IITP RAS

Wireless Networks Lab

KHARKEVICH INSTITUTE FOR INFORMATION TRANSMISSION PROBLEMS
OF THE RUSSIAN ACADEMY OF SCIENCES

# Current Status and Challenges of Li-Fi — IEEE 802.11bb


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# Wireless Networks Lab

Kharkevich Institute for Information Transmission Problems
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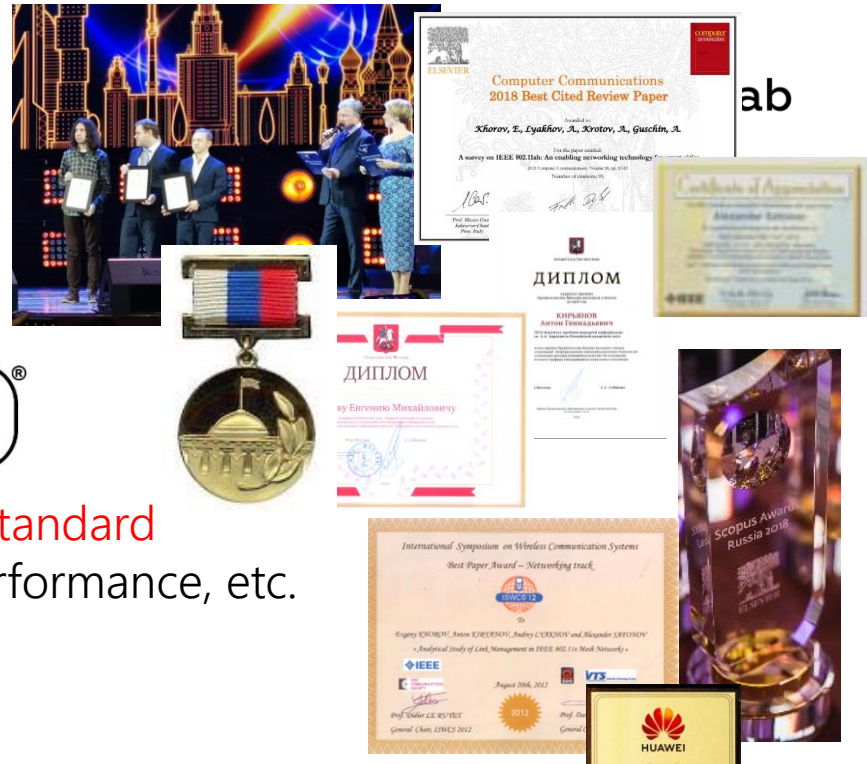
https://wireless.iitp.ru/

# Main Directions

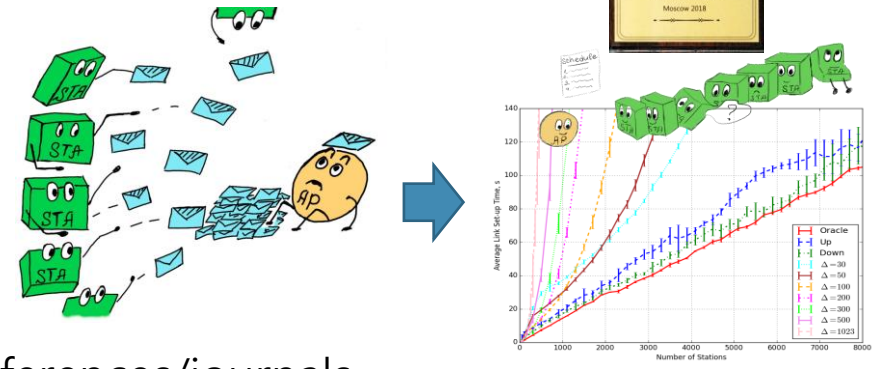
Technological Consulting, Research & Development in Wireless Networks




World-known experts in Wi-Fi
Membership in IEEE 802.11, dozens of contributions to the standard
Numerous mathematical models, algorithms to improve performance, etc.

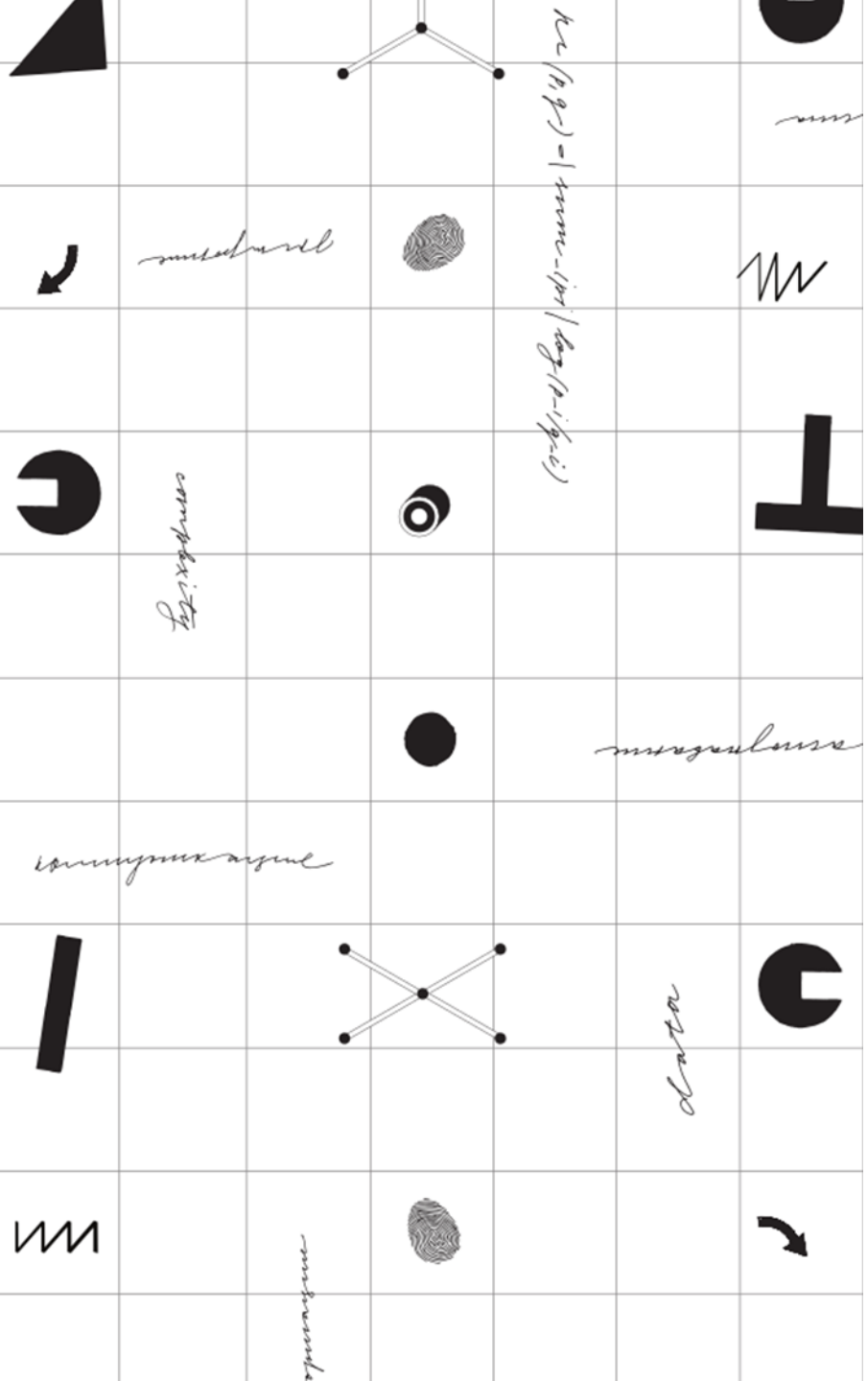
Resource allocation & Cross-layer optimization
xStream, ARBAT, MUST and other solutions for manifold gains in QoE for 5G systems

