WLAN - 1997 bis heute

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Agenda

1. Why to talk about 802.11?
2. Process of Standardization
3. General Regulations
4. Milestones of 802.11
5. Outlook

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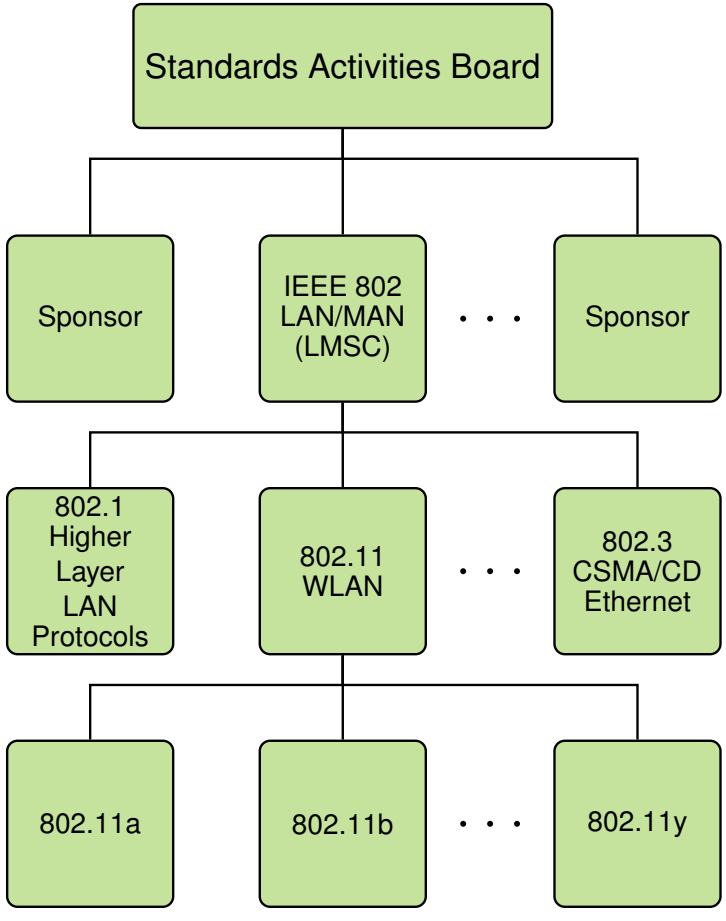
Motivation

What is IEEE 802.11?

- IEEE: Institute of Electrical and Electronics Engineers
  - Conferences
  - Journals
  - **Standards Committees**
    - Protocols
    - Interfaces
    - Methods
    - ...
- 802.11 Standardization Group
  - ≈ 500 Participants
  - ≈ 300 Voting Members
  - Meetings every 2 months (alternating „Plenary/Interim“)



