# IEEE 802.11 be

WI-FI Strikes again

# Outline

- Intro, objective, and timeline
- Key upgrades from 802.11ax
- Disruptive new features in 802.11be
- Performance evaluation

# Who doesn’t use WI-FI

Advantage

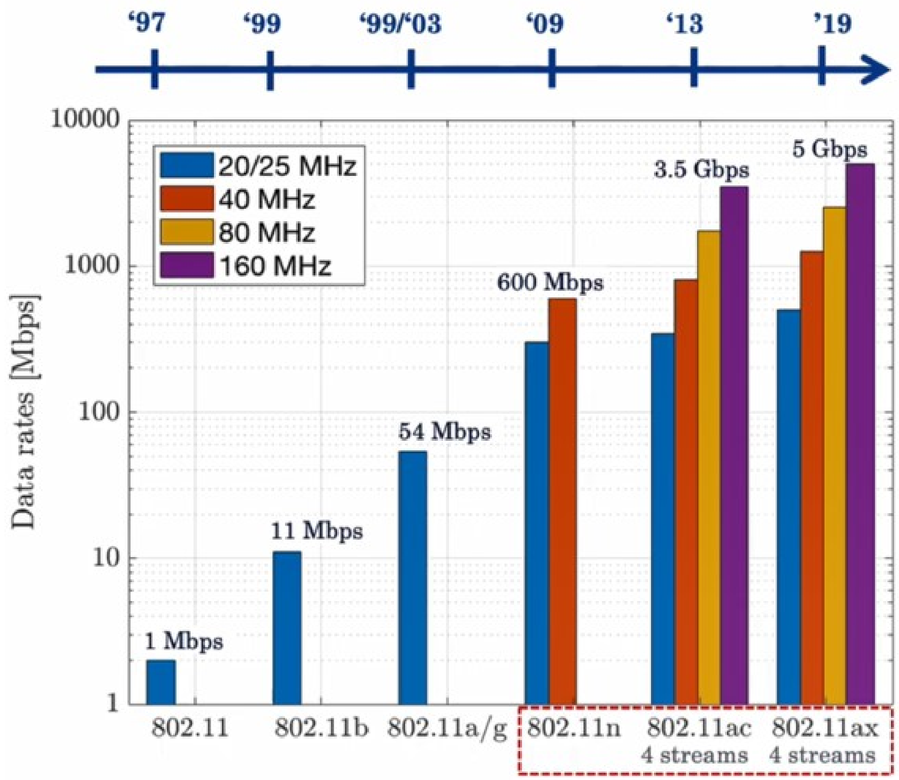
- Unlicensed spectrum is free.
- 13B WI-FI devices installed.
- Widely adopted for residential, public, enterprise, and industrial use.

Challenge

- New digital app requirements:
  - ✓ higher capacity
  - ✓ lower dealy –new!
  - ✓ more reliability –new!

# WI-FI evolution

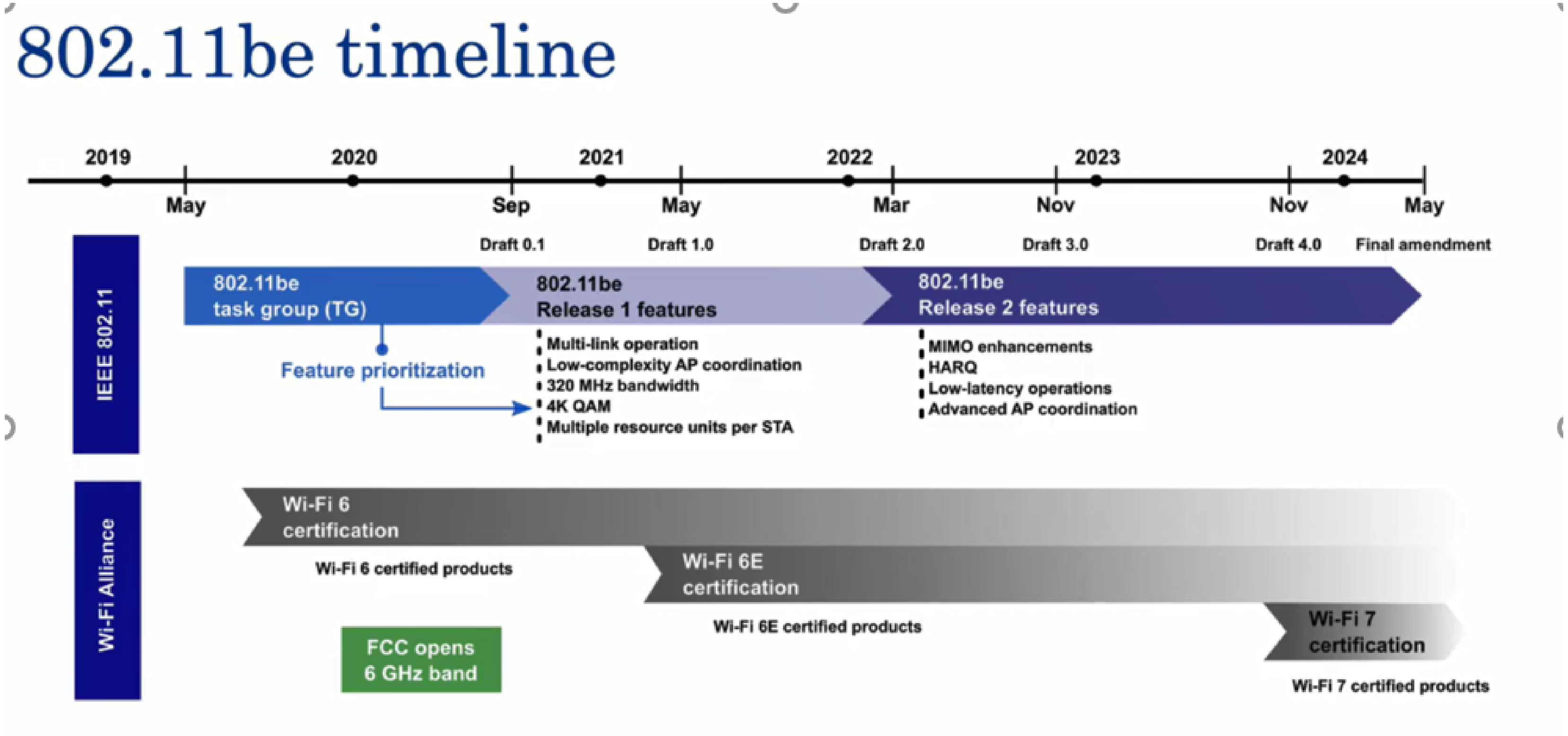
- 802.11n(WI-FI4)
  - Single-user MIMO
  - Packet aggregation
- 802.11ac(WI-FI5)
  - Multi-user MIMO(Downlink)
  - Channel bonding
- 802.11ax(WI-FI6)
  - OFDMA
  - Multi-user MIMO(Uplink)
- 802.11be(WI-FI7)
  - Focus of this topic



