NOKIA

LiFi Standardization Status and Evolution

Max Riegel, Nokia

2022-06-27

LiFi Conference, Eindhoven

Brief introduction of myself

Max Riegel
<maximilian.riegel@nokia.com>
Senior Standardization Specialist
Nokia S&T NSD – IEEE & Wi-Fi Standardization

- Job positions
  - 1998 - 2007
    - Responsible for IETF and IEEE Standardization at Siemens Communications
  - since 2007
    - Responsible for IEEE & Wi-Fi related standardization at NSN/Nokia Networks/Nokia Bell Labs
- Involvement in IEEE 802.11 (Wi-Fi) Standardization since 2000
- Voting member of IEEE 802.1 and IEEE 802.11
- Engagement in Wi-Fi Alliance and Head of Nokia delegation in Wireless Broadband Alliance
- Various research activities related to Wi-Fi and other license-exempt technologies
  - Participation in EU H2020 ELIoT Light Communication research project

Outline

LC Standardization Status and Evolution

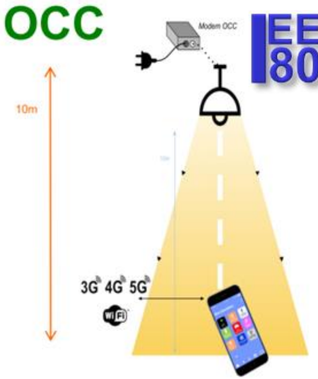
- Introduction
- Early days of light communication standards: IrDA & IEEE 802.15.7
- Highest light communication performance for specialized networks: IEEE 802.15.13
- Light communication companion to home networking standards: ITU-T G.9991
- Light communication standard for the mainstream devices market: IEEE 802.11bb
- Light communications outlook into 5G and beyond
  - Specifications for integration of light communications into 5G networks
  - Challenges for communications beyond 5G?
- Conclusion

Economies of scale require standards

Early days of Light Communication standards – still widely used!

- IrDA – Infrared Data Association
  - Founded 1993 to establish interoperable solution for infrared light data networking
  - Initial IrDA Data standard released in 1994 for PTP communications over IR light
    - Still in broadest use for any kind of remote control and wireless audio transmissions
    - Covers PHY (physical layer), Link Access Protocol (IrLAP) and Link Management Protocol (IrLMP) for up to 4 Mbit/s fully covering usual application cases.
  - Several amendments over the years extending bitrates to 1 Gb/s and providing broad application support

- IEEE 802.15.7 - IEEE 802.15 WPAN™ Task Group 7
  - Task Group established in Jan 2009 on Visible Light Communication
  - Initial standard released as IEEE Std 802.15.7-2011, later revised to IEEE Std 802.15.7-2018
    - Covers point-to-multipoint (broadcast) transmissions using white light and multiple colors for mobile devices, applications in vehicles, and backhauling.
    - 3 different PHY modes for 11 kbit/s up to 96 Mbit/s, later amended with 3 additional PHYs addressing **Optical Camera Communication (OCC)**
  - Current amendment project P802.15.7a (TG7a) fully focuses on enhanced OCC capabilities.



  Public NOKIA Bell Labs

IEEE P802.15.13

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

IEEE Standards Department
445 Hoes Lane
Piscataway, NJ 08854, USA

NOKIA

P802.15.13 Intentions and scope

Reasons to establish a new task group

- New technologies, not included in P802.15.7
  - Mobility support between Li-Fi cells and between Li-Fi and RF
  - Higher data rates through better technologies
    - Up to 10 Gb/s short-range using RGBY LEDs
    - Several 100 Mb/s single-color in wide beams (few meters)
  - Discrete multi-tone (DMT, also denoted as DC-OFDM)
  - Closed-loop rate adaptation
  - Multiple-input multiple-output (MIMO) and distributed multi-user MIMO

