7세대 Wi-Fi 기술 및 표준화 현황

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손주형 팀장

Wi-Fi 6 (IEEE 802.11ax) in the Market

- ASUS RT-AX88U (Wireless 802.11Ax Dual Band AX6000 Router) (Oct.18)
  - 4 antennas: 2.4 GHz 4x4, 5 GHz 4x4
  - 20/40/80/160 MHz
  - OFDMA, 1024-QAM
  - 802.11ac (5GHz) : up to 4333 Mbps
    802.11ax (2.4GHz) : up to 1148 Mbps
    802.11ax (5GHz) : up to 4804 Mbps

- Samsung Galaxy S10 (Mar.19)
- Samsung Galaxy S20 (Mar.20)
- Samsung Galaxy Note 20 (Aug.20)
  - Wi-Fi 802.11 a/b/g/n/ac/ax (2.4/5GHz)
  - 80MHz, MU-MIMO,1024QAM
  - Up to 1.2Gbps DL/UL

- Apple iPhone 11/11 Pro (Sep.19)
  - Wi-Fi 802.11 a/b/g/n/ac/ax (2.4/5GHz)
  - 2x2 MU-MIMO

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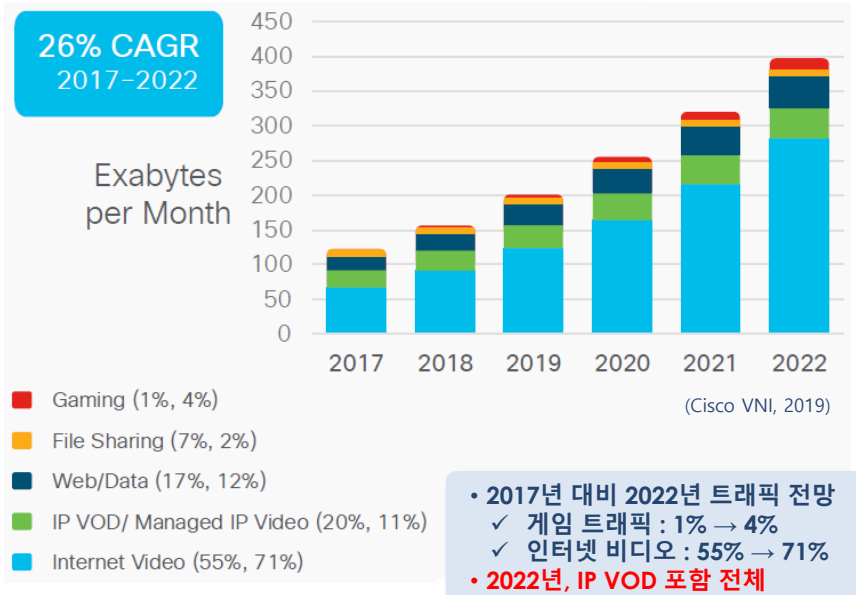
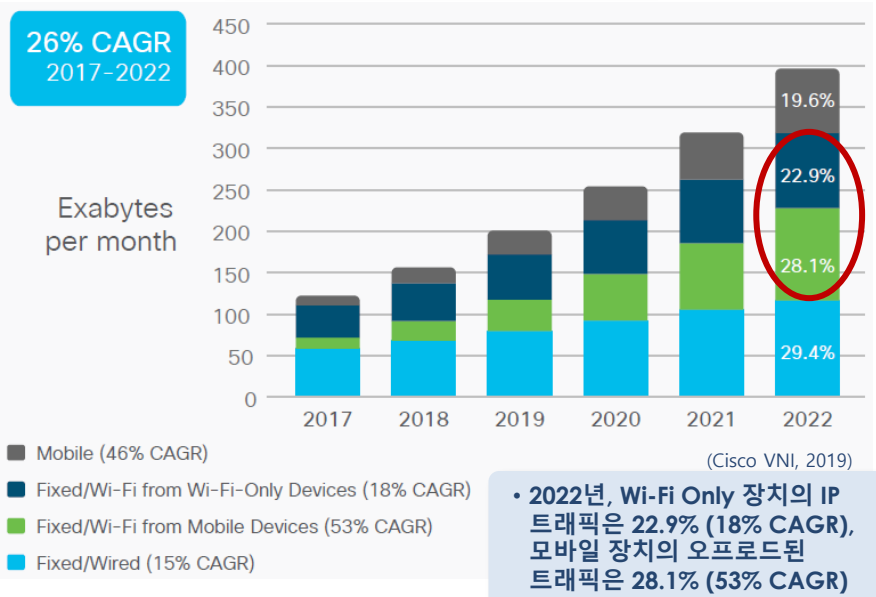
무선랜 시장 및 트래픽 전망

2017~2022 용도에 따른 트래픽 비율



- 2017년 대비 2022년 트래픽 전망
  - ✓ 게임 트래픽 : 1% → 4%
  - ✓ 인터넷 비디오 : 55% → 71%
- 2022년, IP VOD 포함 전체 비디오 트래픽은 82%에 달할 것으로 전망됨

2017~2022 전세계 IP 트래픽 추세



- 2022년, Wi-Fi Only 장치의 IP 트래픽은 22.9% (18% CAGR), 모바일 장치의 오프로드된 트래픽은 28.1% (53% CAGR) 차지, 무선랜을 통한 트래픽이 사실상 전체의 절반을 넘음