# 802.11be objectives

- Extremely high throughput(EHT)
  - Up to 30Gbps per AP
  - New MAC and PHY operations
  - Carriers between 1-7.125GHz
- Improved worst-cast latency and jetter (no specific requirements)
- Backward compatibility and coexistence with legacy 802.11

# timeline



802.11be timeline
2019
2020
2021
2022
2023
2024
May
Sep
May
Mar
Nov
Nov
May
Draft 0.1
Draft 1.0
Draft 2.0
Draft 3.0
Draft 4.0
Final amendment
IEEE 802.11
802.11be task group (TG)
802.11be Release 1 features
802.11be Release 2 features
Feature prioritization
Multi-link operation
Low-complexity AP coordination
320 MHz bandwidth
4K QAM
Multiple resource units per STA
MIMO enhancements
HARQ
Low-latency operations
Advanced AP coordination
Wi-Fi Alliance
Wi-Fi 6 certification
Wi-Fi 6 certified products
Wi-Fi 6E certification
Wi-Fi 6E certified products
Wi-Fi 7 certification
Wi-Fi 7 certified products
FCC opens 6 GHz band

# 802.11be targeted features

- Key upgrades from 11ax:

1. 320MHz
2. Multiple Rus per STA
3. 16 spatial streams
4. 4K-QAM

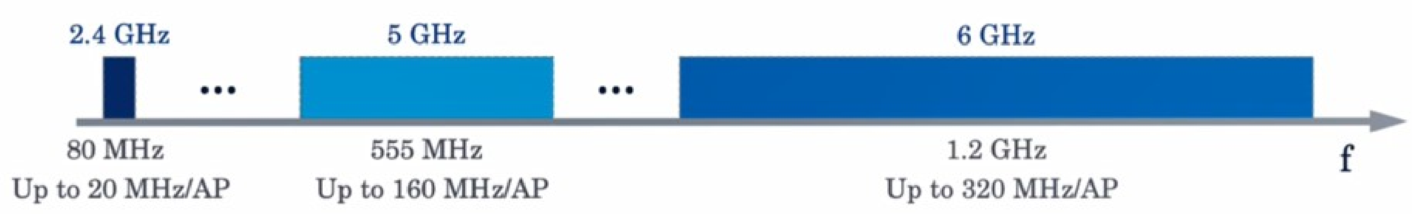
- Disruptive new features in 11be:

5. HARQ
6. Multi-link operation
7. Low-complexity AP coordination
8. Advanced AP coordination

# Key upgrades from 802.11ax: 320MHz

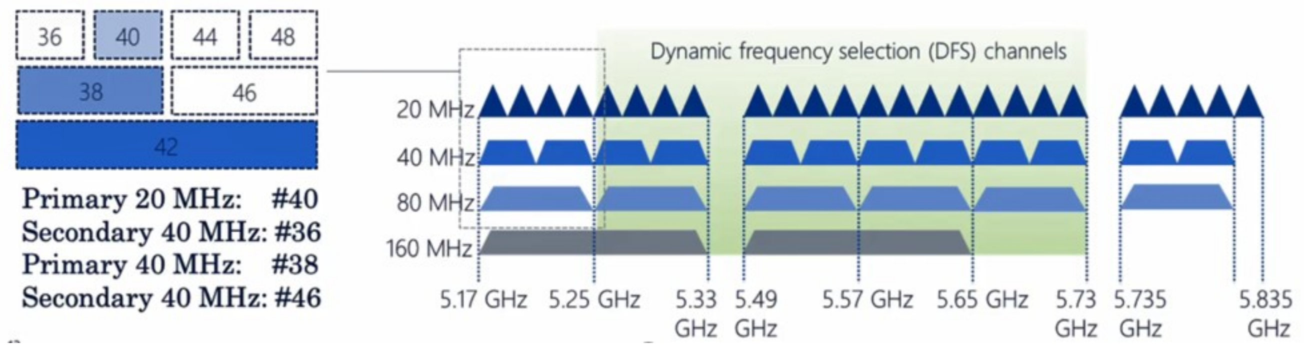
802.11ax/be frequency bands

- 2.4GHz: 11 channels of 20MHz, only 3 non-overlapping
- 5GHz: 25 channels of 20MHz over 555(semi-contiguous)MHz
- 6GHz: up to 60 channels of 20MHz over 1200MHz

