Standardization Status (LC, 5G & Beyond 5G)

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Brief introduction of myself

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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

Standardization Status (LC, 5G & Beyond 5G)

- 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

Early days of Light Communication standards

- IrDA – Infrared Data Association
  - Founded 1993 to establish interoperable solution for infrared light data networking
  - IrDA Data standard released in 1994 for two-way PTP communications over IR light at speed up to 4 Mb/s.
    - IrDA Data PHY (physical layer) for 9.6 kb/s to 4 Mb/s over distances of at least 1m
    - IrDA Data Infrared Link Access Protocol (IrLAP) serial link control protocol adopting basics of HDLC
    - IrDA Data Infra Link Management Protocol (IrLMP) for link control and multiplexing to allow multiple devices sharing a link
  - 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 (TG7) Visible Light Communication
  - TG established in Jan 2009 to create PHY and MAC standard for Visible Light Communications
  - Standard released as IEEE Std 802.15.7-2011, later revised to IEEE Std 802.15.7-2018
    - Non-directed P2MP transmissions using white light and multiple colors
    - Device classes: Infrastructure, mobile, vehicle
    - 3 PHYs: PHY1 w/ 11-266 kb/s using OOK and VPPM, PHY2 w/ 1.25-96 Mb/s using OOK and VPPM, and PHY3 w/ 12-96 Mb/s using Color Shift Keying (CSK) amended in revision with 3 additional PHYs addressing Optical Camera Communication (OCC)
  - Current amendment project P802.15.7a (TG7a) evolves further the OCC capabilities of IEEE Std 802.15.7
    - High-speed data communication aspects were transferred into IEEE 802.15.13 TG established for this purpose in 2017.

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

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

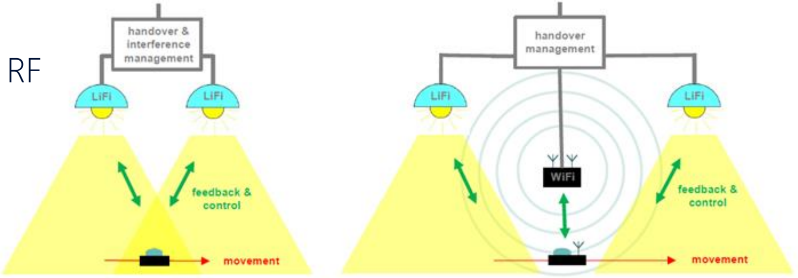
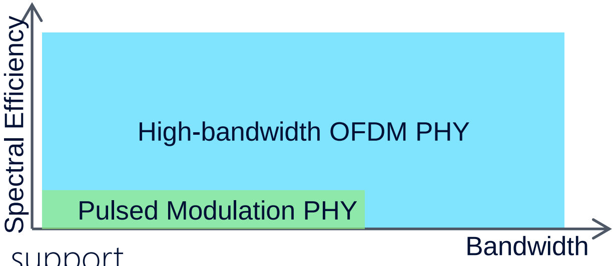


Fig src: https://mentor.ieee.org/802.15/dcn/18/15-18-0066-02-0013-slides-for-joint-workshop-with-itu-t-q18-sg15.ppt

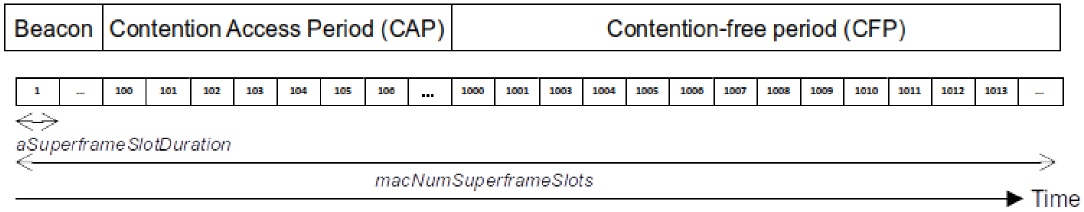
- Scope of Project Authorization Request (PAR) of P802.15.13
  - This standard defines a physical layer (PHY) and medium access control (MAC) sublayer using light wavelengths from 10,000 nm to 190 nm in optically transparent media for optical wireless communications.
  - The standard is capable of delivering 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