- 현재, Wi-Fi 기술의 글로벌 경제적 가치(연간)는 1.96조 USD에 달하며, 2023년에는 3.47조 USD로 늘어날 것으로 예측됨*
- 2018년 기준, 전세계에는 3.4억 개의 Wi-Fi 핫스팟이 설치*되어있으며, 무선랜 기술의 개발 및 보급에 따라 핫스팟의 개수는 지속적으로 증가 예정

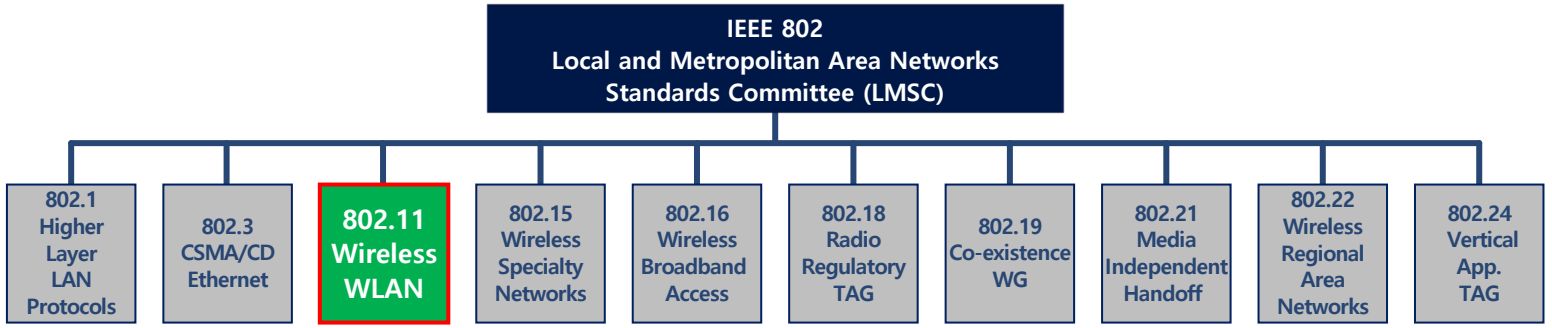
구분	2018년	2023년
전세계	1.96조 USD	3.47조 USD
대한민국	680억 USD	1380억 USD
미국	4990억 USD	9930억 USD
영국	540억 USD	710억 USD
프랑스	440억 USD	640억 USD
독일	940억 USD	1320억 USD
일본	1710억 USD	2480억 USD

* : The Economic Value of Wi-Fi: A Global View (2018 and 2023), Wi-Fi Alliance, Telecom Advisory Services LLC (TAS)

무선랜 표준화 기구

IEEE 802.11 WG ('18.09)

- **IEEE 802.11 Working Group**
  - 무선랜 기술의 표준화는 IEEE[1] 산하 IEEE 802 LAN/MAN 표준 위원회의 11번째 Working Group인 **IEEE 802.11 WG**에서 진행



- **IEEE 표준 개발 절차**

✓ IEEE 802.11 WG에서는 주요 연구/개발 아이템에 대하여 TIG[2]/SG[3]에서 사전 논의를 거친 이후, TG[4]에서 본격적인 표준 규격 개발을 진행

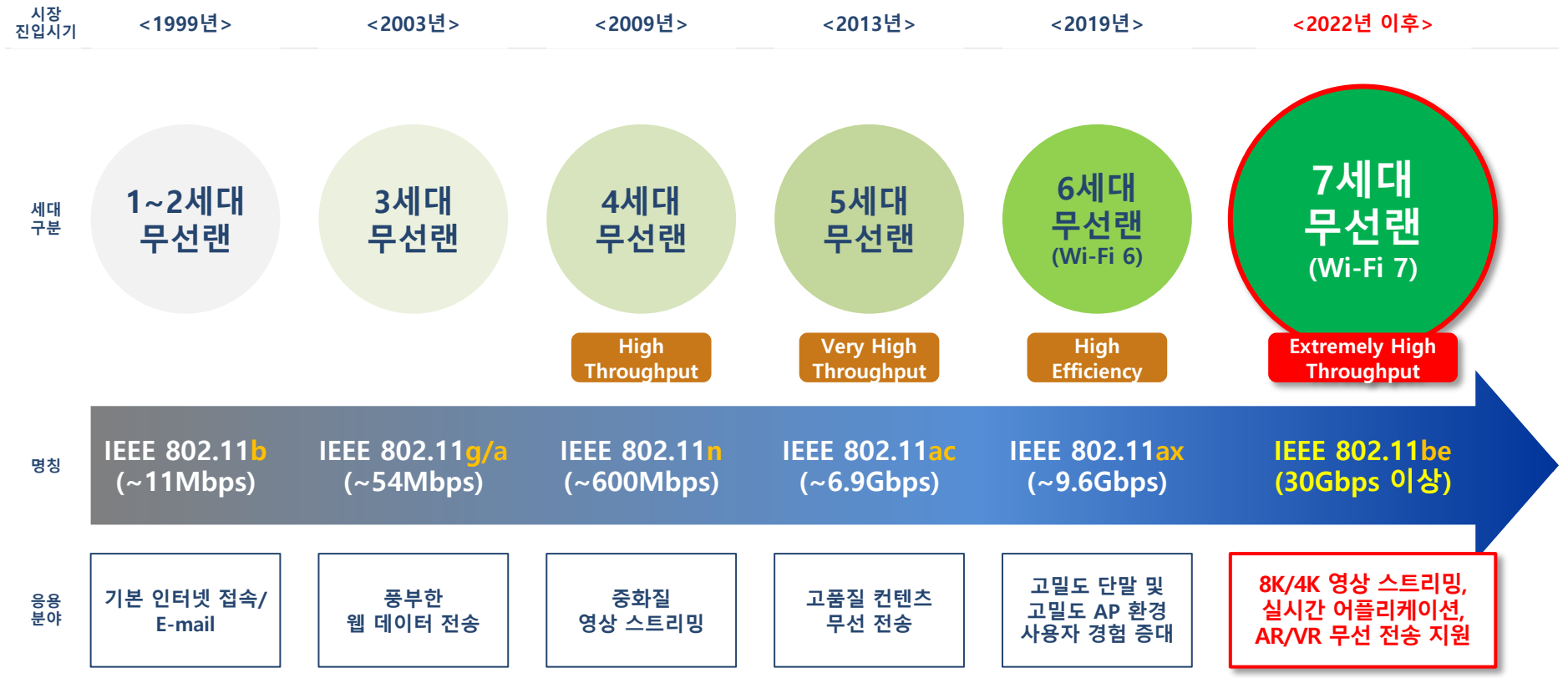
✓ 연구/개발 아이템이 TG 단계로 넘어갈 때 고유의 알파벳을 부여 받음
(... TG ac : 802.11ac 표준 개발, TG ax : 802.11ax 표준 개발, ... , TG be : 802.11be 표준 개발)