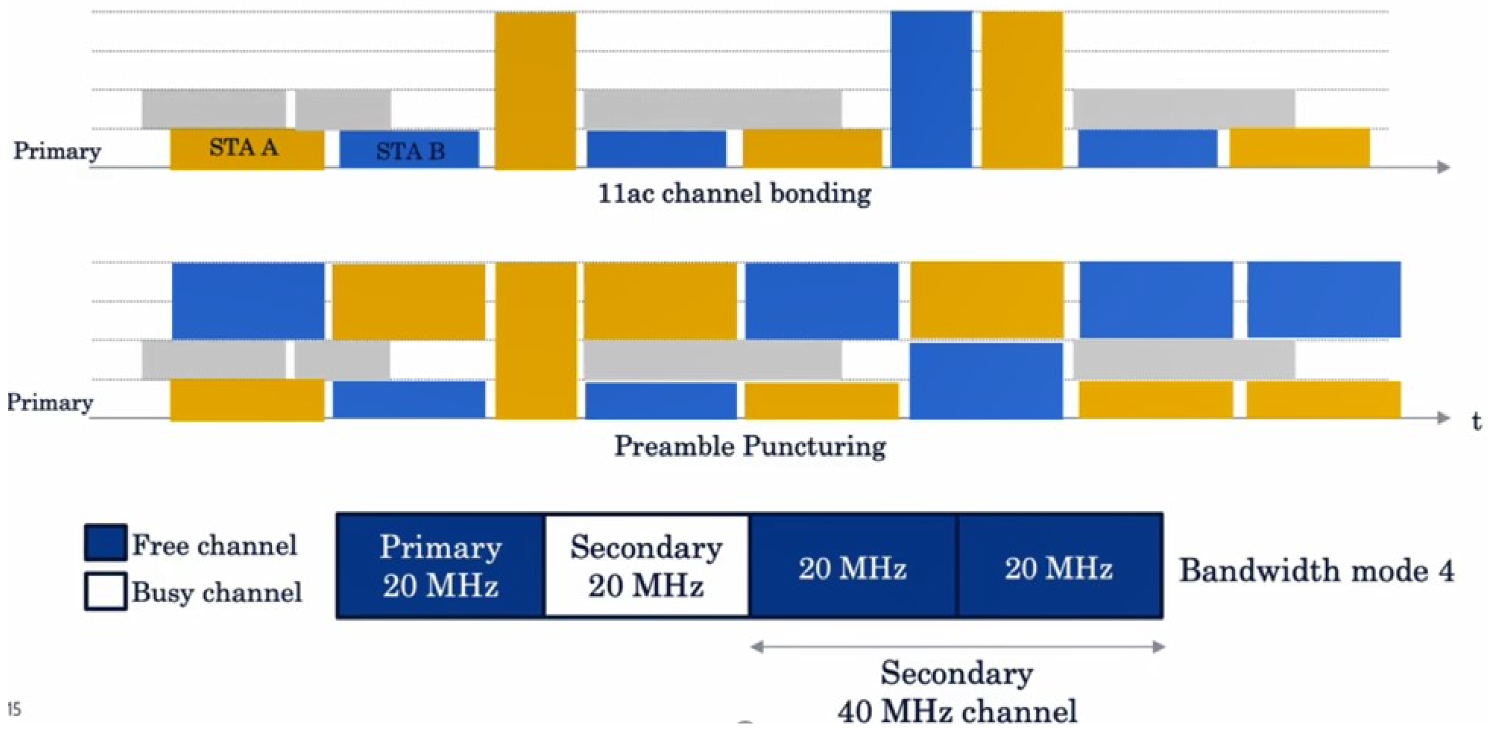


# Channel bonding in 802.11ax

- Increase transmission rates by using wider channels
- 5GHz: 25 channels of 20MHz over 555 (semi-contiguous) MHz
  - 160MHz channel bonding is an optional feature
- Channel bonding performance depends on the spectrum occupancy

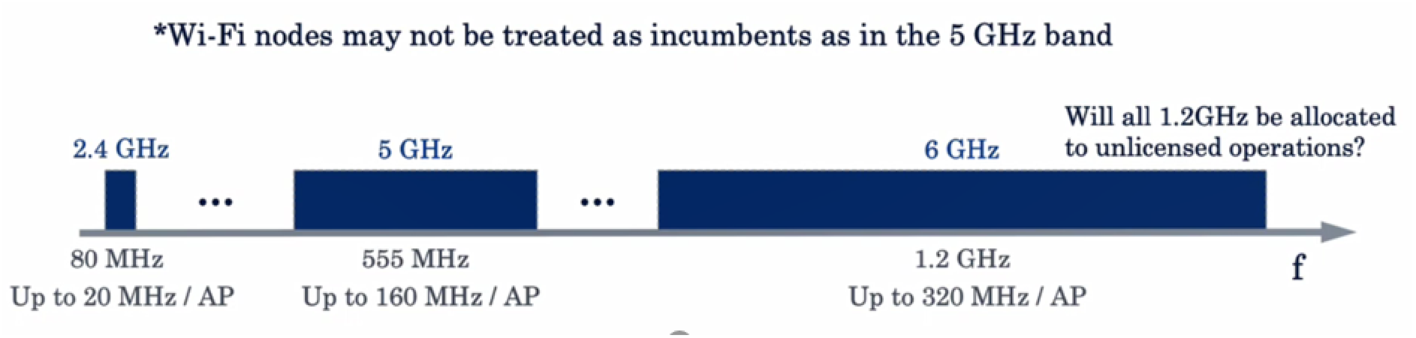


# Preamble puncturing in 802.11ax



# 320MHz per AP in 802.11be

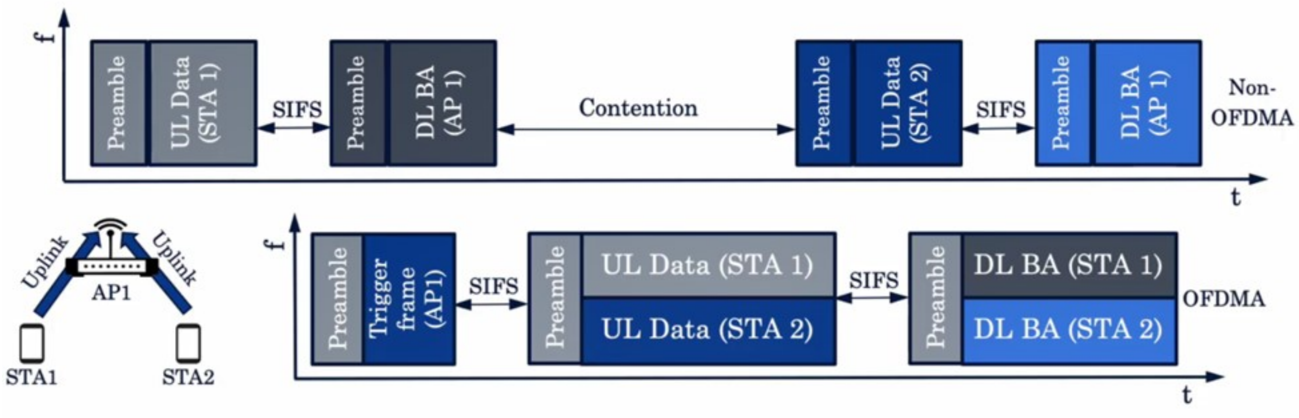
- New unlicensed 6GHz band (5925MHz-7125MHz)
- Adding up to 1.2GHz spectrum and up to 320 MHz channel bonding
- Definition of new channel access rules under discussion