Numerous algorithms to master chaos in Wireless IoT networks
Modifications for the LoRaWAN standard




Multiple keynotes/tutorials @top conferences, Best paper awards @ top conferences/journals

Members of various expert boards



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# Wi-Fi Evolution

# IP Traffic by Access Technology

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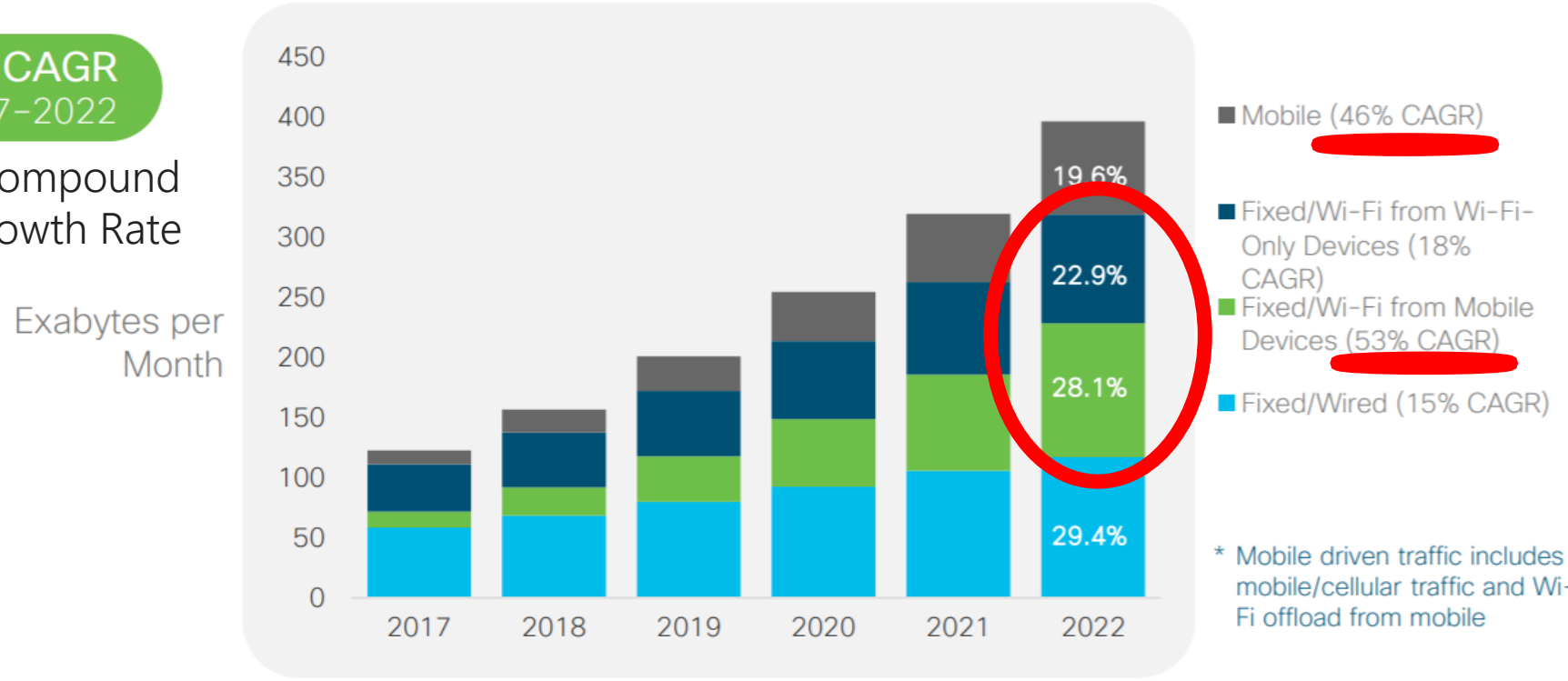
## Global IP Traffic by Local Access Technology

Half of traffic is generated by Wi-Fi devices

**26% CAGR**
2017–2022

CAGR = Compound Annual Growth Rate




Source: Cisco VNI Global Mobile Data Traffic Forecast, 2017–2022



https://www.cisco.com/c/dam/m/en_us/network-intelligence/service-provider/digital-transformation/knowledge-network-webinars/pdfs/190320-mobility-ckn.pdf