1) 전기 전자 기술자 협회 (Institute of Electrical and Electronics Engineers)

2) TIG : Topic Interest Group
3) SG : Study Group
4) TG : Task Group

무선랜 기술의 세대 구분

**무선랜 기술은 사용자 편의 및 시장의 요구에 대응하여 지속적인 발전이 이루어졌으며,
OFDM, MIMO, OFDMA 등 새로운 통신 기술의 도입을 통해 기존의 성능을 훨씬 뛰어넘는 진화를 이룸**



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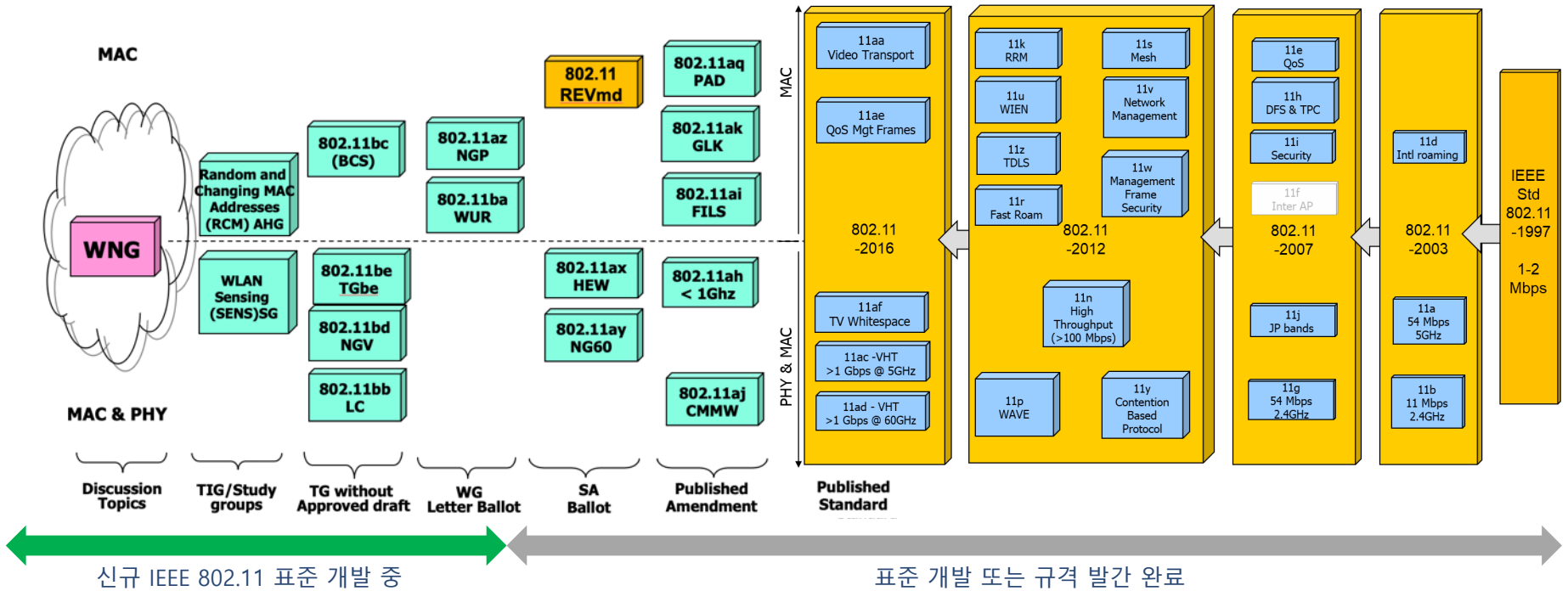
무선랜 표준의 진화

< IEEE 802.11 Standards Pipeline >

* Source: IEEE 802.11, 2020년 1월 기준



6세대

- **802.11ax – High Efficiency in 2.4, 5 (and 6) GHz bands**
- 802.11ay – Support for 20 Gbps in 60 GHz band.
- 802.11az – 2nd generation positioning features
- 802.11ba – Wake up radio, Low power IoT applications
- 802.11bb – Light Communications
- 802.11bc – Enhanced Broadcast Service
- 802.11bd – Enhancements for Next Generation V2X