# Multiple RUs per STA

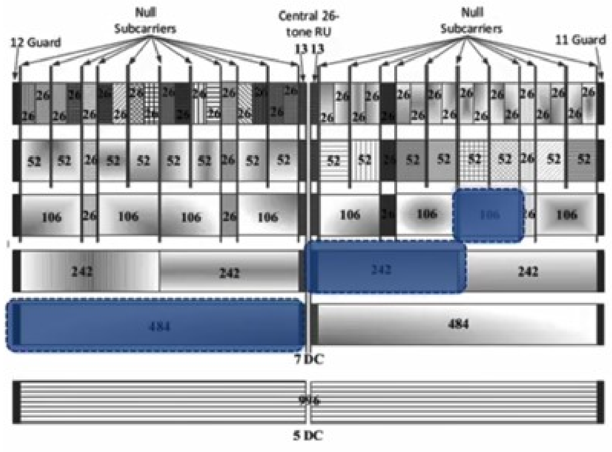
OFDMA in 802.11ax

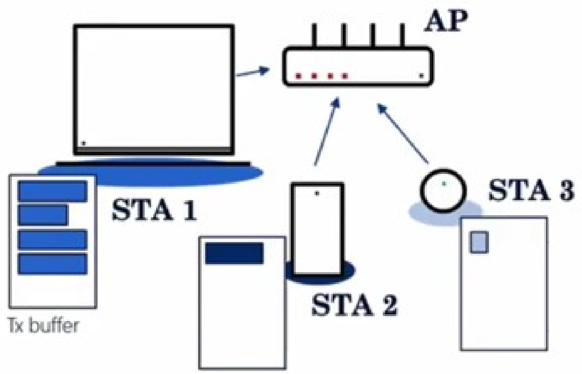
- Multiple devices can be simultaneously scheduled in different subcarriers
- Reduces latency and better allocates resources to different types of traffic

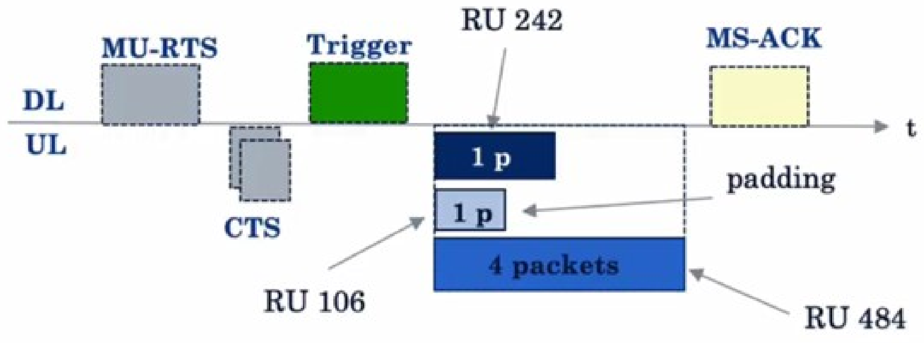


OFDMA in 802.11ax

- Different RU sizes to accommodate different traffic and rate needs
- AP-controlled transmissions: DL,UL
- STA channel and buffer information is required at the AP



OFDMA in 802.11ax

- Key limitation of 802.11ax OFDMA：

  each STA can only be assigned a single resource unit (RU), leading to

  - Unused spectral resourced, and
  - Unexploited frequency diversity gains

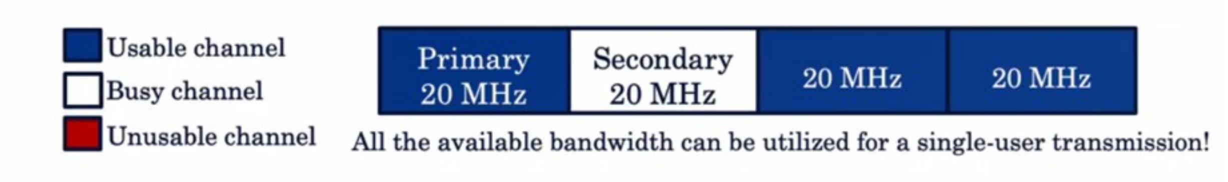
- Illustrative example: Preamble puncturing in 802.11ax

  - In a single-user transmission, no bandwidth aggregation is possible

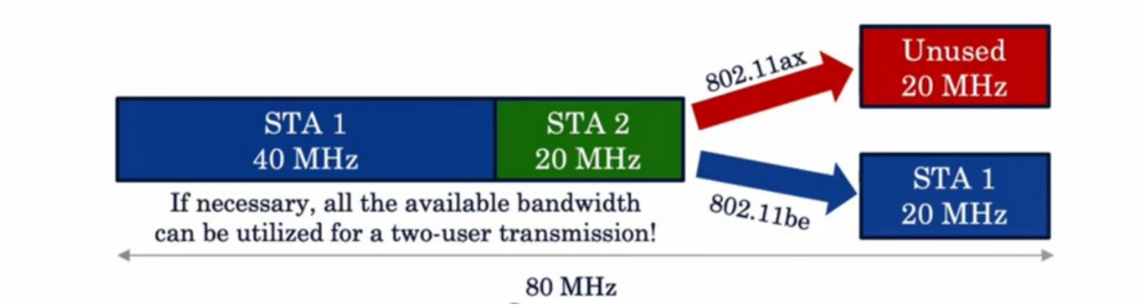
  if the secondary channel is busy

# Multiple RUs per STA in 802.11be

- Example 1 STA: Enhanced preamble puncturing efficiency



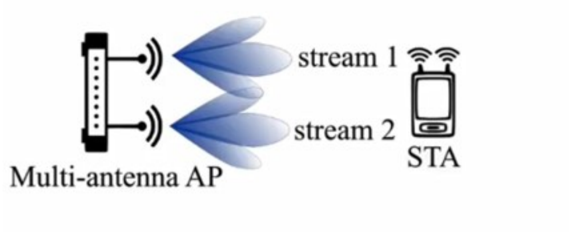

- Example 2 STAS: Improved OFDMA efficiency

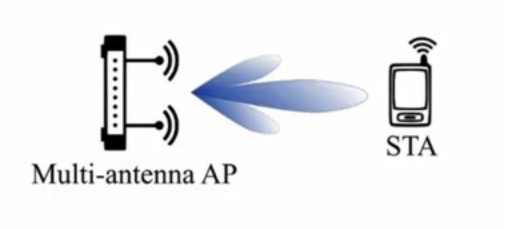


# Key upgrades from 802.11ax: 16 spatial streams

Background : Single-user spatial processing

- Single-user techniques (802.11n/ac/ax)
  - SU-MIMO
    Up to min (Nap , Nsta) streams
    Only enabled for
    - High SINRs
    - Non-line-of-sight propagation
  - Beamforming
    Regulations do not allow to focus energy on a given spatial direction