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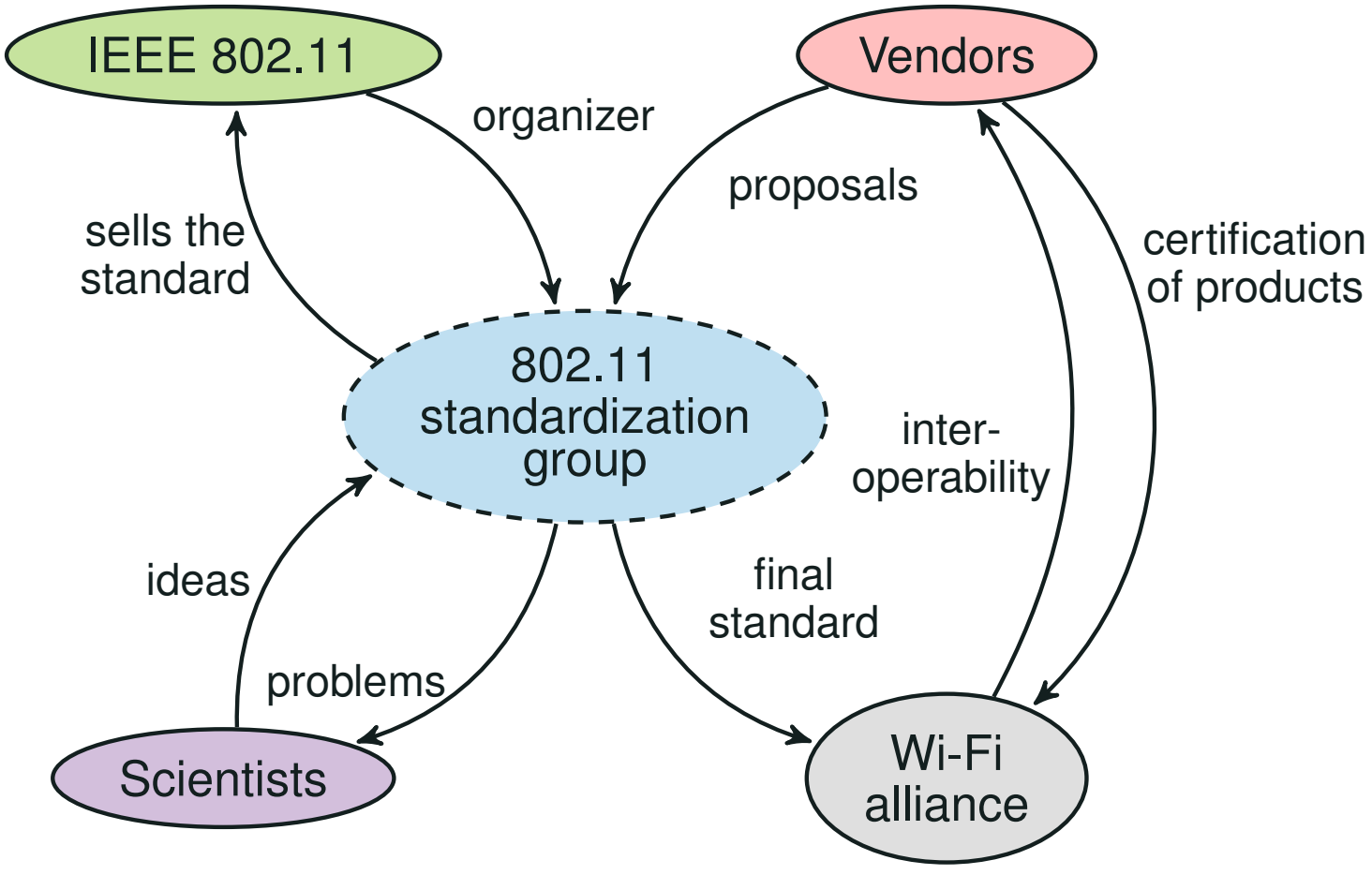
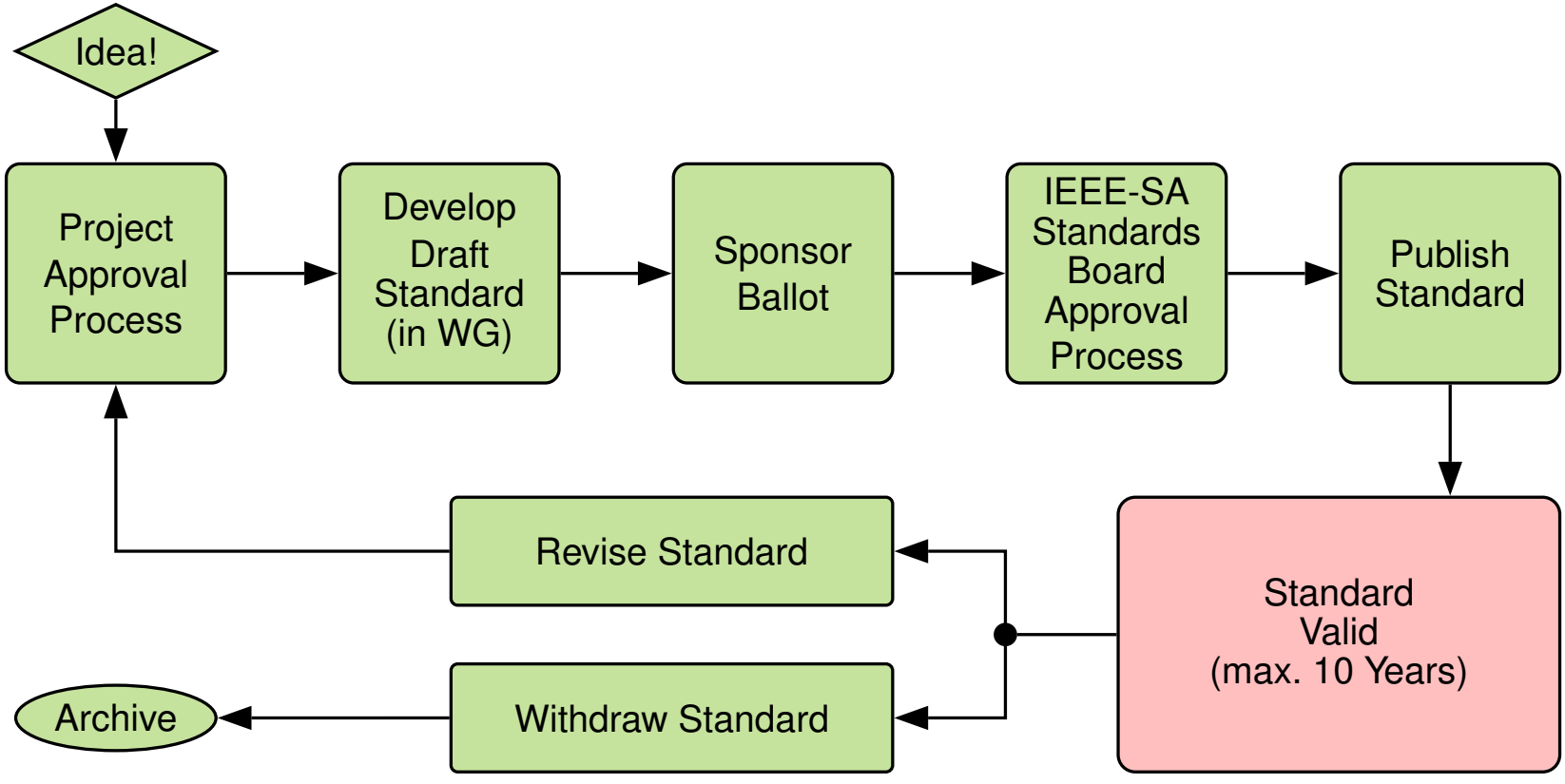
Actors and relations