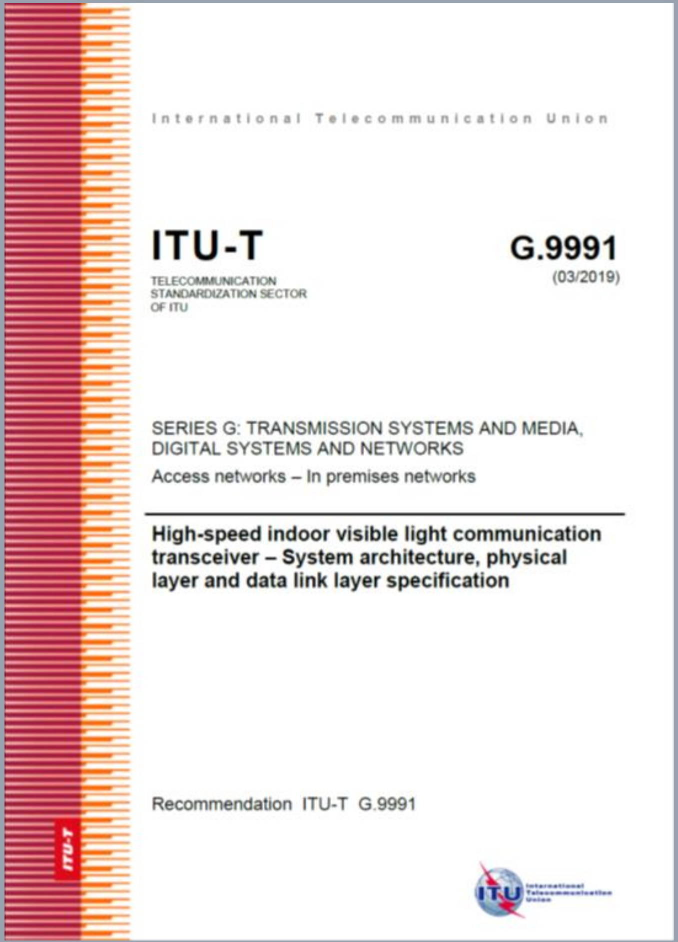
- High-bandwidth OFDM PHY (HB PHY)
  - High bandwidth (25…1.000 MHz), high spectral efficiency (10 bps/Hz): <10 Gbit/s
  - Derived from G.hn (2015) by scaling bandwidth up to 1 GHz