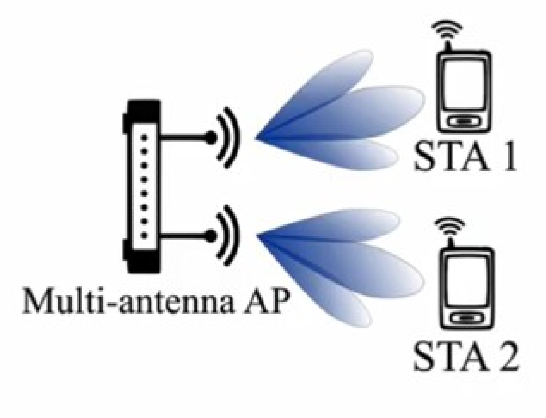
# Background: Spatial multiplexing

- Multi-user techniques(802.11ac)
  - Downlink MU-MIMO:

    802.11ac allows APs to transmit

    8 spatial streams simultaneous to 4 devices
  - Optional standard feature

    included in second-wave products

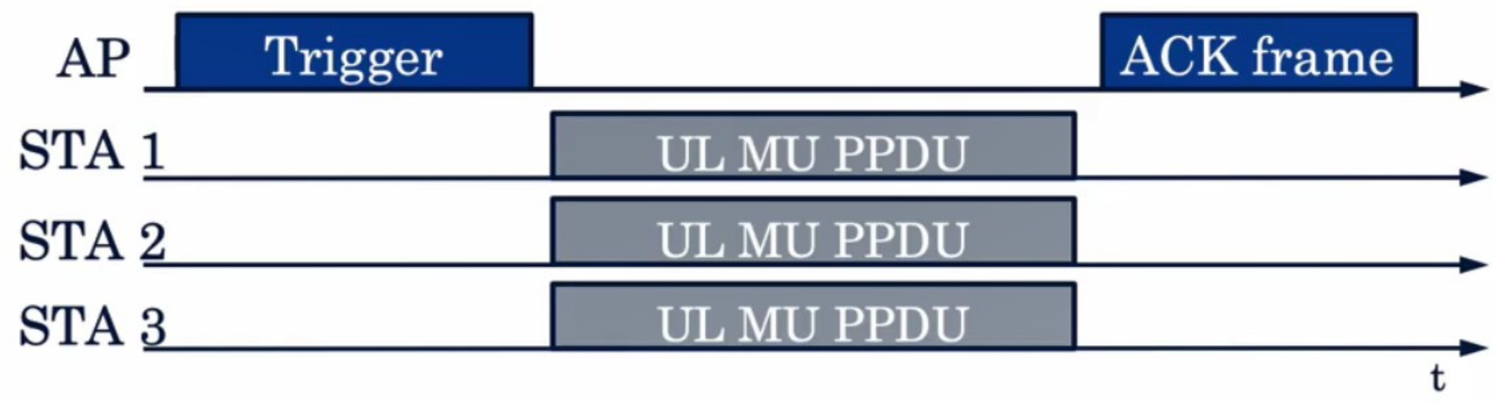



- Known issues:
  - Many STAs are single-antenna
  - STA channel sounding responses are serially transmitted
  - Downlink TCP/IP traffic with uplink ACKs suffers

    because no uplink MU-MIMO is allowed

# Spatial multiplexing in 802.11ax

- Multi-user techniques
  - Downlink and uplink  MU-MIMO:802.11ax allows to transmit 8 spatial streams simultaneously to 8 devices
  - UL MU-MIMO requires UL transmit power control, frequency alignment, and time synchronization



# 16spatial streams in 802.11be

- Support of up to 16 spatial streams
- Enhance channel state information (CSI) acquisition
  - Current approach based on explicit feedback does not scale well
  - Implicit CSI acqucuisition leveraging channel reciprocity
  - Potential overhead reduction for systems with 8 and 16 spatial streams

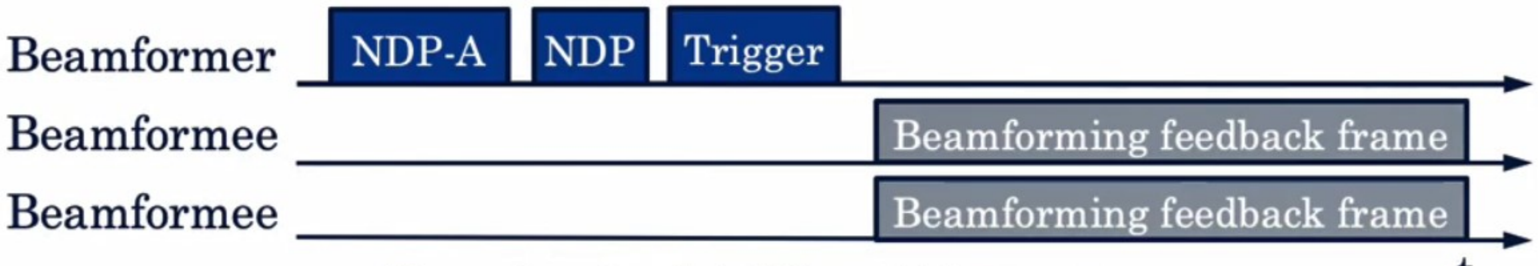
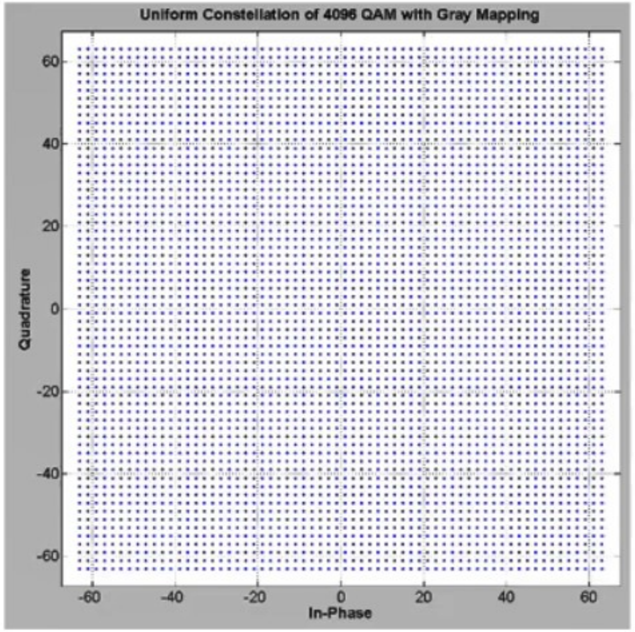