7세대

- **802.11be – Extremely High Throughput in 2.4, 5 and 6 GHz bands**

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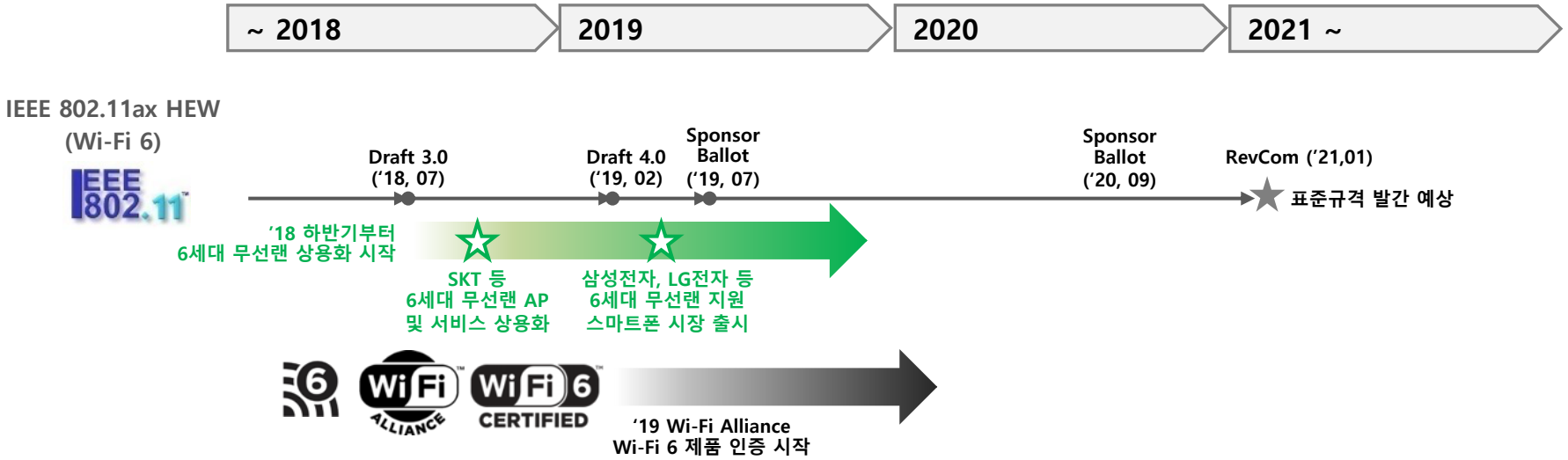
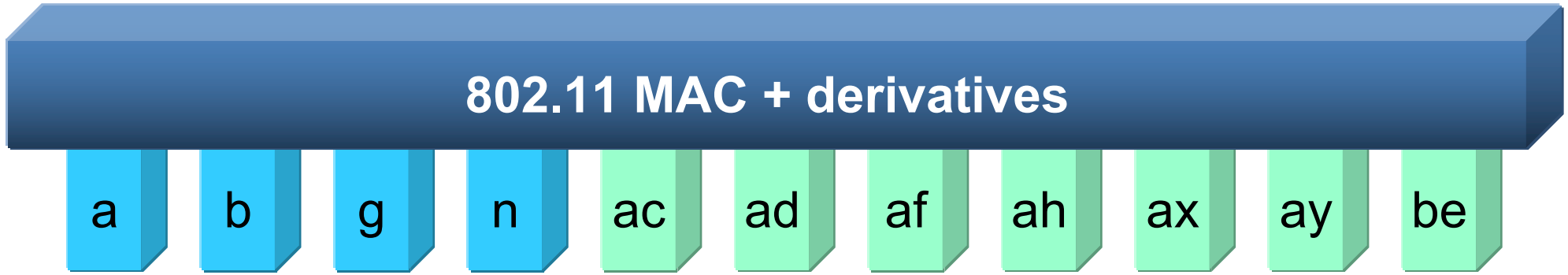
주요 무선랜 표준화 현황



- ✓ 6세대 무선랜 표준인 IEEE 802.11ax는 사실상 표준 개발이 종료되었으며, 2019년 전반기를 기점으로 본격적인 상용화가 시작됨
- ✓ 6세대 이후의 7세대 무선랜 표준 기술을 논의하는 EHT TIG/SG가 2018년에 결성되었으며, 2019년 5월 TGbe를 통해 본격적인 표준 개발을 추진 중임

IEEE 802.11 Baseline Protocols



- **Physical (PHY) layer**
  - Both AP and associated stations use the same frequency (similar to TDD system)
  - Default channel bandwidth = 20 MHz for 2.4 & 5 GHz
  - Multiple transmission rates with different combinations of modulation & coding schemes (MCSs)
- **Medium Access Control (MAC) layer**
  - Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
  - Transmit only if channel is idle (Listen Before Talk)
  - Gradual enhancements for each generations