# Evolution of Wi-Fi

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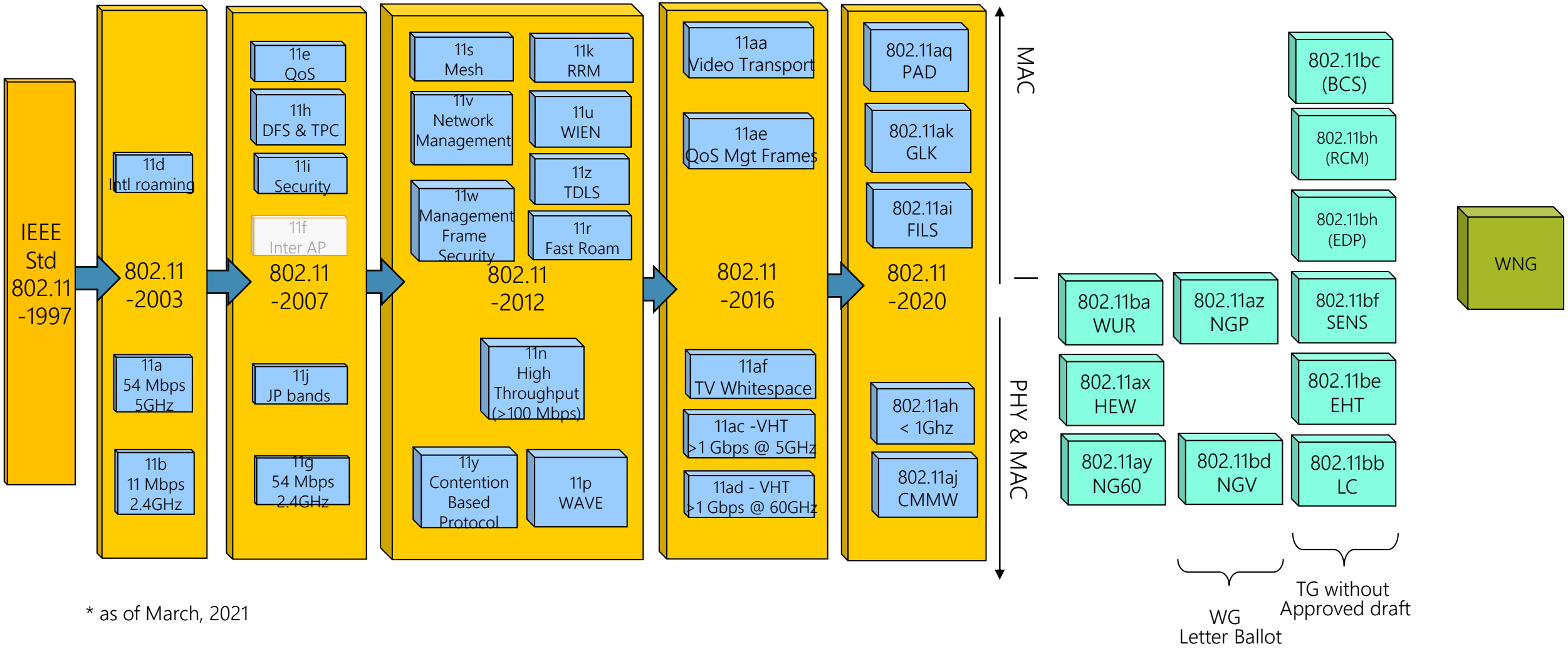
The work has started in September 1990



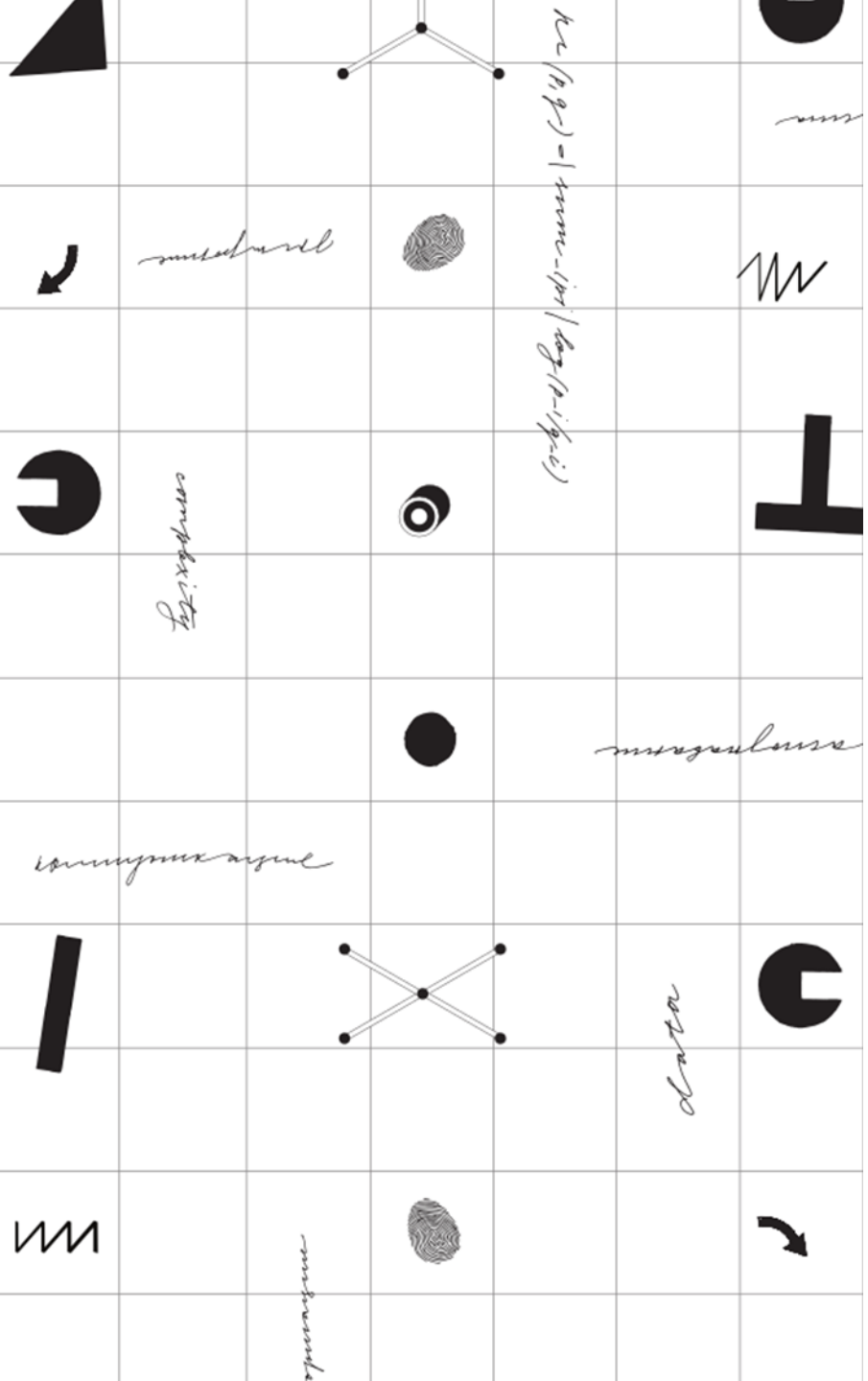

* as of March, 2021

# History of Wi-Fi Rates


| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Data rate, bps | 2M | 54M<br>11M | 54M | 600M | ~8000M | ~7000M | 346M | ~10G | >250G | >>40G | 1.2G per user Stream |
| Freq. band, GHz | 2.4 | 5<br>2.4 | 2.4 | 2.4/5 | 60 | 5 | <1 | 2.4/5/6 | 60 | 2.4/5/6 | Light |
| Max channel Bandwidth, MHz | 22 | 20<br>22 | 20 | 40 | 2160 | 160 | 16 | 160 | 8640 | 320<br>Many links | As in 11n, 11ac,11ax |
| MIMO | - | - | | 4x4 (th) | | 8x8<br>DL-MU | 4x4 | 8x8<br>DL/UL MU | 8x8 | 16x16<br>OFDMA | ? |