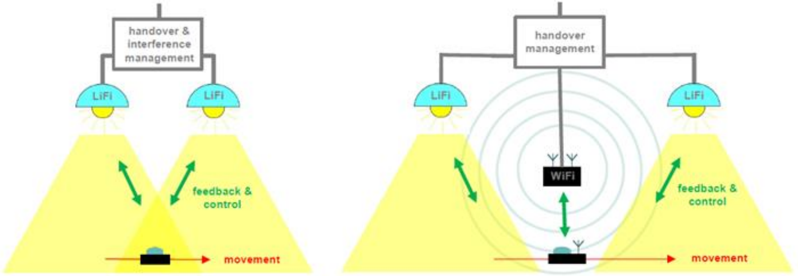
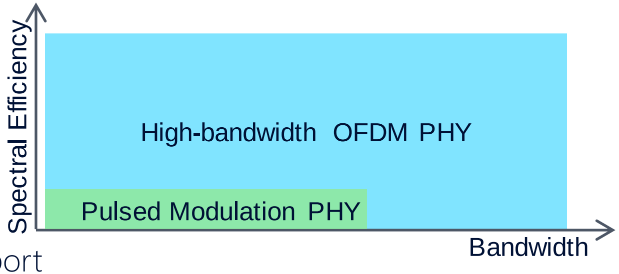


Fig src: https://mentor.ieee.org/802.15/dcn/18/15-18-0066-02-0013-slides-for-joint-workshop-with-itu-t-q18-sg15.ppt

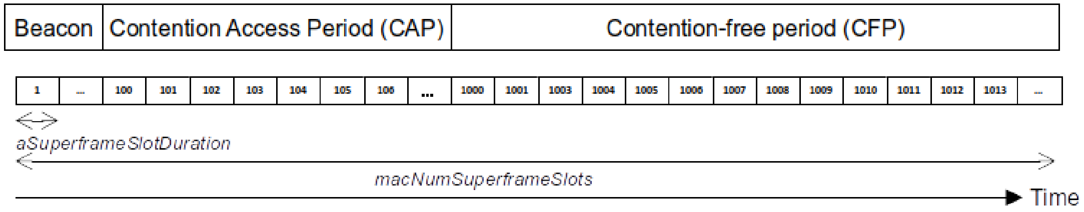
- Scope of Project Authorization Request (PAR) of P802.15.13
  - This standard defines a physical layer (PHY) and medium access control (MAC) sublayer using light wavelengths from 10,000 nm to 190 nm in optically transparent media for optical wireless communications.
  - The standard is capable of delivering data rates up to 2.192 Gb/s at distances in the range of 200 m unrestricted line-of-sight. It is designed for point-to-point and point-to-multipoint communications and adaptation to varying channel conditions.

P802.15.13 PHYs and MAC

- PHYs
  - HB OFDM PHY: use advanced optical frontends and achieve moderate-to-high data rates (downlink) – **aimed for eMBB**
  - PM PHY: use advanced optical frontends and achieve low-to-moderate data rates (uplink) – **aimed for mMTC**
  - All PHYs are useful **for URLLC**, as they provide distributed MU MIMO support



- MAC
  - System architecture consists of array of Optical Front Ends (OFEs) served by a single Coordinator
  - TDMA based channel access controlled by periodic beacons send by the Coordinator defining a superframe.



  - Contention based access for association procedure and requests for granted time slices (GTS).
  - Data transfer and signaling during Contention-free period based on assigned GTSs.

P802.15.13 PHY numerology

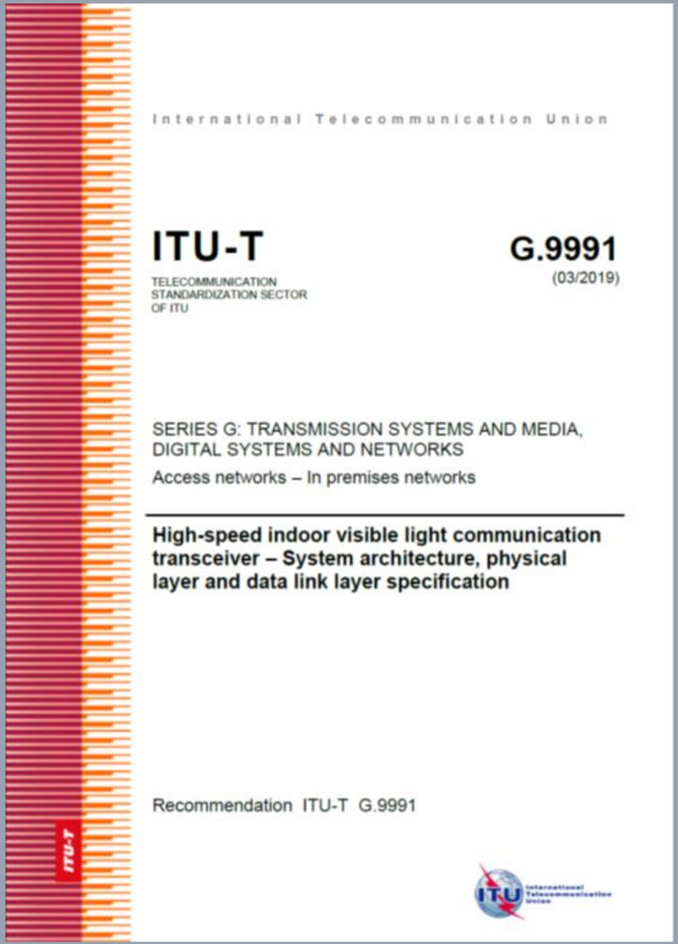
- High-bandwidth OFDM PHY (HB PHY)
  - High bandwidth (25…1.000 MHz), high spectral efficiency (10 bps/Hz): <10 Gbit/s
  - Derived from G.hn (2015) by scaling bandwidth up to 1 GHz