Illustration of explicit CSI acquisition process

# Key upgrades from 802.11ax: 4K QAM

4K-QAM transmissions in 802.11be

- The typical short ranges of 802.11 favors the use of high MCSs:
  - 1024-QAM already supported in WIFI 6 as an optional feature
- The use of 4k-QAM seems feasible in configurations with:
  - transmit beamforming,
  - low number of spatial streams, and
  - strict receive EVM requirements and/or multiple receive antennas

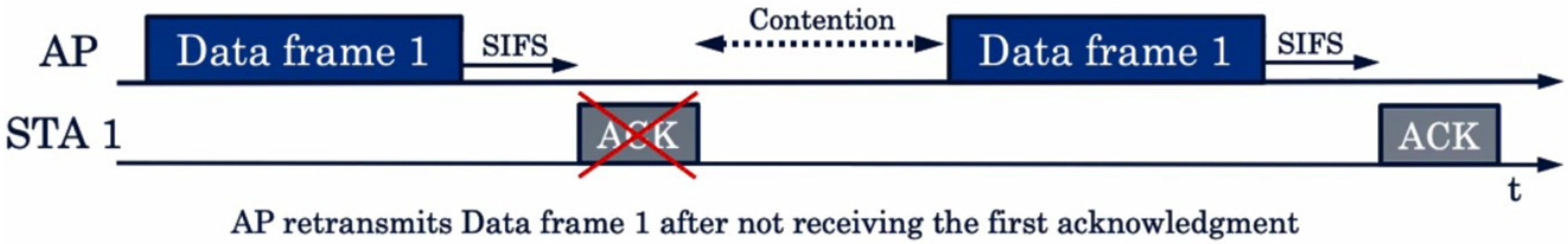



**4k-QAM constellation**

# Disruptive new features in 802.11be:HARQ

Automatic repeat request (ARQ) in 11n/ac/ax

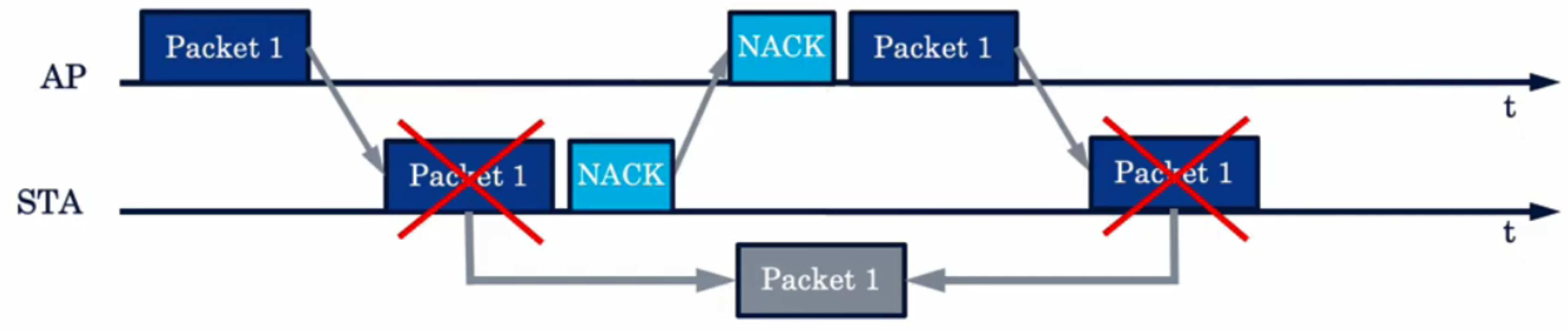
- Lack of acknowledgement (ACK) triggers frame retransmissions




- Block ACKs used to acknowledge multiple frames simultaneously

# Hybrid ARQ (HARQ) in 11be

- Boosting link adaptation via more efficient re-tx
  - Theoretical SNR gains in the order of 4 to 6 dB
  - Already discussed in 11ac and11ax standardization
- Main concern: HARQ might not be robust against collisions caused by the unpredictable interference conditions in 802.11



# Disruptive new features in 802.11be: Multi-link operation

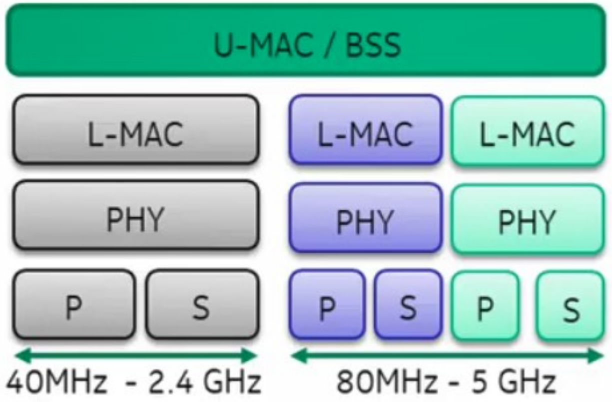
- What does “multi-link” actually mean?

  Think of it as multi-band or multi-channel
- This feature has attracted great

  interest, since:
  - many APs already operate in three bands

    (e.g., 2.4, low-5, and high-5GHz)
  - many STAs are dual-band
  - 6GHz band will be available for unlicensed use
- Main target: make a more efficient use