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

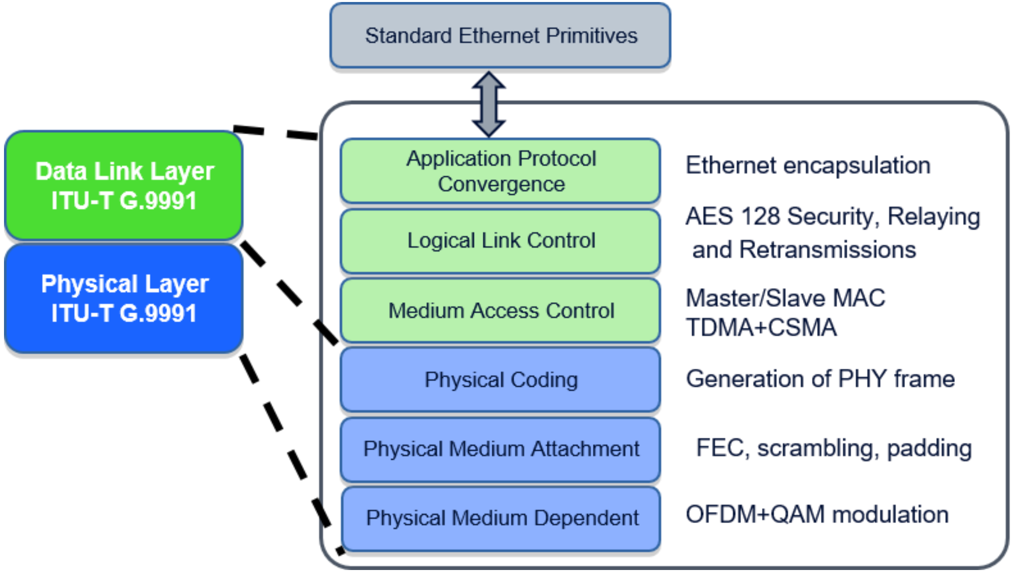
Access networks – In premises networks

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

Recommendation ITU-T G.9991

ITU-T

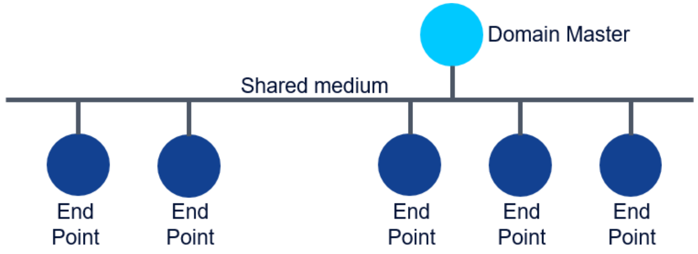
ITU-T G.9991 (‘G.vlc’)



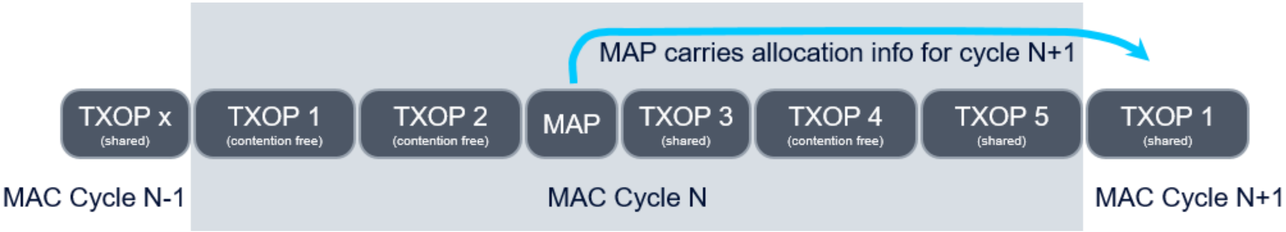
- Based largely on G.9960/61 (aka G.hn)
- Objective: Leverage the highly flexible OFDM engine provided by G.hn
  - Part of ITU-T G.999x series (optical transmission)
    - LC = VLC + IR
- Developed by ITU-T SG 15 (Q18/15 In-premises networking)
  - Started 2H2015, first approval 2019-04-01
  - Revised through 2 amendments and a corrigendum
  - Latest release: April 2021
- 2 PHYs on common MAC
  - PHY 1: G.9960 (DCO-OFDM)
    - Performance oriented, up to 2 Gbps
  - PHY 2: 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.

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™/D1.0 November 2021
(amendment to IEEE P802.11-2020,
IEEE 802.11ax™
IEEE P802.11ay™
IEEE P802.11az™
IEEE P802.11ba™
IEEE P802.11bc™/D2.0
IEEE P802.11bd™/D2.1)