Modulation				DC-biased OFDM	
Subcarrier spacing				195.3125 kHz	
OFDM symbol duration				5120ns	
Cycle prefix				160ns or 1280ns	
# of bits/subcarrier				1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	
FEC information block size				LDPC, 120 or 540 bytes	
Code rates				1/2, 2/3, 5/6, 16/18, 20/21	
Bandwidth	Clock cycle	Frequency up-shift	Subcarriers (used)	Gross data rate	
				min	max
50 MHz	20ns	25 MHz	256 (245)	23 Mbps	530 Mbps
100 MHz	10ns	50 MHz	512 (501)	47 Mbps	1084 Mbps
200 MHz	5ns	100 MHz	1024 (1013)	96 Mbps	2192 Mbps

- Pulsed Modulation PHY (PM PHY)
  - High bandwidth (3-200 MHz) and low spectral efficiency (PAM-16): < 100 Mbit/s
  - Increased bandwidth and low SNR => power-efficient PHY for advanced frontends

Modulation		2-PAM
FEC		Reed-Solomon
FEC code rates		Header: RS(36,24) Payload: RS(256,248)
Line coding		8B10B
Clock rates		12.5, 25, 50, 100, 200 MHz
Cyclic prefix		160ns or 1280ns
Clock rate	Clock cycle	Data rate
12.5 MHz	80ns	8.99 Mbps
25 MHz	40ns	17.41 Mbps
50 MHz	20ns	32.94 Mbps
100 MHz	10ns	59.43 Mbps
200 MHz	5ns	99.42 Mbps

ITU-T G.9991


International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.9991
(03/2019)

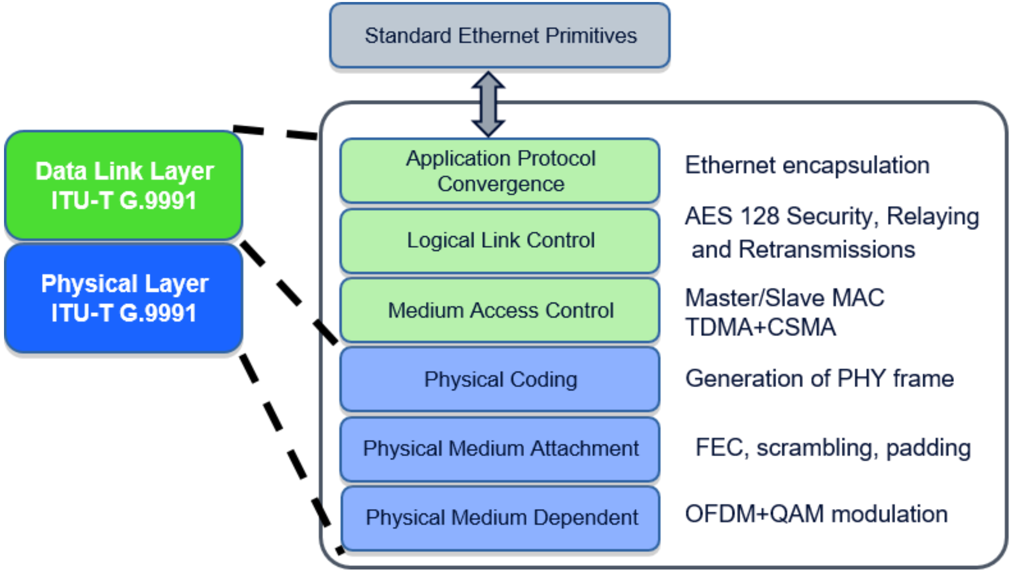
SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

