pp. 59383-59399, 2022, https://ieeexplore.ieee.org/abstract/document/9777967