E. Khorov, A. Kiryanov, A. Lyakhov and G. Bianchi, "A Tutorial on IEEE 802.11ax High Efficiency WLANs," in *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 197-216, Firstquarter 2019

E. Khorov, I. Levitsky and I. F. Akyildiz, "Current Status and Directions of IEEE 802.11be, the Future Wi-Fi 7," in IEEE Access, vol. 8, pp. 88664-88688, 2020.



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# Li-Fi aka IEEE 802.11bb*

*E. Khorov, I. Levitsky. Current Status and Challenges of Li-Fi - IEEE 802.11bb. IEEE Communications Standards Magazine, 2022*

**Acknowledgement to Ilya Levitsky for these slides*

# What is Li-Fi?

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- Coined by Harald Haas
- A wireless communication technology which utilizes **light to transmit data** between devices.
- Devices use LEDs to communicate

https://habr.com/en/post/435262/

# Why Li-Fi?

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- About 500-700THz of license-free spectrum
  - Allows transmission rates up to 100 Gbit/s.
- A now-common worldwide LED lighting infrastructure can be reused
- More energy-efficient
- Light does not cause EMI
- Light communication is containable, hence more secure

# What is IEEE 802.11bb?

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- A modern standard defines one medium access control (MAC) and several physical layer (PHY) to support light communications (LC)
- A “member” of the Wi-Fi standards family

- Goals
  - Bring LC technology in WLANs
  - Satisfy modern requirements (10Mbps - 1.2 Gbps per stream)
  - Allow for mass deployment
  - Support RF-complementing.

- Currently under development

# IEEE 802.11bb Timeline

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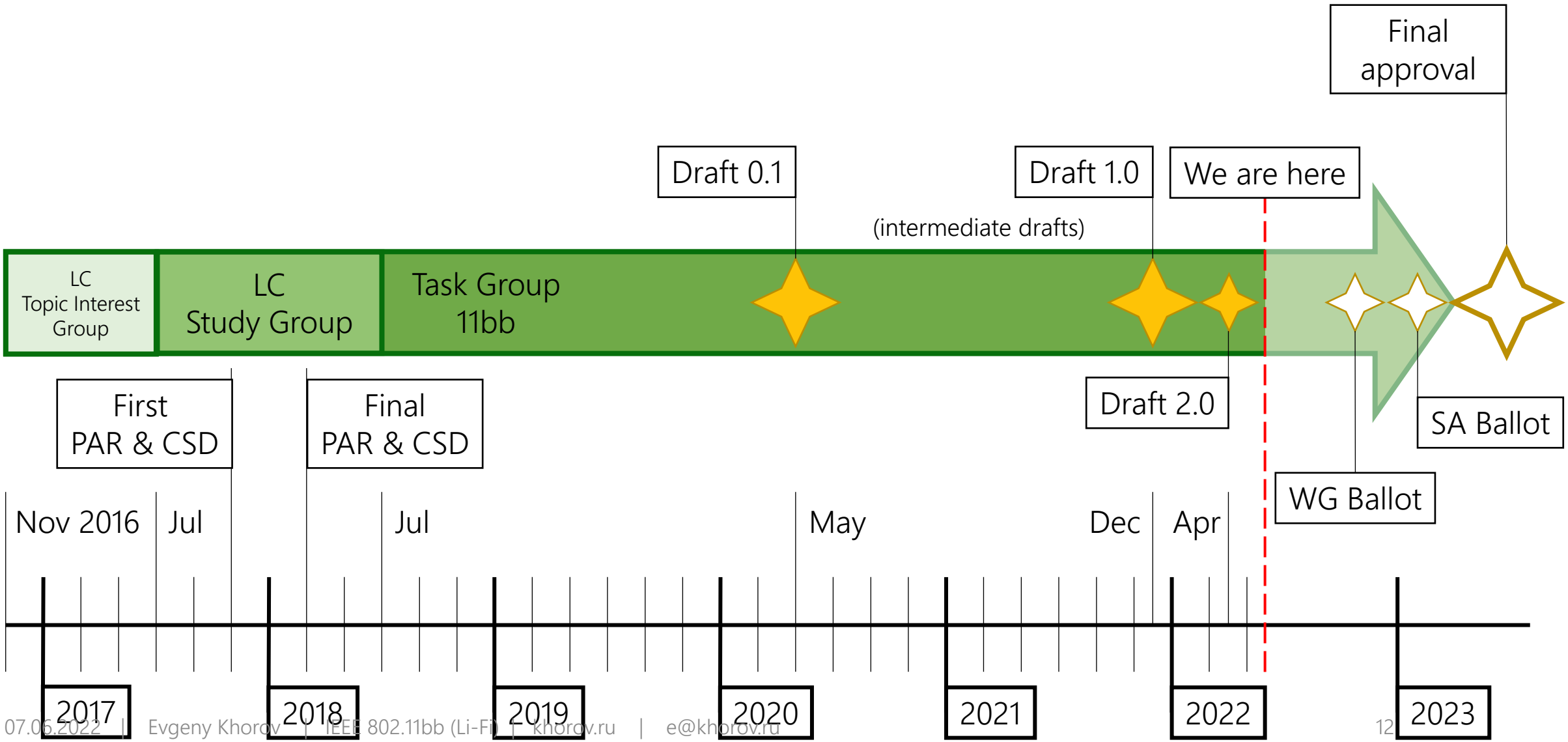