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

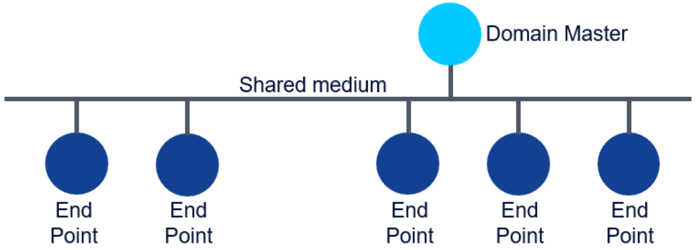
ITU-T G.9991 (‘G.vlc’)



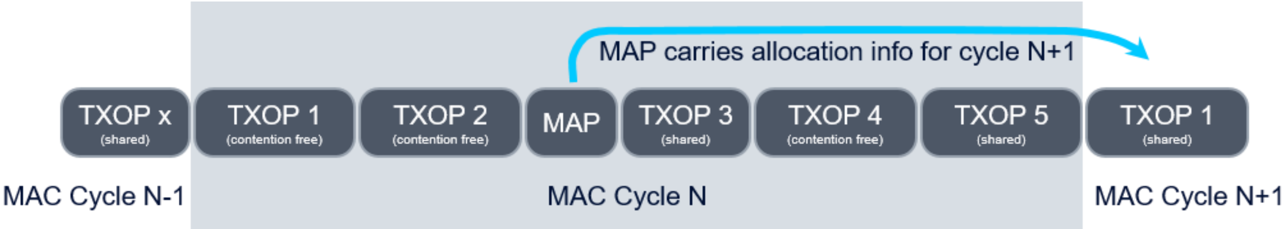
- Based largely on G.9960/61 (aka G.hn)
- Objective: Leverage the highly flexible OFDM engine provided by G.hn
  - Part of ITU-T G.999x series (optical transmission)
    - LC = VLC + IR
- Developed by ITU-T SG 15 (Q18/15 In-premises networking)
  - Started 2H2015, first approval 2019-04-01
  - Revised through 2 amendments and a corrigendum
  - Latest release: April 2021
- 2 PHYs on common MAC
  - PHY 1: DC biased Optical (DCO) - OFDM
    - G.9960, performance oriented, up to 2 Gbps
  - PHY 2: Asymm.-Clipped Optical (ACO) - OFDM
    - More flexible, e.g. in case of dimming
  - MAC: G.hn MAC + additions (FD-prepared)
- Topologies: P2P & P2MP

G.9991 System and MAC

- G.9991 network is based on a master/slave architecture with synchronized media access
- Functional decomposition:
  - **Domain Master (DM)** builds the network domain, builds Medium Allocation Plan (MAP), manages security, etc.
  - **End Point (EP)** follows MAP broadcast by DM, send/receives user data, etc.



- The DM periodically broadcast a Media Access Plan (MAP) message, that contains allocation information for the next MAC cycle.



- Using the MAP, the DM can divide the MAC cycle into multiple Transmission Opportunities (TXOP)
  - CFTXOP (Contention Free TXOP) - Used for TDMA mode. Only one node can transmit during this TXOP
  - STXOP (Shared TXOP) - Access is defined amongst a group of nodes. Used for token-passing and CSMA mode.

NOKIA

ITU-T G.9991 Key parameters

Layer	Area	Value	Notes
Physical Layer	Line code	OFDM	Configurable OFDM parameters (cyclic prefix, per-subcarrier PSD, etc)
	Max modulation	12 bits/subcarrier	Each sub-carrier is modulated with a different QAM, depending on SNR
	FEC	LDPC	Multiple FEC rates (1/2, 2/3, 5/6, 16/18, 20/21) dynamically selected
	Spectrum	5-200 MHz (VLC)	Individual sub-carriers can be notched to coexist with other services
	Subcarrier spacing	195 kHz (VLC)	Sub-carrier spacing optimized for the expected delay spread in each medium
Data Link Layer	Logical topology	P2P, P2MP	Support for multiple topologies to support both access/in-home services
	MAC protocol	TDMA	TDMA ensures no-collisions, while enabling CSMA slots for registration CSMA is also described in the standard but not used for other purposes than registration
	Retransmission protocol	Yes	Retransmission protocol provides zero-loss operation and flow-control
	Encryption	AES-128	Standard enables each node in the network to use different AES keys
	QoS	8-levels	8-level prioritization to support voice, video, data, control messages, etc
	Multicast & Broadcast	Native Multicast & Broadcast support	Including reliable multicast with Rx acknowledgement
	Bandwidth Allocation	Per user & per direction	Supports different service tiers on the same network