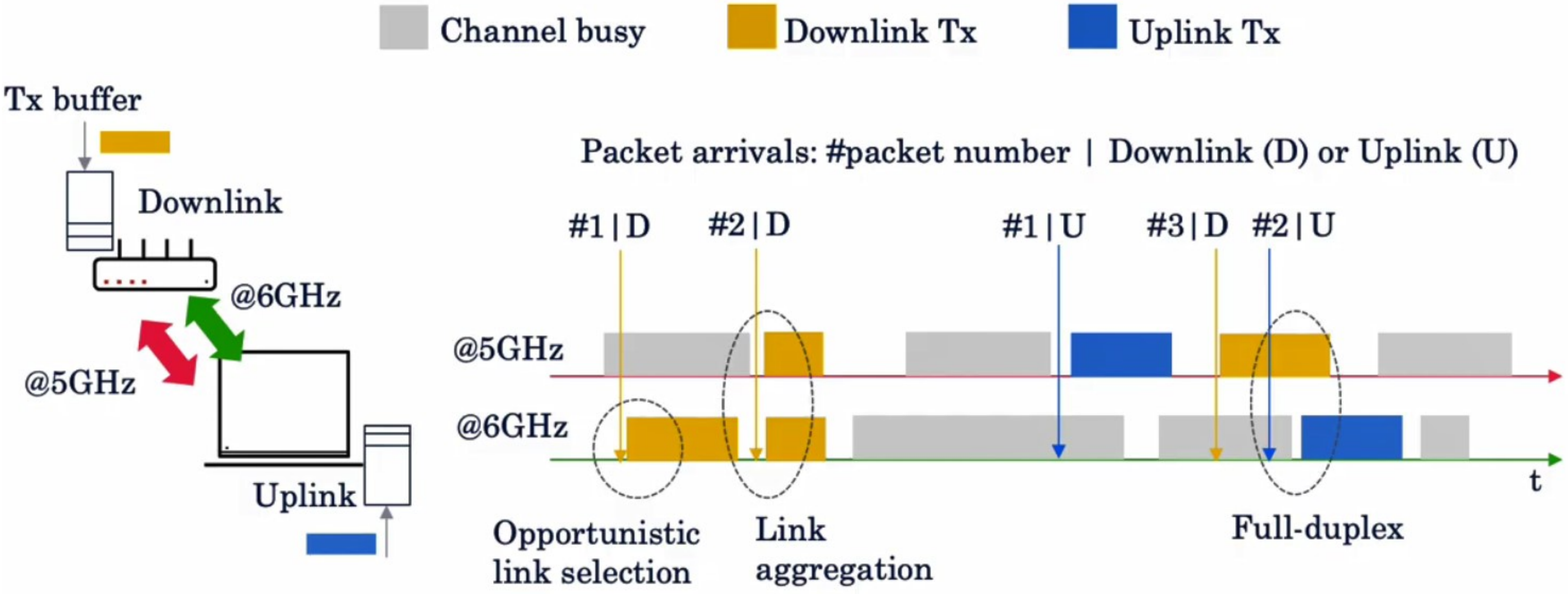
  of multiple bands/channels




Protocol stack and channel allocation of an illustrative multi-link device

- Simultaneous use of 2.4GHz, 5GHz, and 6GHz bands:
  - Load balancing according to traffic needs
  - Data aggregation in different bands
  - Data tx/rx separated in different bands
    - E.g., low bands for uplink and high bands for downlink
  - Control and data plane separated in different bands
    - E.g., low bands for control info and high bands for data tx/rx

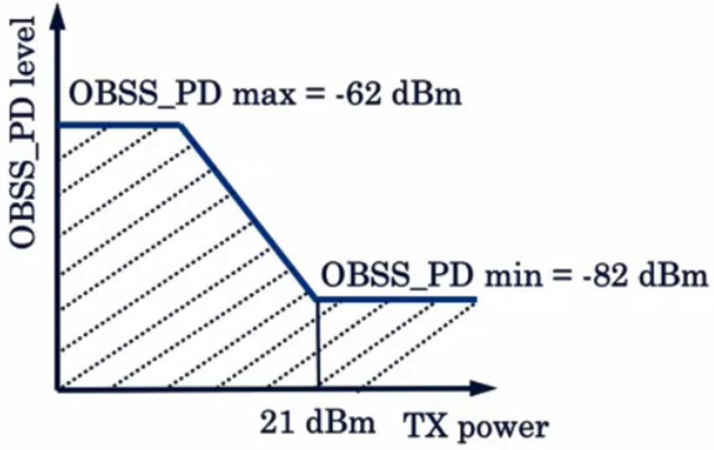
# Multi-link operation: Example



# Disruptive new features in 802.11be: Low-complexity AP coordination

## Uncoordinated spatial reuse in 802.11ax

### OBSSs/PD




TX power function of RX power

### Parameterized Spatial Reuse (PSR)

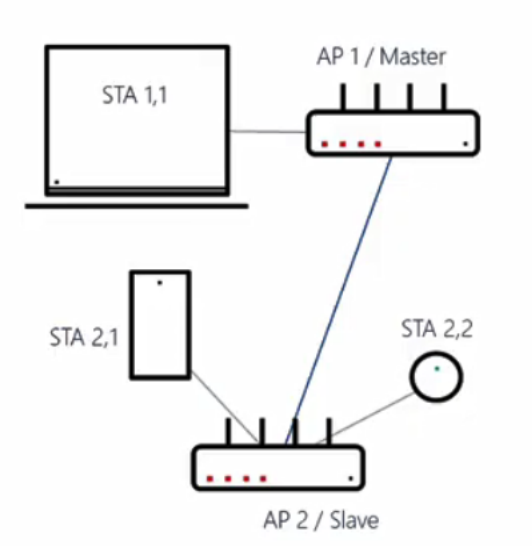
AP activates SR via trigger frame

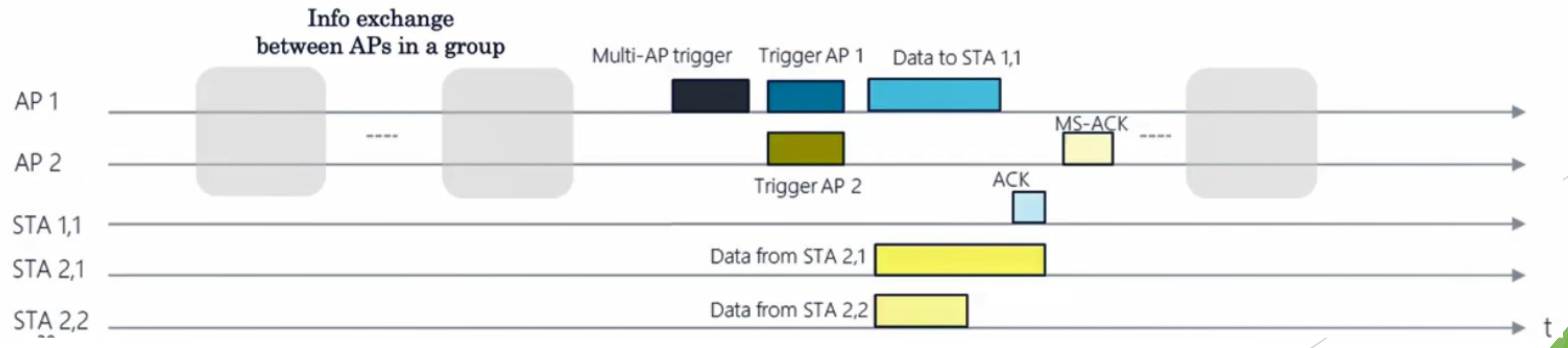
SR opportunities identified, TX power adjusted


max TX duration shorter than that of the SR-enabling AP

# AP coordination in 802.11be

- Nearby Aps coordinate their TX:
  - Avoid channel contention, improve resource sharing
  - Time/frequency or power coordination (over the air)
- Challenges:
  - Overhead, creation/management of multi-AP groups
  - Master AP requires channel/buffer/node state for all STAs