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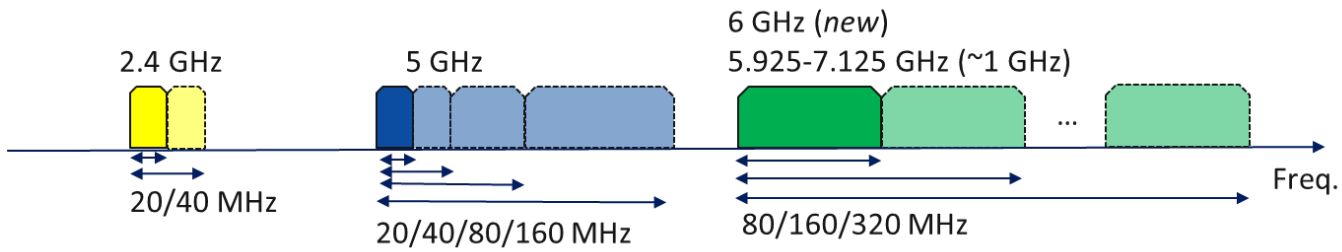
IEEE 802.11n to 11be

Feature	Wi-Fi 4 IEEE 802.11n (HT) -High Throughput	Wi-Fi 5 IEEE 802.11ac (VHT) - Very High Throughput	Wi-Fi 6 IEEE 802.11ax (HE) - High Effeciency	Wi-Fi 7 IEEE 802.11be (EHT) - Extremely High Thput
Frequency bands [GHz]	2.4, 5 GHz	5 GHz	2.4, 5 and 6 GHz	2.4, 5 and 6 GHz
Channel widths [MHz]	20, 40	20, 40, 80, 160(80+80)	20, 40, 80, 160(80+80)	20, 40, 80, 160(80+80) 320(160+160)
OFDM numerology	64 tones / 20 MHz	64 tones / 20 MHz	256 tones / 20 MHz	256 tones / 20 MHz
OFDM symbol duration	3.2 μs (GI = 0.4/0.8 μs)	3.2 μs (GI = 0.4/0.8 μs)	12.8 μs (GI = 0.8/1.6/3.2 μs)	12.8 μs (GI = 0.8/1.6/3.2 μs)
Modulations	BPSK, QPSK, 16/64-QAM	BPSK, QPSK, 16/64-QAM, 256-QAM	BPSK, QPSK, 16/64/256-QAM, 1024-QAM	BPSK, QPSK, 16/64/256/1024-QAM 4096-QAM
Forward Error Correction	BCC mandatory, LDPC optional	BCC mandatory, LDPC optional	BCC mandatory, LDPC mandatory	BCC mandatory, LDPC mandatory
MU transmissions	SU-MIMO	SU-MIMO DL MU-MIMO	DL & UL SU/MU-MIMO DL & UL OFDMA	DL & UL SU/MU-MIMO DL & UL OFDMA
OFDMA (RU sizes, subcarriers)	-	-	26, 52, 106, 242, 484, 996, 2x996	26, 52, 106, 242, 26+52, 26+106 484, 996, 2x996, 242+484, 484+996, 4x996
MU-MIMO stations	Up to 4 STAs (4SS)	Up to 4 STAs (8SS)	Up to 8 STAs (8SS)	Up to 8 STAs (16SS)
Max. throughput	600 Mbps	6.933 Gbps	9.607 Gbps	Approx. 40 Gbps

Wi-Fi 7: Wider Bandwidth (~320 MHz) Operation

- **High-Throughput Data Pipe in 6 GHz Band**
  - Hard to find idle 80 or 160 MHz spectrum in the 2.4/5 GHz bands
  - Transmit 80/160 MHz wideband signals in the 6 GHz band
  - Even larger than 160 MHz data transmission is possible
    - 320 MHz operation in the 6 GHz band
    - 80/160+160 MHz across the 5 and 6 GHz bands
- **Tri-band operation in 2.4/5/6 GHz bands**
  - Wider bandwidth by multi-channel aggregation across 2.4/5/6 GHz bands
  - Use the 6 GHz band mainly for high-throughput data transmissions
  - Management frames transmitted in the 2.4/5 GHz bands