IEEE P802.11bb

IEEE P802.11bb™/D2.1 June 2022
(amendment to IEEE Std. 802.11(TM)-2020,
IEEE Std. 802.11ax(TM)-2021,
IEEE Std. 802.11ay (TM)-2021,
IEEE Std. 802.11ba(TM)-2021,
IEEE P802.11az(TM) D4.0,
IEEE P802.11bc(TM) D3.0,
IEEE P802.11bd(TM) D2.1)

P802.11bb™/D2.1
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

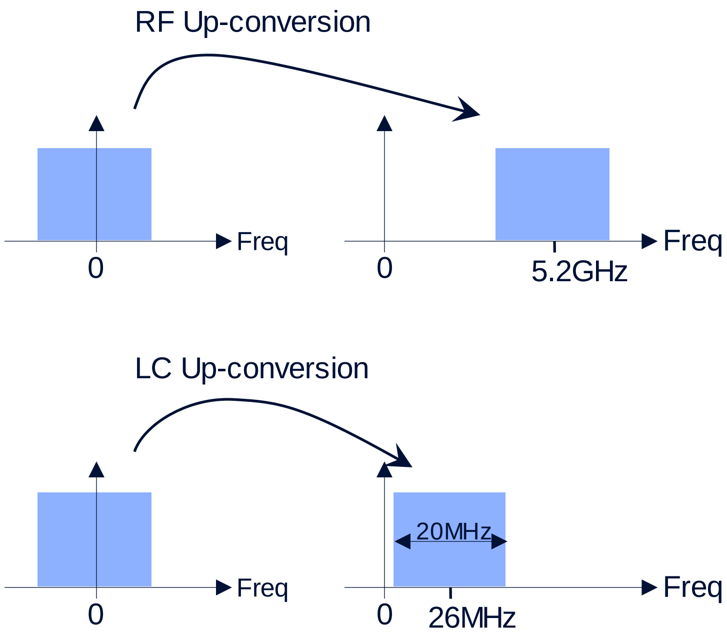
Prepared by 802.11 Working Group of

LAN/MAN Standards Committee of the **IEEE Computer Society**

Addressing the real mass-market through amending Wi-Fi

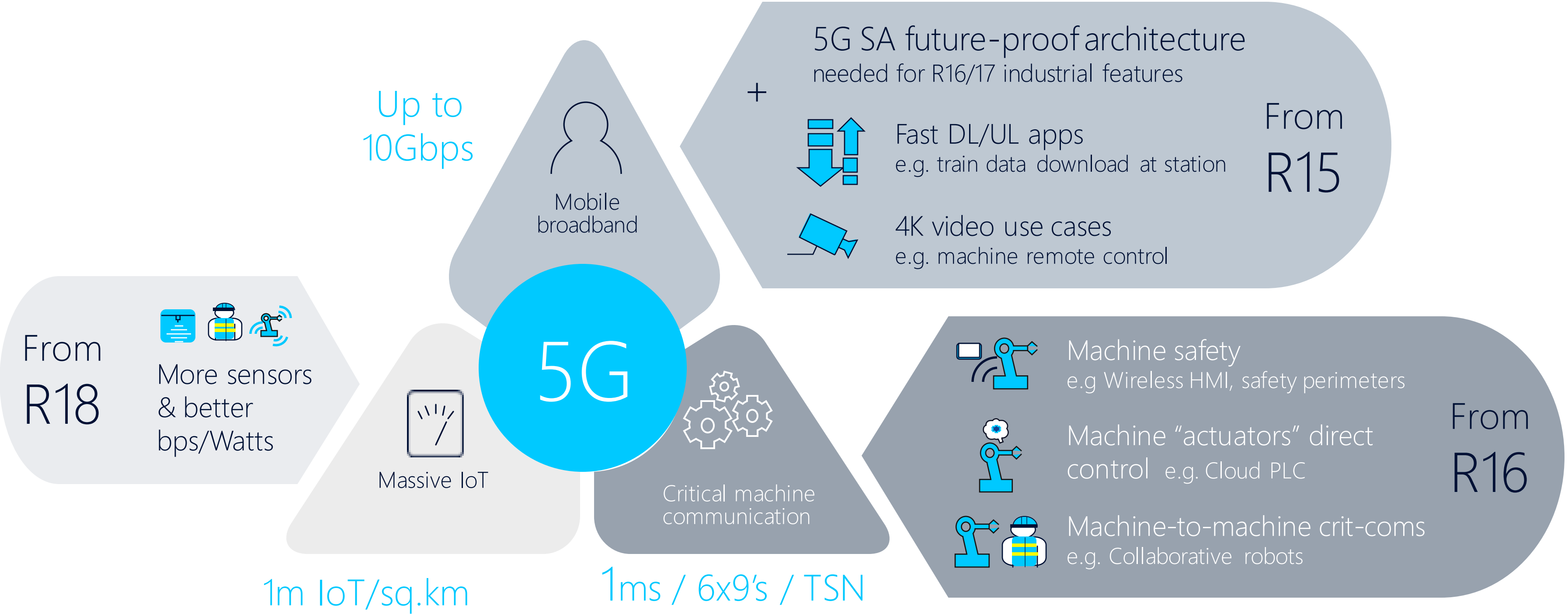
IEEE P802.11bb provides LiFi interface with the least modification effort to existing chips