# Waveform

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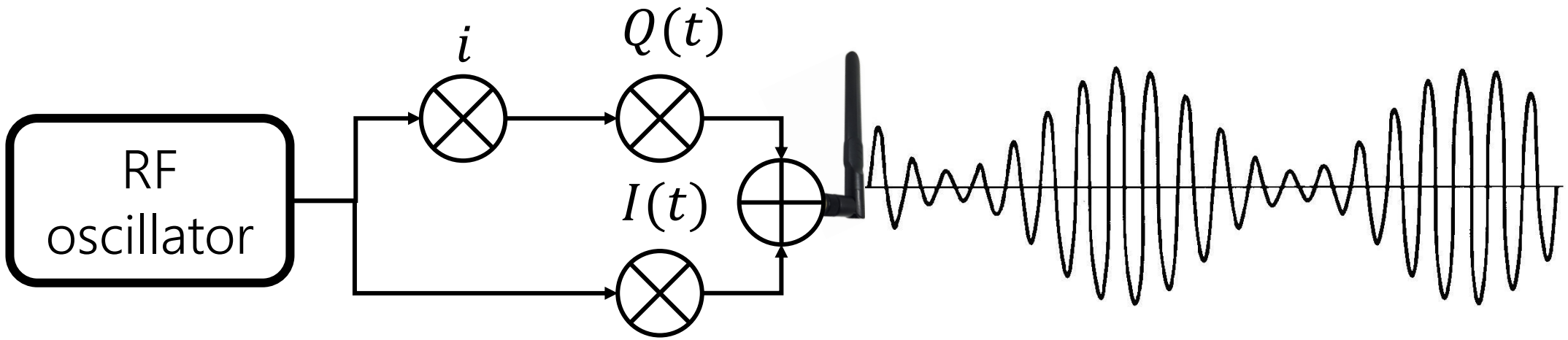
RF – a bipolar complex signal modulates a carrier, produced by an oscillator




LC – a monopolar real signal modulates intensity of light, produced by LED

# DCO-OFDM: LC upconversion

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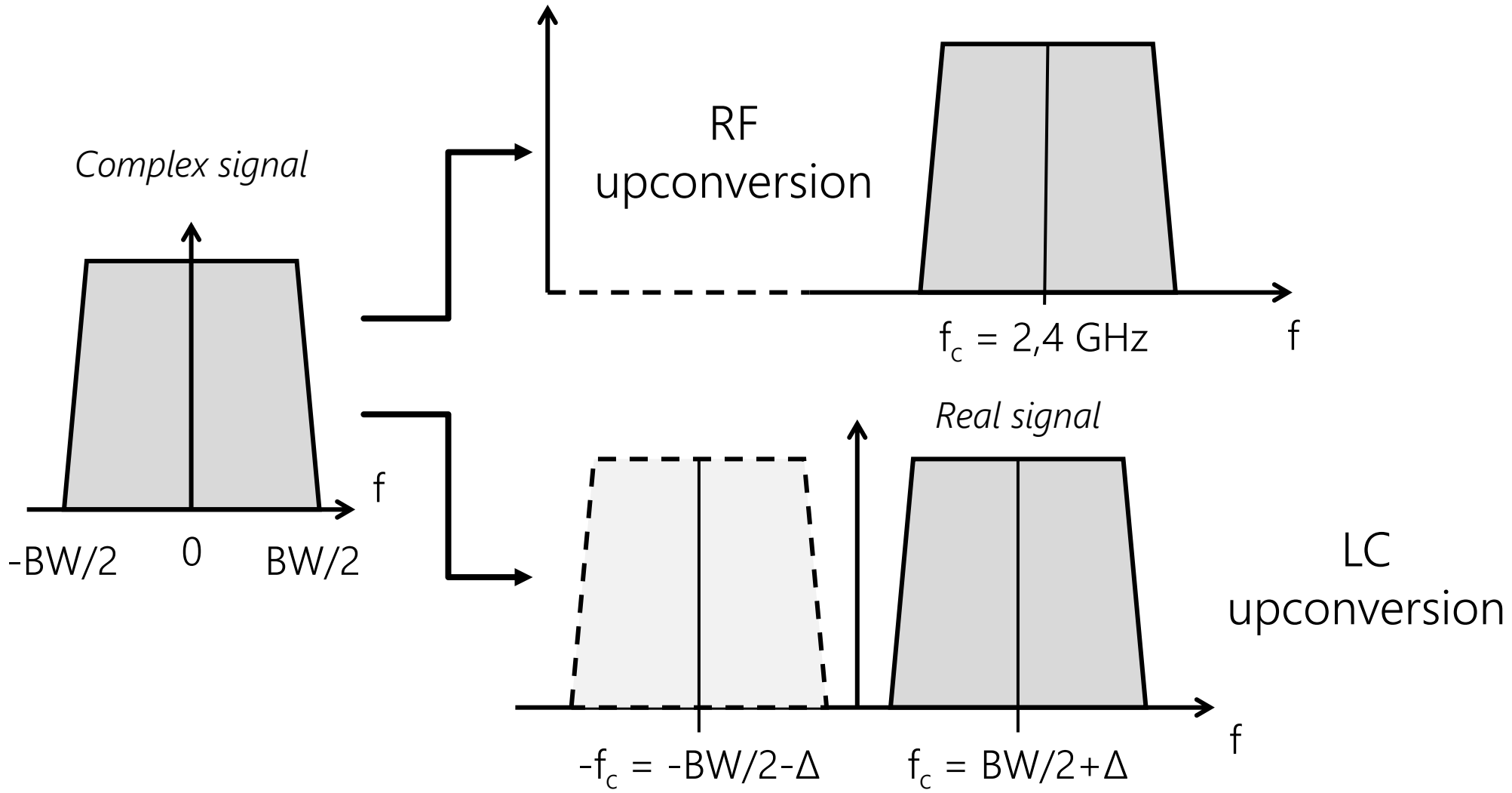
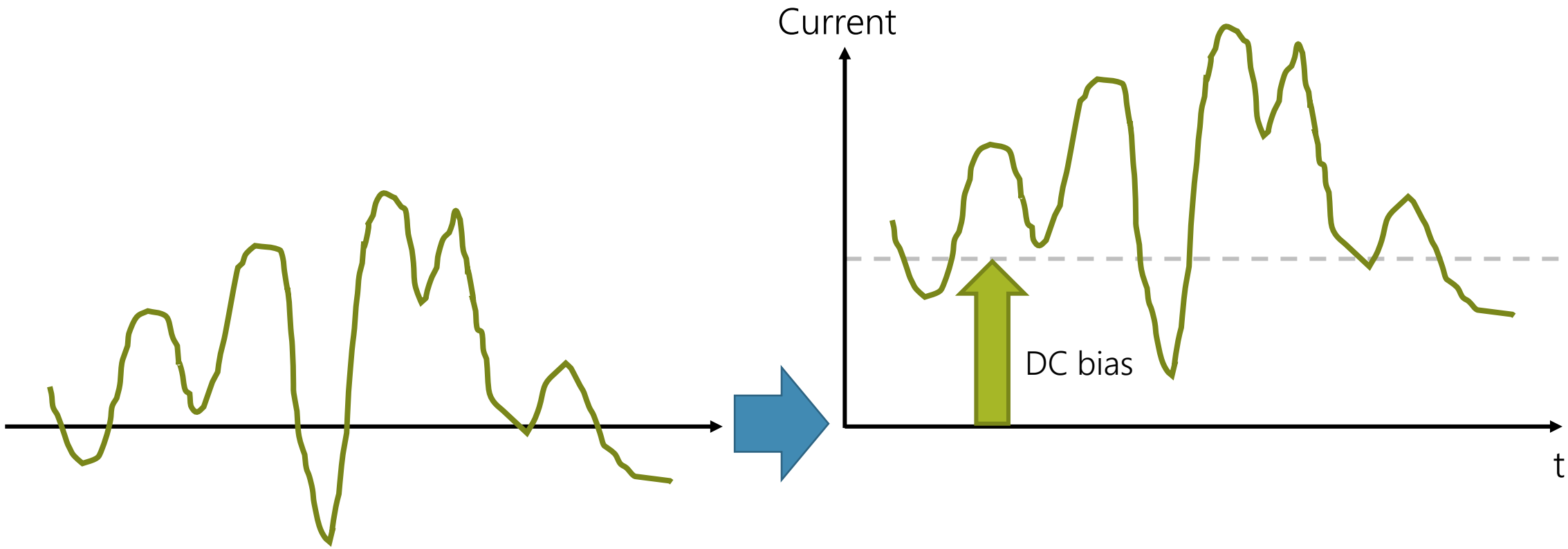