P802.11bb™/D1.0
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

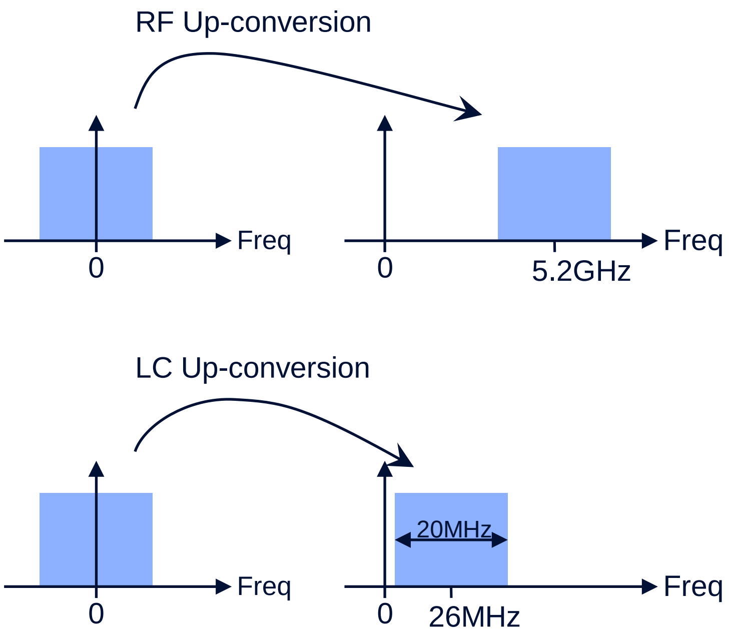
Prepared by 802.11 Working Group of

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

P802.11bb Intentions

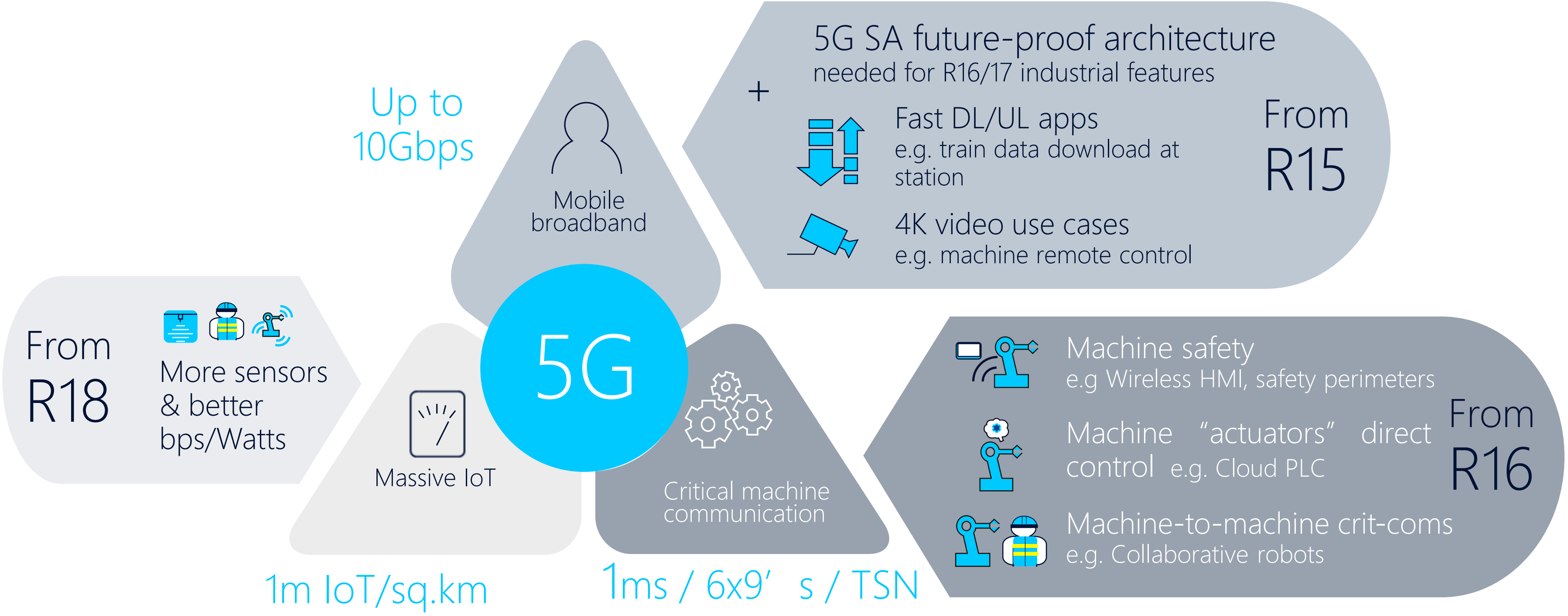
Provide LiFi interface with the least modification effort to available radio solutions

- 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.
- P802.11bb exactly follows that approach
  - Simple amendment to 802.11n, 802.11ac, and 802.11ax for light communications
  - Same bitrates, same system interfaces
  - Slight modifications to MAC for Clear Channel Assessment.