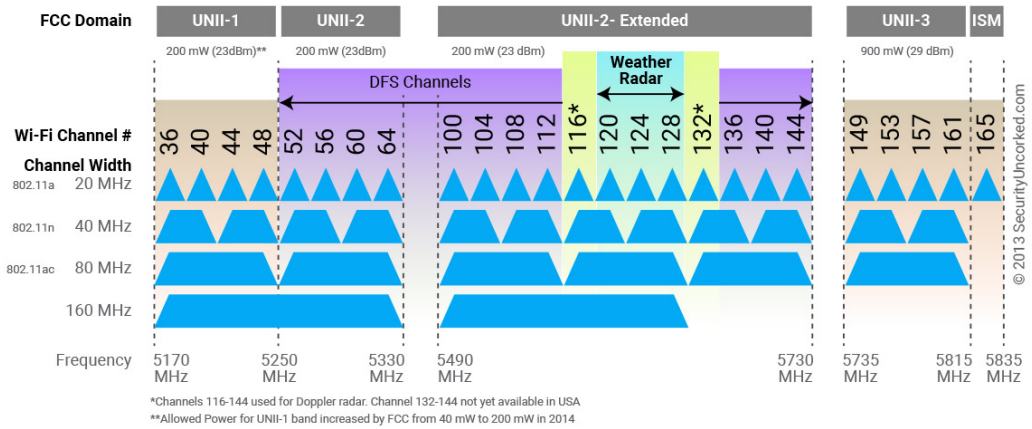


* Source: IEEE 802.11-18/0857r0

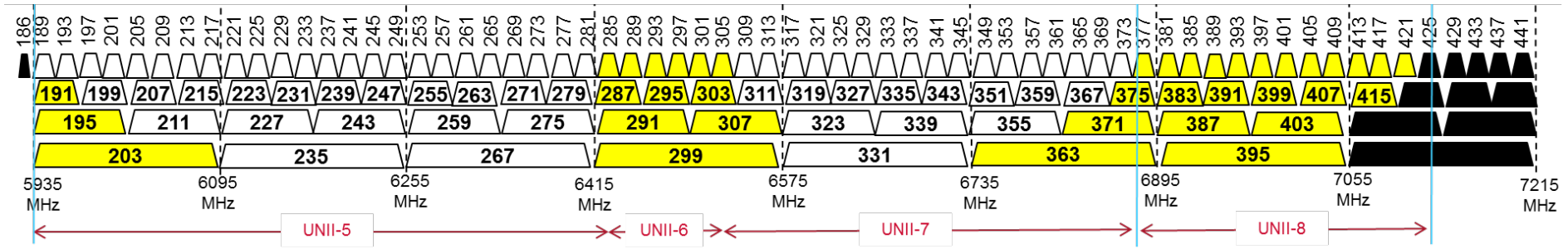
- Source: IEEE 802.11-18/0789r10
- Source: IEEE 802.11-19/0754r0

Wi-Fi 7: Additional spectrum in 6GHz band

5 GHz band (US)



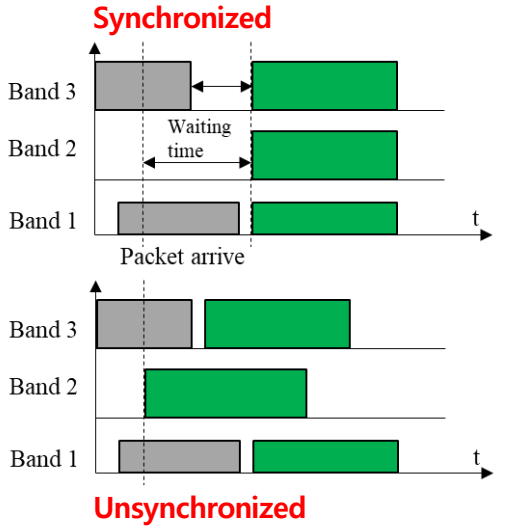
6 GHz band (US)



- For 5 GHz, two 160 MHz contiguous channels can be provided
- For 6 GHz, 3 possible 320 MHz contiguous channels, 7 possible 160 MHz contiguous channels
  - UNII-5 and UNII-7 requires availability check based on database access

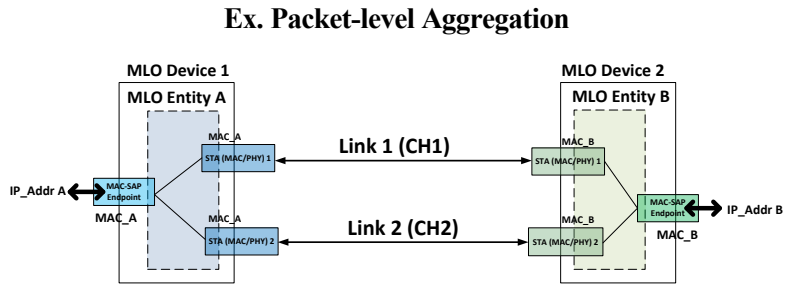
Wi-Fi 7: Multi-Link Operation

- **Synchronization between Multi Bands**
  - Each band has independent channel access
    - Higher channel access efficiency
  - Optimized throughput with per band individual MCS
    - Channel condition and regulatory power limits are different for different bands



* Source: IEEE 802.11-18/1184r1

- **Multi-Link framework to consider the following aspects:**
  - Aggregation of packets sent on multiple bands/channels concurrently
    - Addresses the use-case for improving peak-throughput and reduce latency
  - Fast Link Switching
    - Seamless transition between different channels/bands to address the use-case for efficient load balancing, coexistence constraints, etc.
  - Control/Data separation
    - Addresses the use cases for efficient utilization of channel and power-save