# DCO-OFDM: DC bias



# LC frontends

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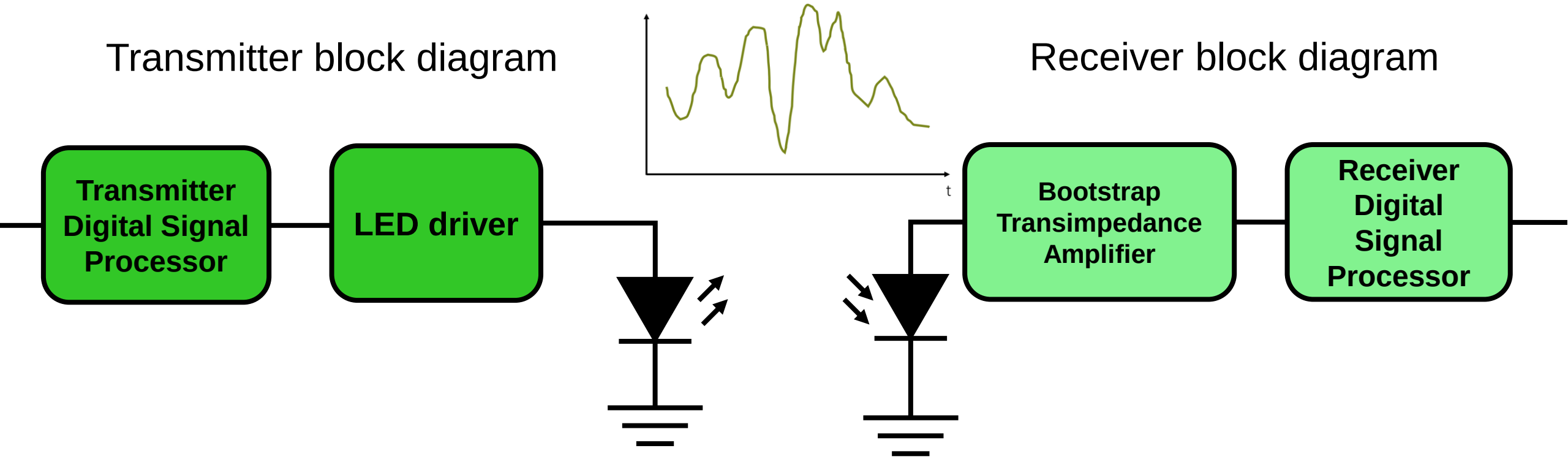
Transmitter block diagram

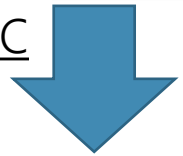



Receiver block diagram

# LC PHYs – the two ways


Quick and easy

- ~~LC Common-Mode (CM) PHY~~
  - ~~Based on 802.11a OFDM PHY~~
- LC High Throughput (HT) PHY
  - Based on 802.11n HT PHY
- LC Very High Throughput (VHT) PHY
  - Based on 802.11ac VHT PHY
- LC High Efficiency (HE) PHY
  - Based on 802.11ax HE PHY



Optimized for LC

- LC-optimized (LCO) PHY
  - Based on ITU-T G.9991 (G.vlc)
- Other PHYs included

# LCO in short

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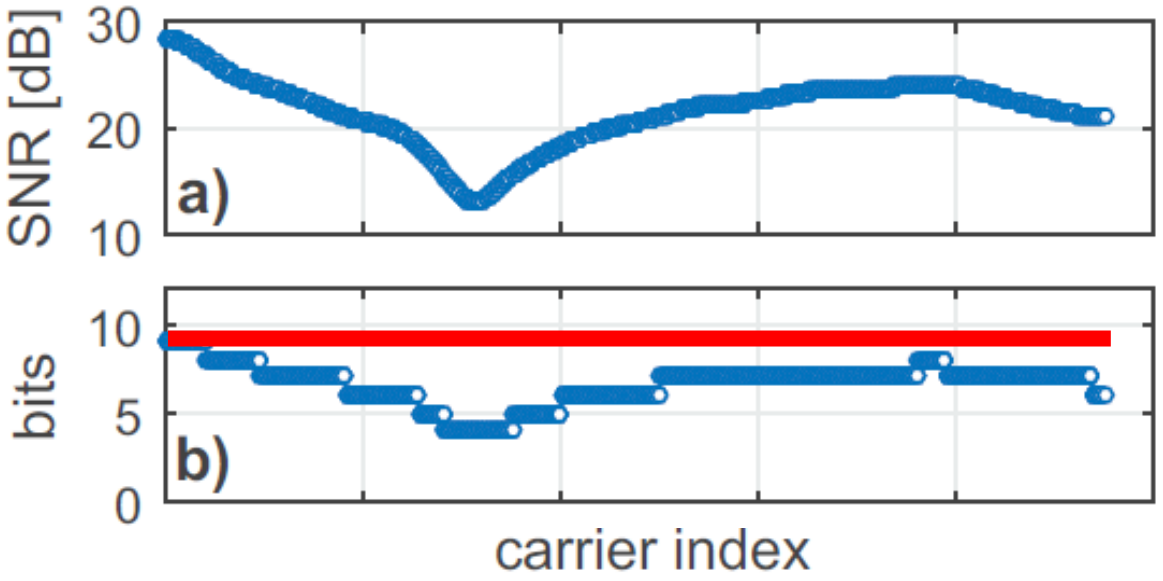
The main idea is adaptive bitloading