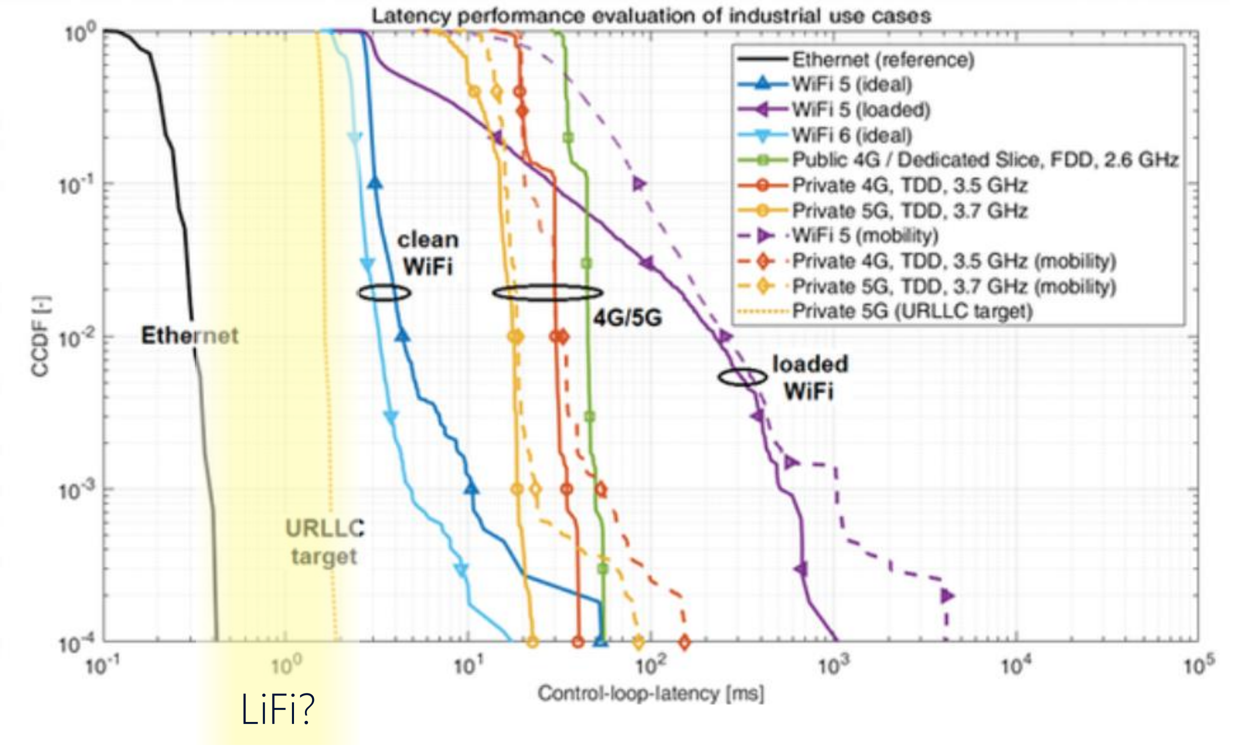
Outlook into 5G and beyond

3GPP 5G evolution



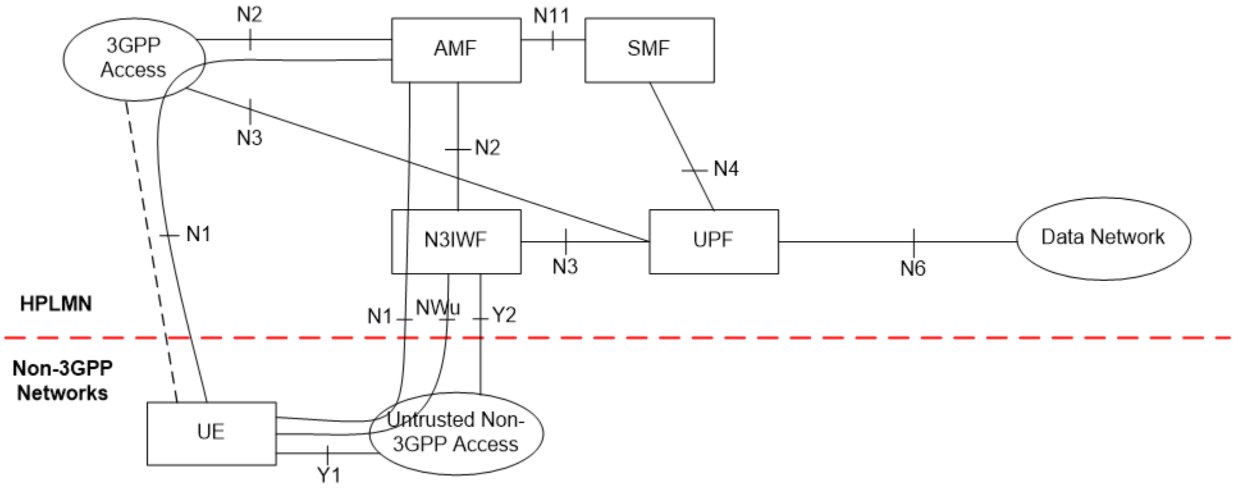
The gap between wired and wireless technologies