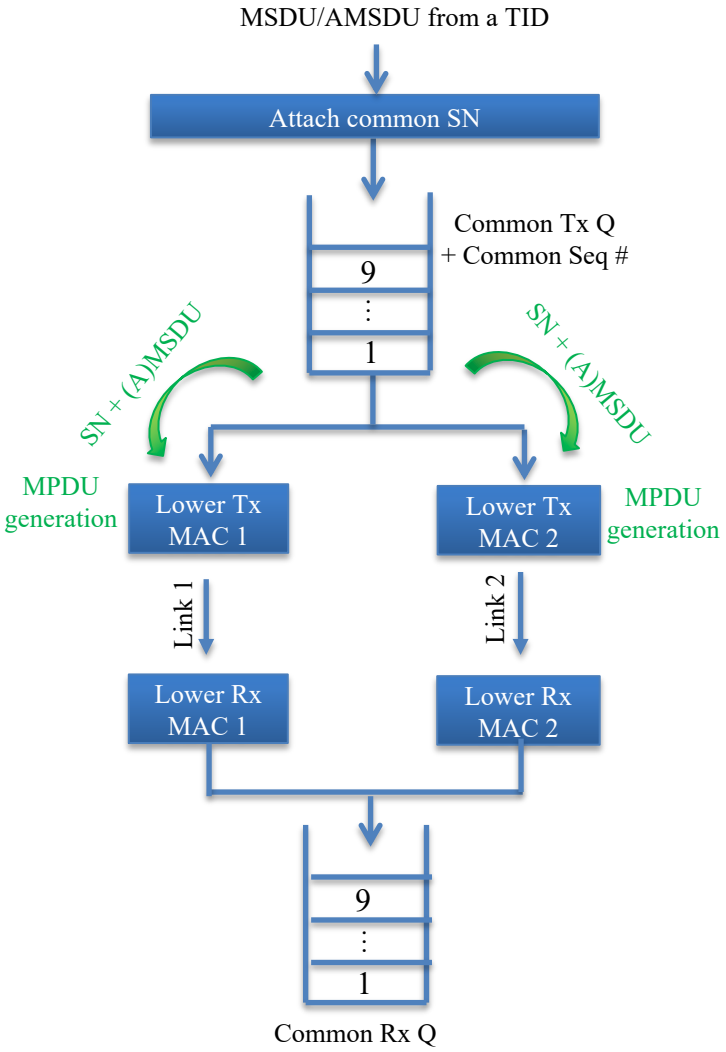


* Source: IEEE 802.11-19/0823r0

Wi-Fi 7: Multi-Link Operation Architecture

- **Common upper MAC**
  - Single-link interface to higher layer
  - Shared sequence # space and BA scoreboard
    - Retransmissions need not be on the same link
  - ACKs need not be sent on the same link as the MPDUs
    - Single BAR can elicit BA for MPDUs sent on any/all links
    - ACKs can be aggregated with MPDUs on a reverse link
  - Increase BA Bitmap length to 1024
    - Accounts for increase in peak throughput
  - Management
    - Single association (on 'home' channel)
      - A STA that is idle monitors only the home channel
    - Dynamically signal expansion to additional links

- **Independent lower MAC/PHY instances**
  - Each link has a MAC instance that performs link specific functionality independently
    - e.g., EDCA, CCA, sounding, etc

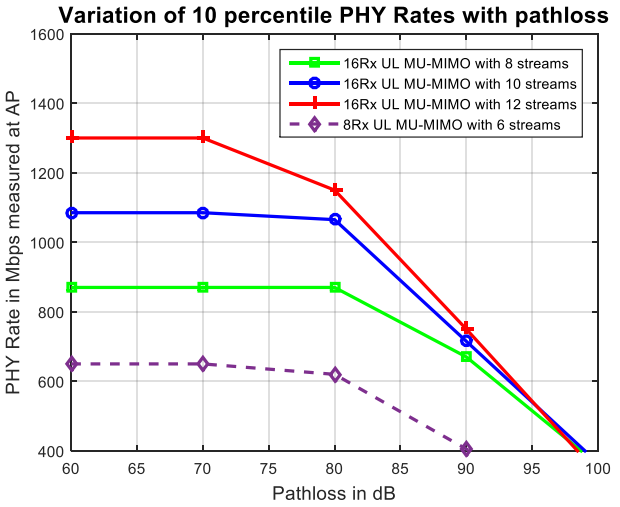


* Source: IEEE 802.11-19/0823r0

Wi-Fi 7: 16 Spatial Streams

- **Spatial multiplexing gain has been a key technology driver for 802.11 in the last few standards cycles**
  - **802.11ac and 802.11ax extended the benefits further by adding MU-MIMO**
    - DL MU-MIMO in 11ac and DL/UL MU-MIMO in 11ax
    - Provides substantial spatial multiplexing gains even with STAs having a limited number of antennas

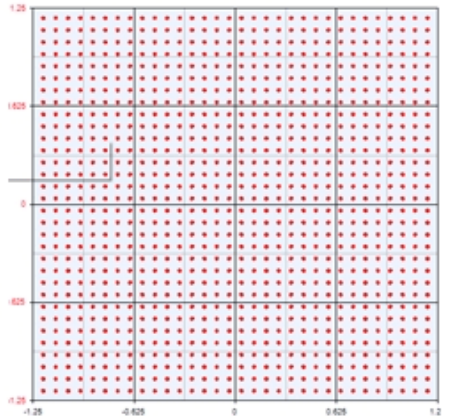
* Source: IEEE 802.11-18/0818r3



- **Setup**
  - UL MU-MIMO
  - 2Tx STAs, 16Rx/8Rx AP
  - MMSE receiver
  - Perfect rate adaptation
- **Key observations**
  - 2x the throughput of 8Rx UL MU-MIMO
  - Linear increase in throughput from 8 to 12 streams

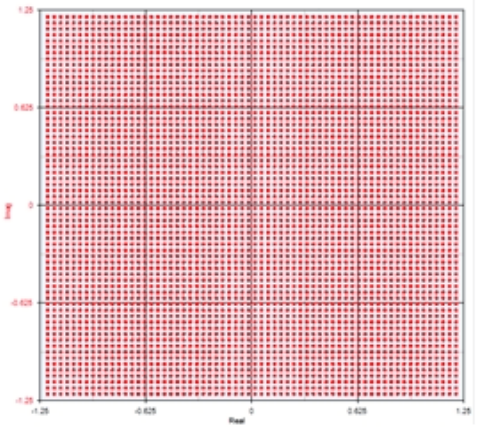
Wi-Fi 7: 4096 QAM

- In 802.11, the supported maximum modulation size has been increased gradually
  - Initially OFDM supported BPSK, QPSK, 16QAM and 64QAM
  - 256QAM was introduced in 11ac
  - 1024QAM was introduced in 11ax