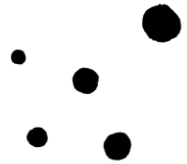



Bit interleaving

Adaptive bitloading

P. W. Berenguer, V. Jungnickel, and J. K. Fischer, “The benefit of frequency-selective rate adaptation for optical wireless communications,” in 2016 10th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP). IEEE, 2016, pp. 1–6.

# Problems of LCO in 11bb



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- Different numerology of legacy 802.11 and the reference ITU-T G.9991
  - Leads to coexistence issue
- Increased encoding and modulation complexity
- A set of dedicated MAC features is required

Lesson: Not all optimized solutions come to the spec.

# LC PHYs

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| | LC HT PHY | LC VHT PHY | HE PHY |
|---|---|---|---|
| Base PHY | IEEE 802.11n HT PHY | IEEE 802.11ac VHT PHY | IEEE 802.11ax HE PHY |
| Bandwidth | 40 MHz | 20, 40, 80, 160, 80+80 MHz | 20, 40, 80, 160, 80+80 MHz |
| Modulation | BPSK, QPSK, 16-QAM, 64-QAM | BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM | BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM |
| Coding | BCC: 1/2, 2/3, 3/4, 5/6 | BCC and LDPC: 1/2, 2/3, 3/4, 5/6 | BCC and LDPC: 1/2, 2/3, 3/4, 5/6 |
| Features | Max rate: 150 Mbps per 1 stream | Max rate: 866.7 Mbps per 1 stream | **Max rate: 1.2 Gbps per 1 stream, OFDMA** |

# Multiple TX & RX chains

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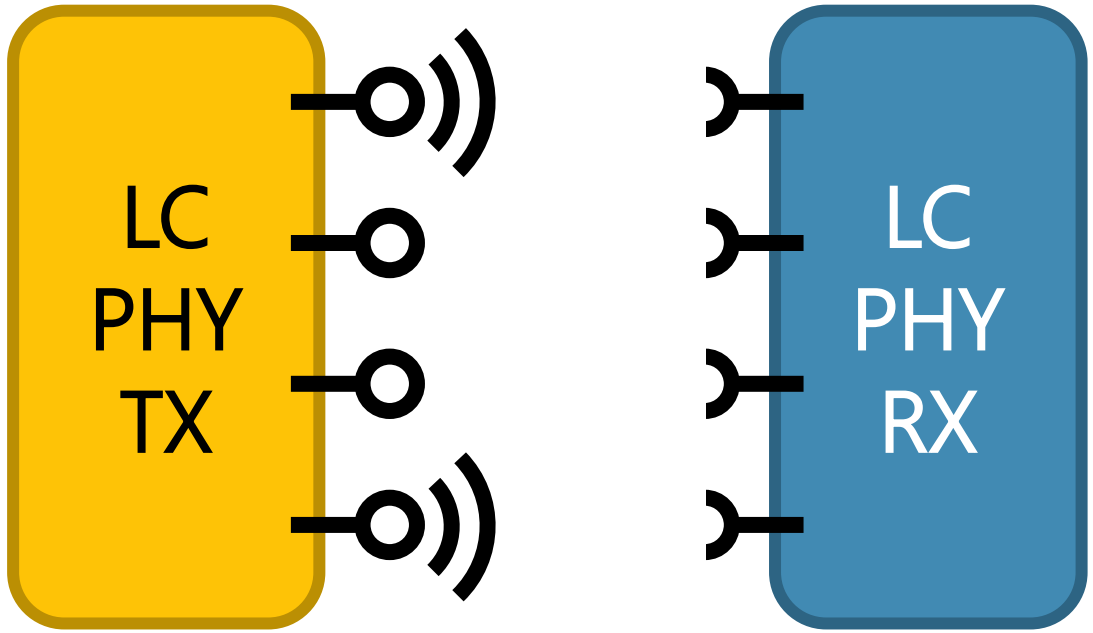
802.11bb allows using many RF frontends on the same STA.

Draft 2.0 does not specify mechanisms to use multiple chains

Different chains may transmit spatially multiplexed signals or use different directions / polarization / color…