How Standards are Made



Source: [standards.ieee.org, 2015]

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What happened before?

1971 ALOHAnet [Kuo, 1981]

- 9600 bit/s
- 400 MHz

1985 Release of the ISM-Bands (433 MHz, 900 MHz, 2.4 GHz, 5.7 GHz, 61 GHz)

1988 WaveLAN by NCR (later AT&T)

- alternative to Ethernet and Token Ring
- specified for ISM-Bands (900 MHz or 2.4 GHz)
- DSSS/DQPSK, 2 Mbit/s

→ Contributed its designs to IEEE 802.11

1990 first meeting of the 802.11 study group

1996 HIPERLAN by European Telecommunication Standards Institute (ETSI)

1998 Magic WAND project demonstrates OFDM modems for wireless LAN

Relevant ISM-Bands (unlicenced)

Band	$f_{\min}$	$f_{\max}$	Bandwidth
900 MHz	(755 MHz)	(928 MHz)	5 MHz to 32 MHz
2.4G	2.4 GHz	2.5 GHz	100 MHz
5G	5.15 GHz	5.725 GHz	$\approx$ 600 MHz
60G	57.24 GHz	65.88 GHz	$\approx$ 8640 MHz

- Channel width, EIRP, maximum Power Spectral Density, ...
- one of the limiting factors
  (from engineering point of view)
- not static
- defined by BNA (Germany), OFCOM (United Kingdom), FCC (United States)
  $\rightarrow$ location specific

Scope & Purpose

Scope

- specify MAC and PHY
- wireless connectivity
- local area (residence, school, laboratory, . . .)
- fixed, portable and moving stations

Compared to cellular

- simple (no handover, base station protocols, . . .)
- cheap
- no telcos $\rightarrow$ business model benefits vendors

- both systems are getting closer

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1st Milestone 802.11-1997

- Physical Interface
  - Radio at 2.4 GHz
    - FHSS $\rightarrow$ DBPSK and DQPSK
    - DSSS $\rightarrow$ 2GFSK and 4GFSK
  - Infrared
- 1 Mbit/s and 2 Mbit/s
- 5 MHz-Channels
  - 5 channel spacing (25 MHz) for non interference
  - 11 MHz sampling and 22 MHz spreading
- released in 1997 after 7 Years of standardization
- simple and cheap

802.11
2.4 GHz
2 Mbit/s

2nd Milestone 802.11b (1999)