- Approach: Use existing PHYs and MAC
  - RF frontend up-converts baseband signals onto e.g. 5.2 GHz
  - LC frontend up-converts baseband onto low carrier suited for directly driving the LED, e.g. 26 MHz in the case of 20 MHz baseband signal.
    - Such conversion could even be realized through analog up-/down mixing of the RF signal.
  - Could allow to convert any existing Wi-Fi chip solution into a LC solution through adding cheap external circuitry.
- IEEE P802.11bb exactly follows that approach
  - Simple amendment to 802.11n, 802.11ac, and 802.11ax for light communications
  - Same bitrates, same system interfaces, same capabilities as Wi-Fi
  - Slight modifications to MAC for Clear Channel Assessment.



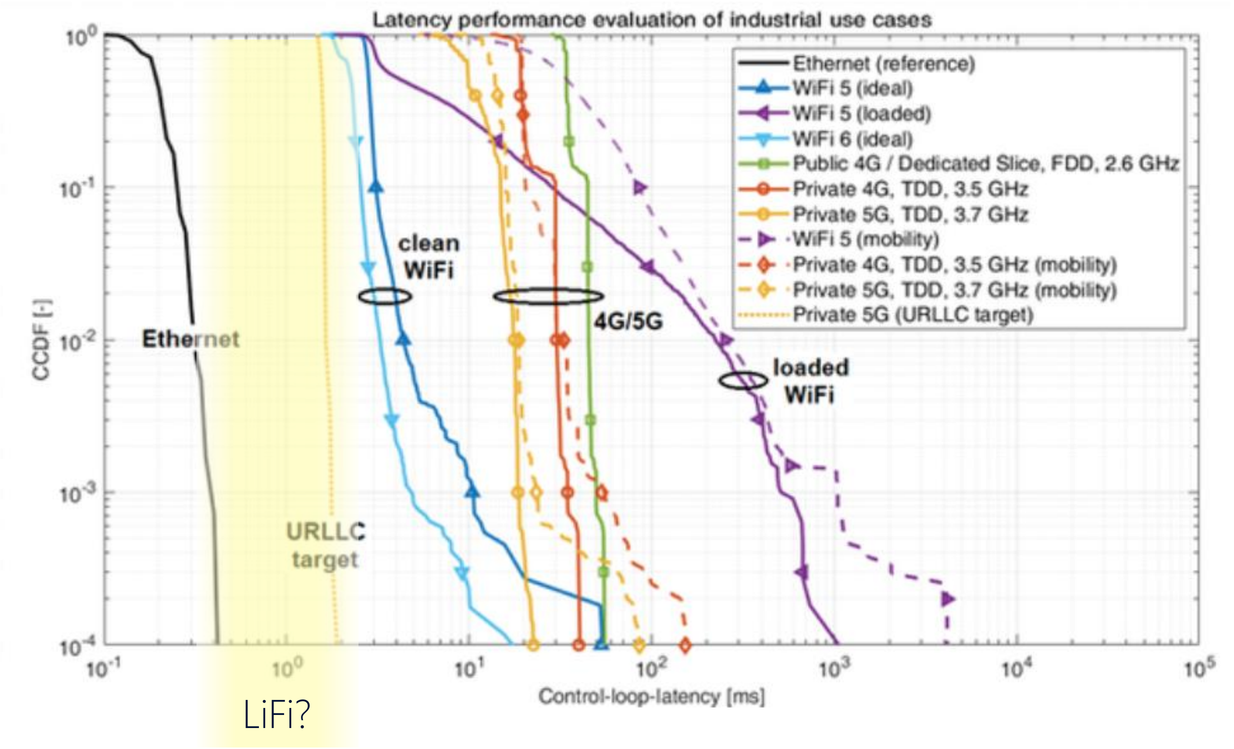