# LC MAC features: LC repetition*

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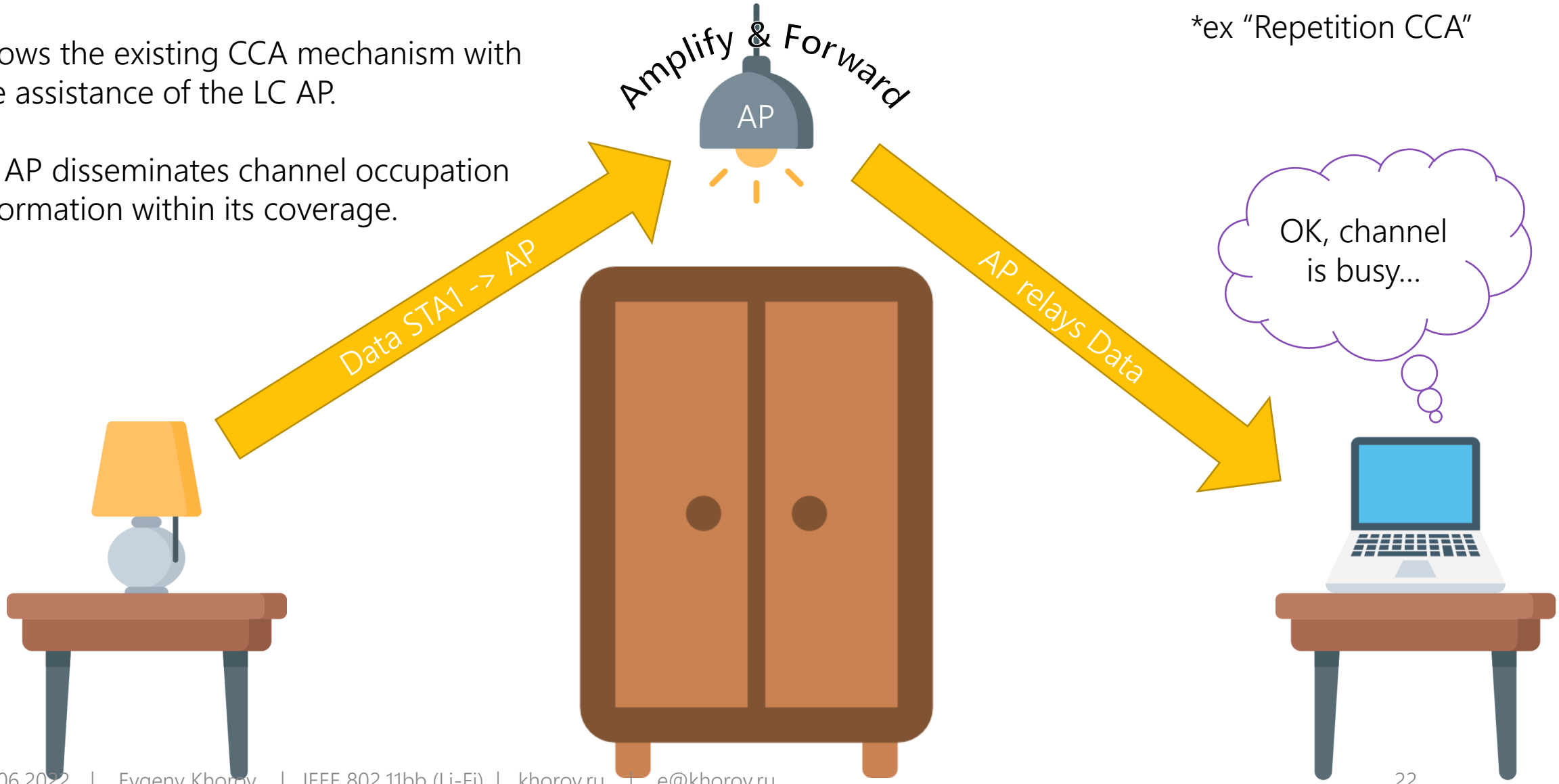
*ex “Repetition CCA”

Allows the existing CCA mechanism with the assistance of the LC AP.

LC AP disseminates channel occupation information within its coverage.



# LC MAC: Fast Session Transfer

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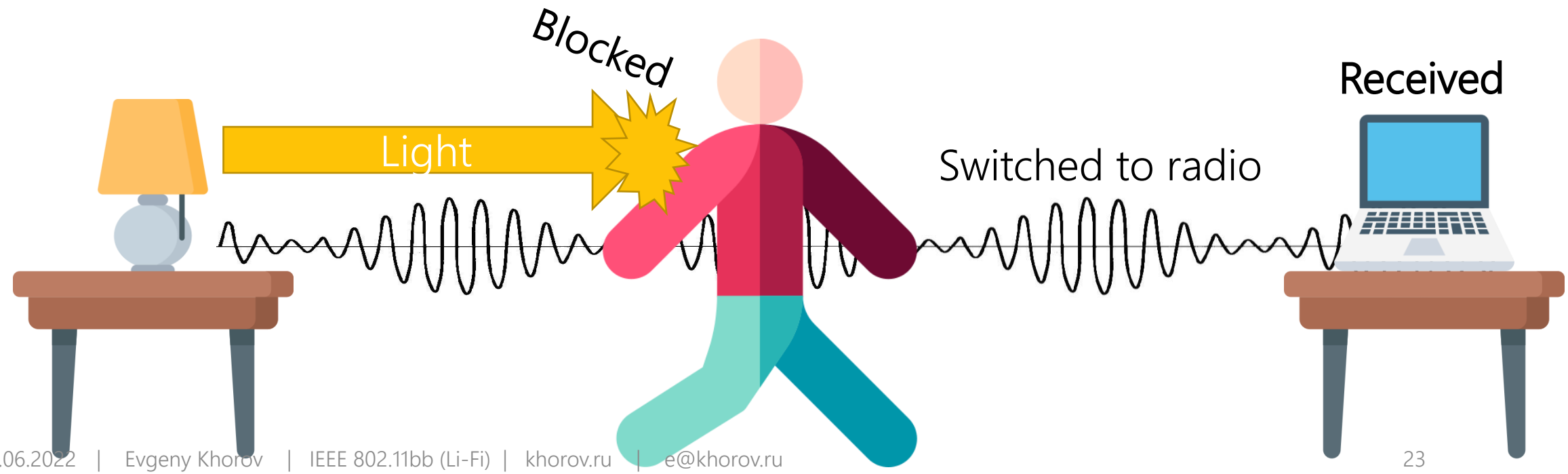
Simultaneous or separate communications using RF and LC is supported in multi-band capable devices.

One way is to use Fast Session Transfer (FST), which is used in 11ad and 11ay (60 GHz operation).



# Open problems [0]

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- LCO PHY
  - Requires new MAC supporting LCO (e.g. sounding protocols)
  - Requires new algorithms to control transmission parameters
- MIMO / beamforming in LC [1,2]
  - Ways to design TX/RX chain array on real devices
  - Types of precoding and equalizing
  - Design for channel state feedback
- Allow Full Duplex [3]
- Introduce multi-link support as in 802.11be [4]


[0] *E. Khorov, I. Levitsky. Current Status and Challenges of Li-Fi - IEEE 802.11bb. IEEE Communications Standards Magazine, 2022*
[1] A. Purwita et al., "Overview on MU-MIMO for LC," April 2020, IEEE Mentor 11-20/0582r1
[2] C. Sun et al. "Beam Domain Massive MIMO for Optical Wireless Communications With Transmit Lens," in IEEE Transactions on Communications, vol. 67, no. 3, pp. 2188-2202, March 2019
[3] "Full-Duplex based MAC enhancements," May 2018; IEEE Mentor 11-18/0864r0
[4] E. Khorov, I. Levitsky and I. F. Akyildiz, "Current Status and Directions of IEEE 802.11be, the Future Wi-Fi 7," in IEEE Access, vol. 8, pp. 88664-88688, 2020.


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