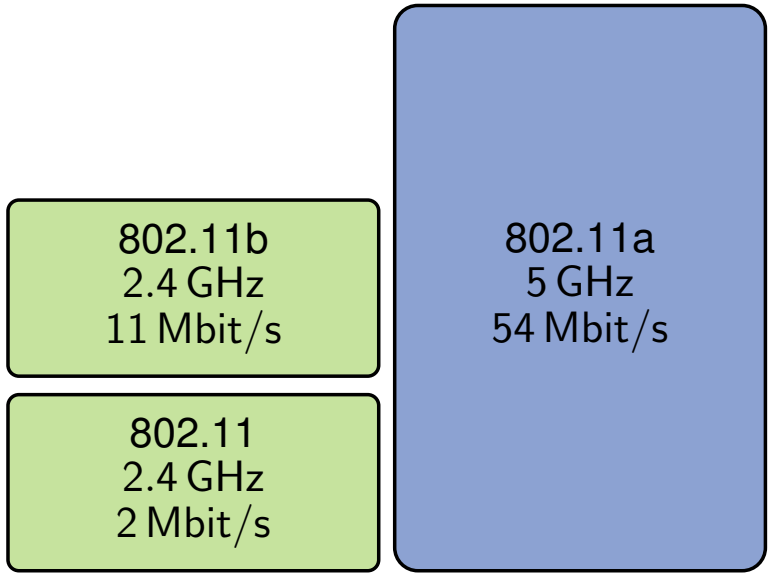
- Physical Interface
  - Radio at 2.4 GHz (same as 802.11)
- new MCS (High Access Rate)
  - using CCK (complementary code keying)
  - 5.5 Mbit/s
  - 11 Mbit/s
- Coding
  - scrambling
  - convolutional code (optional)
- 5 MHz-Channels (same as 802.11)
- OFDM not allowed in 2.4 GHz-Band
  $\rightarrow$ dropped during standardization

802.11b
2.4 GHz
11 Mbit/s

802.11
2.4 GHz
2 Mbit/s

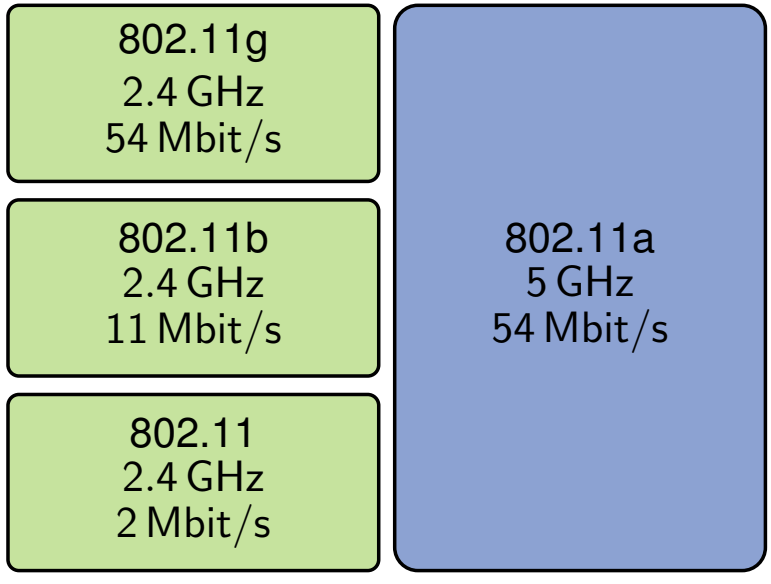
3rd Milestone 802.11a - for 5 GHz (1999)

- Physical Interface 5 GHz only
  - now using **OFDM**
    - **52 Subcarriers → 64 FFT**
    - **20 MHz Channel Bandwidth (16.6 MHz OCBW)**
- new MCS up to 54 Mbit/s
  - BPSK, QPSK, 16QAM, 64QAM
- Coding
  - convolutional code
  - $R = 1/2,\ 3/4$
- Market
  - technical difficulties in 1st-wave products → 802.11b more reliable and cheaper
  - later significant adoption on enterprise due to capacity and reliability