QAM-1024

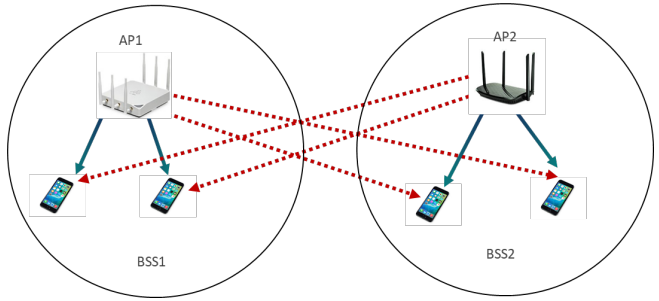
- 4096QAM has been suggested for EHT
- BF may be the key to support of 4096 QAM
  - With BF, 4096 QAM can be supported at lower SNR
  - Most BF gain for lower number of streams

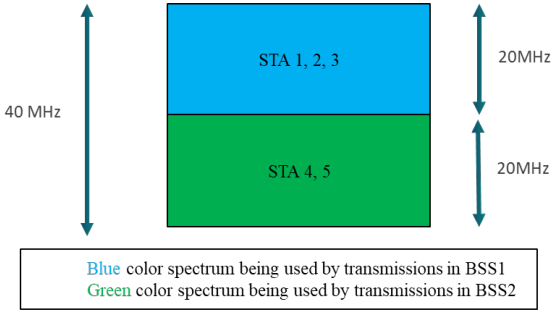


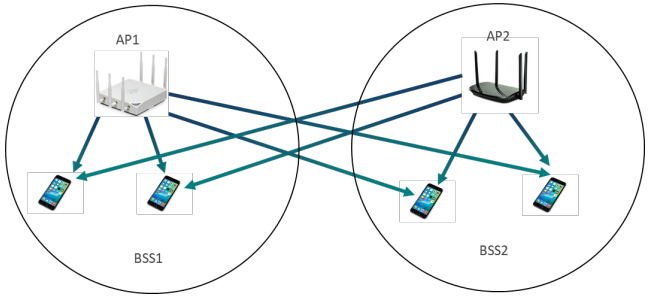
QAM-4096

Wi-Fi 7: Multi-AP Coordination

- **Coordinated transmission**
  - **Coordinated nulling**
    - Signal for a user is only transmitted from one AP while forming nulls to OBSS STAs
  - **Coordinated OFDMA**
    - Efficient utilization of frequency resources across the network
  - **Joint (Distributed) MU-MIMO**
    - Signal for a user is transmitted from multiple APs
    - Data of participating STAs needs to be available at APs
    - MU-MIMO using one giant precoder over the combined array consisting of the Tx antennas of all APs



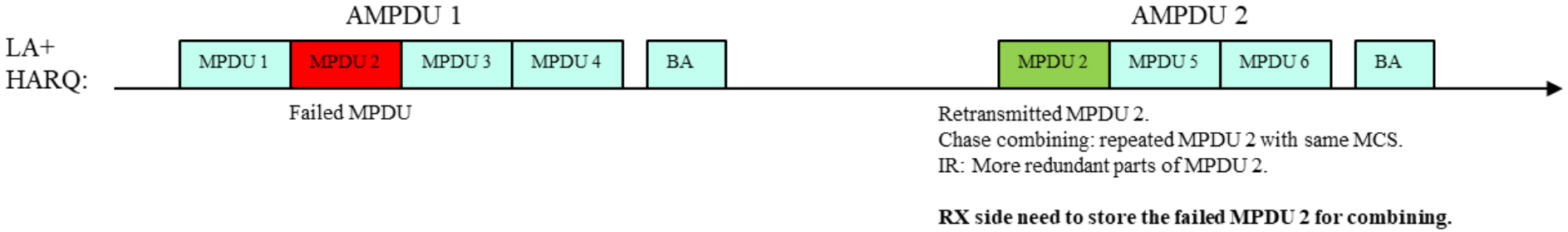




* Source: IEEE 802.11-18/1926r2

Wi-Fi 7: Hybrid ARQ

* Source: IEEE 802.11-18/1955r0,
IEEE 802.11-18/1979r0



- **Introducing HARQ in 802.11**
  - **Improved link performance**
    - By combining several retransmissions
  - **Link range extension (improved coverage)**
    - Particularly at the low SNR region
  - **Making link adaptation more robust and efficient**
    - Extended set of MCSs with finer granularity
    - Supports operation with reduced backoff (smaller fade margin) in the rate selection algorithm
- **HARQ major complexity and cost**
  - **Chase combining (CC)**
    - Extra memory to store the failed MPDUs.
  - **Incremental redundancy (IR)**
    - Additional memory at the Tx side
    - More implementation complexity such as modification of existing coding chain.

Summary

- **IEEE 802.11be (Wi-Fi 7)**
  - EHT (Extremely High Throughput) WLAN
  - Supporting at least 30Gbps
  - Task Group starts from May 2019
  - Final Standard published at May 2024

- **802.11be Candidate Features**
  - Increased Bandwidth Transmission (320 MHz)
    - peak throughput increase
  - Multi-Link Operation
    - efficiency and peak throughput increase, latency reduction
  - 16 spatial streams and MIMO enhancements
    - peak throughput increase
  - Multi-AP Coordination
    - efficiency and peak throughput increase, latency reduction
  - Hybrid Automatic Repeat Request (HARQ)
    - reliability and efficiency increase, latency reduction