Outlook into 5G and beyond

3GPP 5G evolution



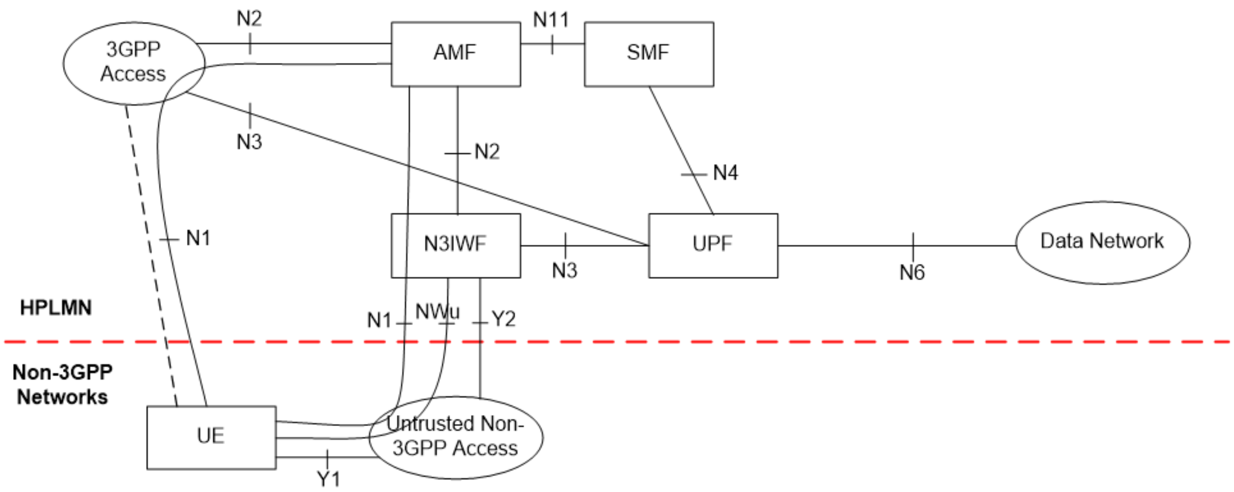
The gap between wired and wireless technologies

LiFi could fill the performance gap providing near wire-quality



LiFi integration following 3GPP WLAN integration model

Straightforward, but probably not really the desired solution



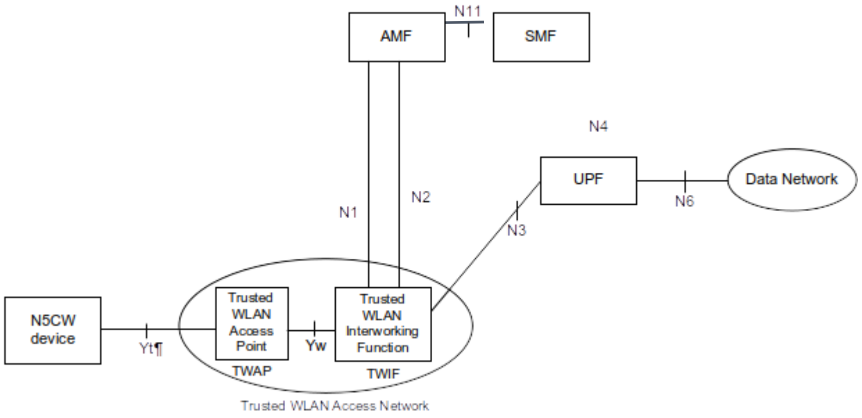
3GPP TS 23.501 Figure 4.2.8.2.1-1: Non-roaming architecture for 5G Core Network with untrusted non-3GPP access

- N3IWF gateway function propagates 5G data and control traffic through an IPsec tunnel (NWu) secured through IKEv2/EAP-AKA' between UE and 5G core.
- Fulfils security requirements, however adds complexity, delay, and hinders proper QoS handling.