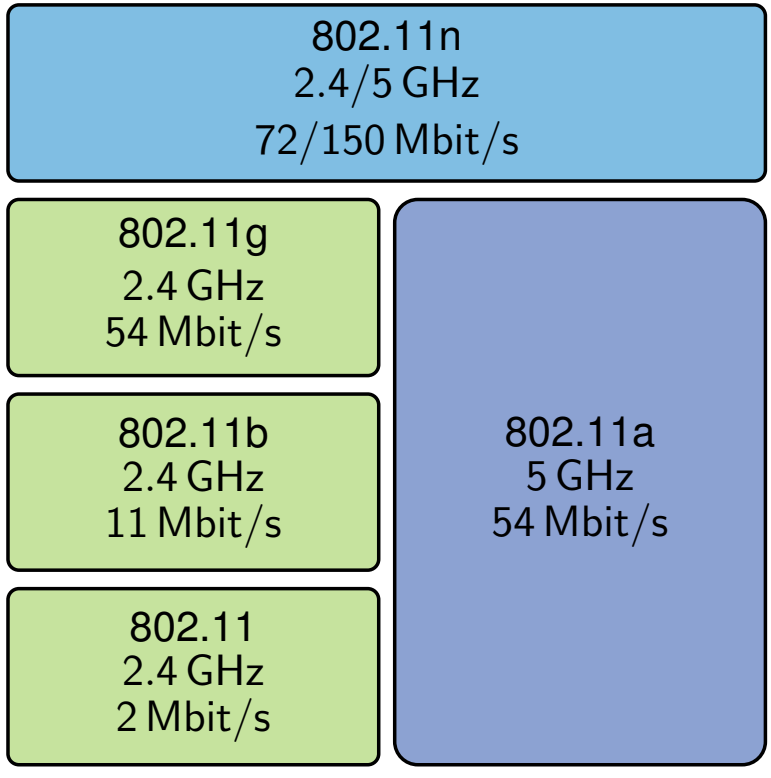
4th Milestone 802.11g - OFDM for 2.4 GHz (2003)

- Physical Interface 2.4 GHz only
  - now using OFDM (copied from 802.11a)
- same MCS as 802.11a, up to 54 Mbit/s
  - BPSK, QPSK, 16QAM, 64QAM
- Coding
  - convolutional code
  - $R = 1/2,\ 3/4$
- implements 802.11 and 802.11b as fallback
- Market
  - widely deployed



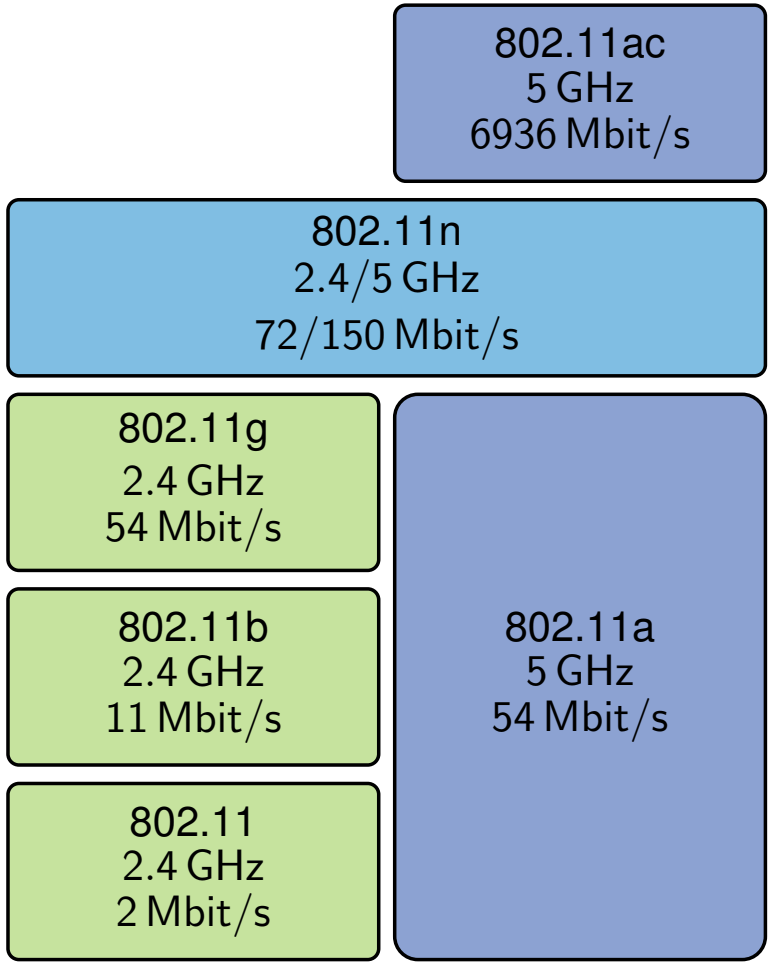
5th Milestone 802.11n - dualband (2009)