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



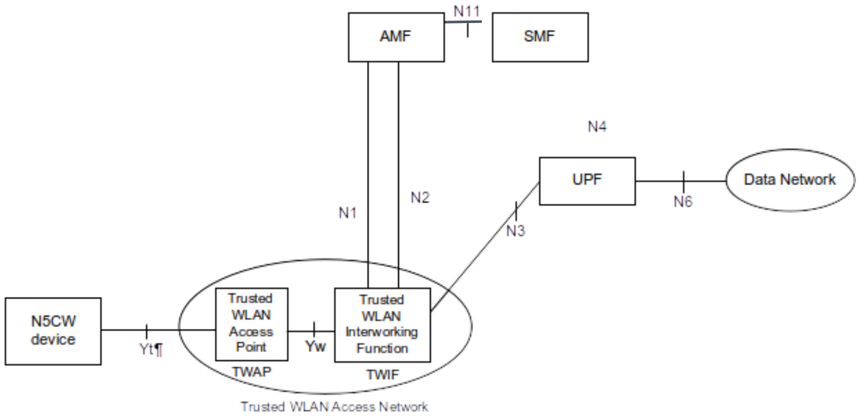
3GPP TS 23.501 Figure 4.2.8.2.1-1: Non-roaming architecture for 5G Core Network with untrusted non-3GPP access

- 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.

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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 non-radio amendment for the huge 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
- 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.

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 span a wide variety of applications, a single standard is not able to serve all potential applications enabling high-performance cost-optimized solutions.

A first light communications standard specifying short-range visible light communications (VLC) was initiated in 2008 and ratified in 2011 through IEEE Std 802.15.7-2011. The standard provides three different PHY modes with a common MAC to deliver data rates sufficient to support audio and video multimedia services. It considers mobility of the VLC link, impairments due to noise and interference from sources like ambient light. The specification was later revised to IEEE Std 802.15.7-2018 broadening its applicability to wave lengths in the range 190 nm to 10 000 nm, and adding further 3 PHY modes to fully incorporate Optical Camera Communication (OCC) solutions. Currently, an amendment to 802.15.7 is in development further evolving the specification regarding OCC to address more use cases in particular in the domain of Vehicle-to-everything (V2X) communications, and for various deployments in industrial automation.

Parallel to the past and ongoing enhancements to 802.15.7, IEEE initiated P802.15.13 to address 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 three different PHY modes for data rates of up to 2.2 Gb/s per stream. Ratification is expected for 2022.

The IEEE 802.11 working group, the home of Wi-Fi, initiated also efforts to complement Wi-Fi with a LC interface. The project P802.11bb is aimed for the high volume mass market to facilitate the extension of common Wi-Fi deployments with LiFi, when radio communication is not possible or is impacted through exhaustion of the radio spectrum. It vastly leverages the IEEE 802.11ax capabilities and minimizes additional functions to the essential pieces to enable very cost-effective chip implementations for the transmission of the base band signal over light instead of a high frequency radio channel. Completion of the amendment is expected for end of 2022.

Aside of IEEE, other global standardization organizations are active in light communications as well. The ITU-T Study Group 15 Question 18 started in 2015 an effort to create a light communication variant of its home networking standard G.hn. G.9991, as the LC standard is denoted, adopts basic architecture, the principal design of the OFDM-based PHY, the DL functions, and the management interface from the G.hn base specifications G.9960 to G.9964. The G.9991 specification, initially released in 2019, incorporates a second PHY mode based on Asymmetrically Clipped Optical OFDM that better adapts to the nature of light. Later amendments released in 2020 and 2021 added port based access control according to IEEE 802.1X, and enhanced mobility support to address the needs of mobile terminals in larger deployments.

Current light communication standards already fulfill many of the requirements covered in the 5th generation mobile communication system (5G) and can be leveraged to provide 5G services over light communication. However, further standards developments can be expected to better leverage the capabilities of light communications addressing use cases and requirements that are currently outside of the possibilities of wireless interfaces.

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