3GPP could adopt LiFi as trusted non-3GPP technology

The 'better' integration model for LiFi

- The Trusted WLAN Interworking Function (TWIF) provides interworking functionality that enables N5CW devices to access 5GC.
  - "Non-5G-Capable over WLAN" (N5CW) devices are not capable to provide 5GC NAS signaling over a WLAN access network.



3GPP TS23.501 Figure 4.2.8.5.2-1: Non-roaming and LBO Roaming Architecture for supporting 5GC access from N5CW devices

- The TWIF supports the following functions:
  - Terminates the N1, N2 and N3 interfaces.
  - Implements the AMF selection procedure.
  - Implements the 3GPP NAS protocol stack for session and QoS control.
  - Adapts the native user plane (link layer) of WLAN to the N3 interface.
  - May implement a local mobility anchor within the trusted WLAN access network.

NOKIA

Going forward beyond 5G

Conclusions

- Several light communication standards are available or are becoming available soon
  - ITU-T G.9991 as extension to home networking for usual broadband applications
  - IEEE P802.15.7a for standardized solutions of Optical Camera Communications applications
  - IEEE P802.15.13 for vertical solutions demanding high-performance eMBB, mMTC, or URLLC communications
  - IEEE P802.11bb as light-communications amendment to address the huge mainstream Wi-Fi market
- None of the LC standards is really going beyond current radio interface capabilities
  - Current LC standards can only be the beginning of light communication applications, further standardization needed.
- Future light communication standards have to provide unique selling points beyond radio capabilities.
  - The next generation mobile communication system (6G) is expected to provide an order of magnitude better performance in each of the dimensions.
  - Overarching topics of the current decade are sustainability and privacy.

  Public NOKIA

Annex

Abstract

Keywords: IEEE, ITU-T, standard, specification, ratification, PHY, MAC, Wi-Fi, LiFi, VLC, OCC, OFDM, G.9960, G.9991, IEEE Std 802.15.7, P802.11bb, mobile terminal, short-range, IEEE 802.11, P802.15.13

Standards are an important prerequisite for mass deployment of communication technologies. As Light Communications is able to serve a wide variety of applications, a single standard is not sufficient to allow for high-performance cost-optimized solutions for all cases.
After a first light communications standard initiated in 2008 and ratified in 2011 through IEEE Std 802.15.7-2011, LC standardization further evolved to cover the various deployment domains. Parallel to past and ongoing enhancements of 802.15.7, IEEE P802.15.13 addresses high speed light communication needs with up to 10 Gb/s over distances of up to 200m unrestricted line. It leverages latest technologies like distributed MU-MIMO and offers different PHY modes for data rates of up to 2.2 Gb/s per stream.

To address the real mass market, IEEE 802.11 complements Wi-Fi with a LC interface through P802.11bb. The specification mostly leverages existing IEEE 802.11ax/Wi-Fi 6 capabilities to minimize efforts for LiFi chip implementations, an to facilitate easy adoption of LiFi to common applications through inheritance of the Wi-Fi system layer.
Aside of IEEE, the ITU-T SG15/Q18 amended its home networking standard G.hn with a light communication variant closely following the base specifications G.9960 to G.9964. The LC amendment G.9991 adopts basic architecture, the principal design of the OFDM-based PHY, the data-link layer, and the management interface from the base specifications and amended a second PHY mode based on Asymmetrically Clipped Optical OFDM that better adapts to the nature of light. Port based access control according to IEEE 802.1X, and enhanced mobility support were added to better support larger deployments.

Current light communication standards already fulfill many of the requirements covered through the 5th generation mobile communication system (5G) and can be leveraged with current 3GPP specifications to provide 5G services over light communication. However, further standardization is required to fully leverage the capabilities of light communications for use cases and requirements that are currently outside of the possibilities of wireless interfaces.

NOKIA