- Physical Interface 2.4 GHz **and** 5 GHz
  - up to 4×4 **MIMO** with **4SS**
  - 20 MHz Bandwidth at 2.4 GHz $\rightarrow$ 72 Mbit/s
  - 40 MHz Bandwidth at 5 GHz $\rightarrow$ 150 Mbit/s
  - max. $4 \times 150 =$ 600 Mbit/s
  - BPSK, QPSK, 16QAM, 64QAM
- multiple **Beamforming** methods
- Coding
  - convolutional code
  - $R = 1/2,\ 3/4,\ \mathbf{2/3},\ \mathbf{5/6}$
- Market
  - implemented in all new released products $\rightarrow$ replaces 802.11g & a



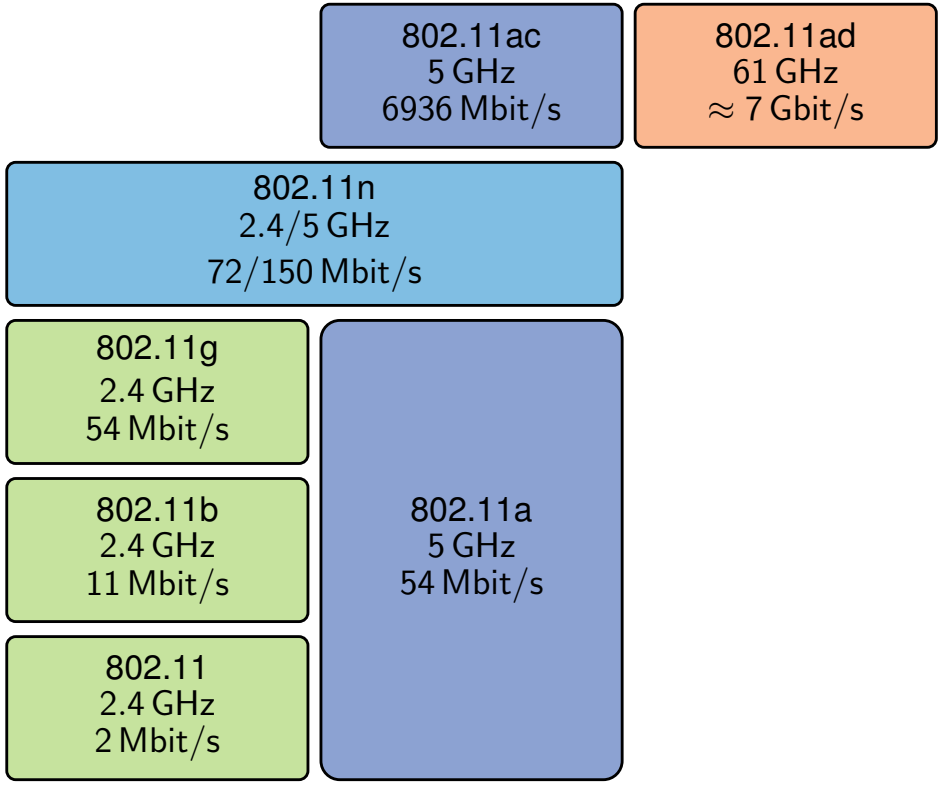
6th Milestone 802.11ac - 5 GHz (2013)

- Physical Interface 5 GHz only
  [Perahia and Stacey, 2013]
  - up to 8×8 MIMO with **8SS**
  - 20/40/80 MHz Bandwidth
    $\rightarrow$ 96.3/200/433 Mbit/s
  - **80 + 80/160 MHz Bandwidth**
    $\rightarrow$ **867 Mbit/s**
  - max. $8 \times 867 = 6936$ Mbit/s
  - **MU-MIMO** in downlink
    (AP to STA)
  - simplified Beamforming
    (sounding and feedback)
  - adds **256-QAM**
- Market
  - first products in 2012



7th 802.11ad - 60 GHz (2012)

- Physical Interface **61 GHz** only
  - 4 Channels à 2.61 GHz BW
  - Single Carrier up to 16-QAM, $R = 3/4$ $\rightarrow$ 4620 Mbit/s
  - OFDM up to 64-QAM, $R = 13/16$ $\rightarrow$ 6756.75 Mbit/s
  - Beamforming
  - less „crowded“ spectrum
  - Drawbacks
    - huge path-loss (O_2 absorption)
    - only LOS
- Usecases
  - Wireless Display / TV Content
  - Wireless filetransfer
  - File sync (digital stores)



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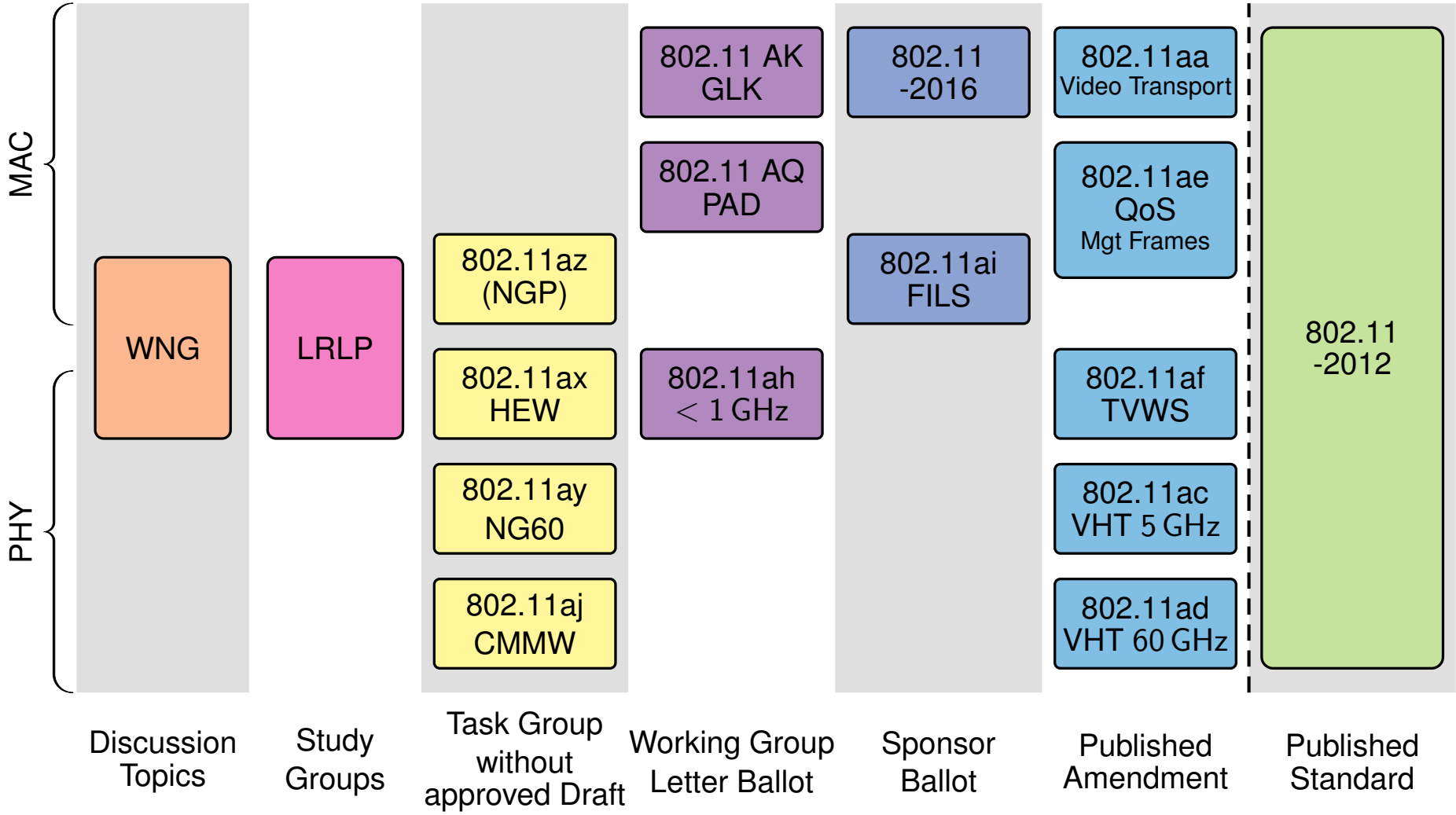
The Standardization Pipeline



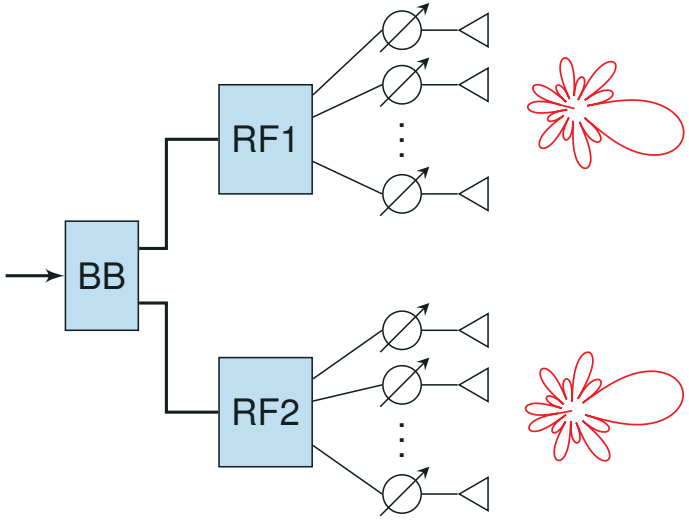
Outlook

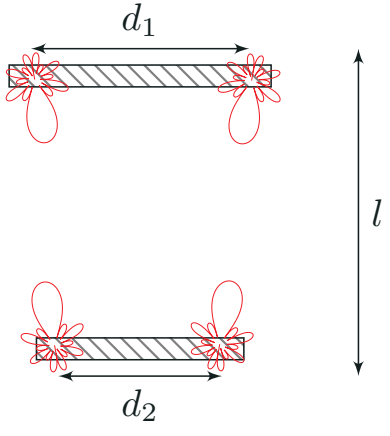
- Current topics
  - Next Generation Positioning [Yang and Shao, 2015]
  - NG60 WiFi at 60 GHz
  - WiFi LTE integration [Ling et al., 2015]
  - Internet of Things $\rightarrow$ 802.11ah sub 1 GHz
- Overall trend
  - until now: more datarate
  - future: more functionality

NG60 (≈ 2019) - Overview

- Reasons for 60 GHz Band
  - new spectrum just available
  - huge bandwidth
  - RF technology is getting cheaper
- Upcoming problems
  - huge pathloss
  - → directionality (two angular dimensions)
  - blockage
  - MIMO and Beamtraining
  - channel models
- Approaches
  - usage of raytracing for channel modeling
  - hybrid MIMO and phased array antennas

[Xin et al., 2015]

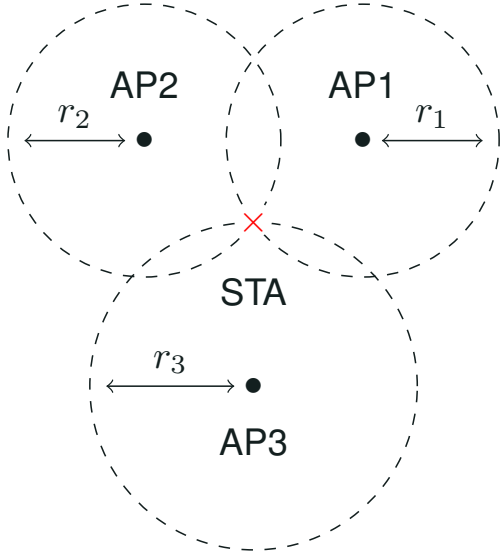




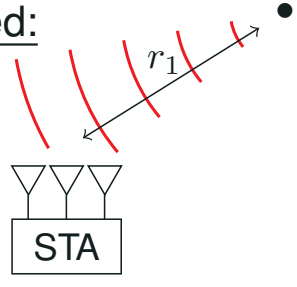
Next generation Positioning - Overview

- Usecases
  - Navigation in public buildings
  - Indoor geotagging
    [Handte et al., 2015]
  - Home Audio
    (follow me, positioning)
  - ...
- Requirements [Segev et al., 2015]
  - highly scalable (home to stadium)
  - Non-AP Positioning
  - MAC & PHY modifications
- Research topics
  - Modification of Channel Model
    [Nahata et al., 2015]
  - Synchronization of APs
  - measurement & estimation of TOA/AOA
    (Fine Time Measurement, FTM)

RTT based:



RTT/AOA based:



[Yang and Shao, 2015, Segev et al., 2014]

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