# Coordinated OFDMA in 802.11be

- Time/frequency coordination: OFDMA
  - Aps jointly allocate time/freq. resources
  - Minimize inter-BSS collisions
  - More efficient use of spectrum resources

- Channel allocation to the different BSSs
  - To overlap or not to overlap?

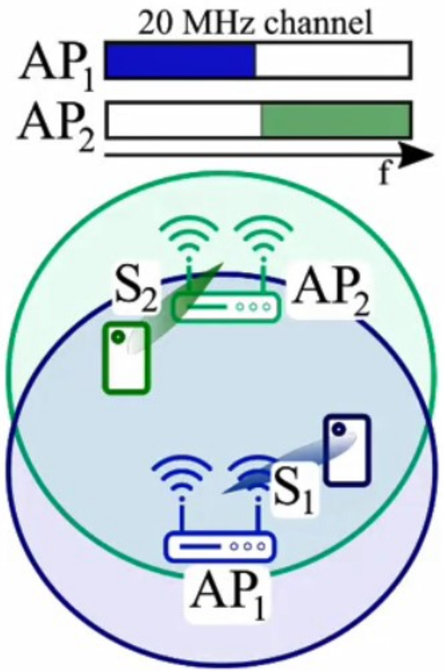



Illustration of coordinated OFDMA

# Coordinated spatial reuse in 802.11be

- Power coordination: Spatial reuse (SR)
- 802.11ax facilitates a more aggressive channel access

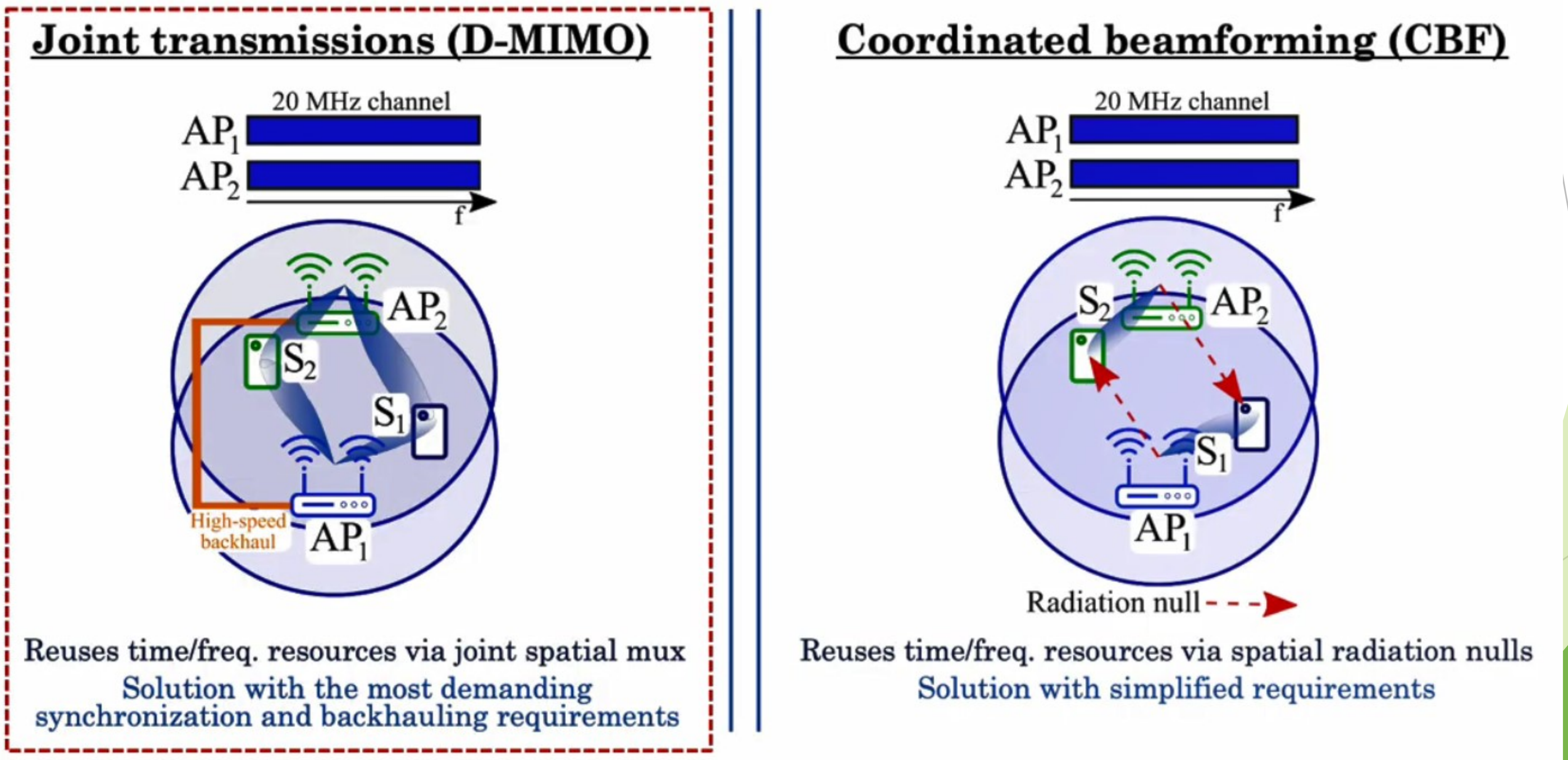
  channel access decisions solely based on measured power
- 802.11be may allow Aps to jointly schedule their transmissions

  Objective: Enhance spatial reuse preventing “uncontrolled” collisions


Non-coordinated TX:
generates a collision

Coordinated TX:
AP1 reduces its TX power to prevent the collision

# Disruptive new features in 802.11be: Advanced AP coordination

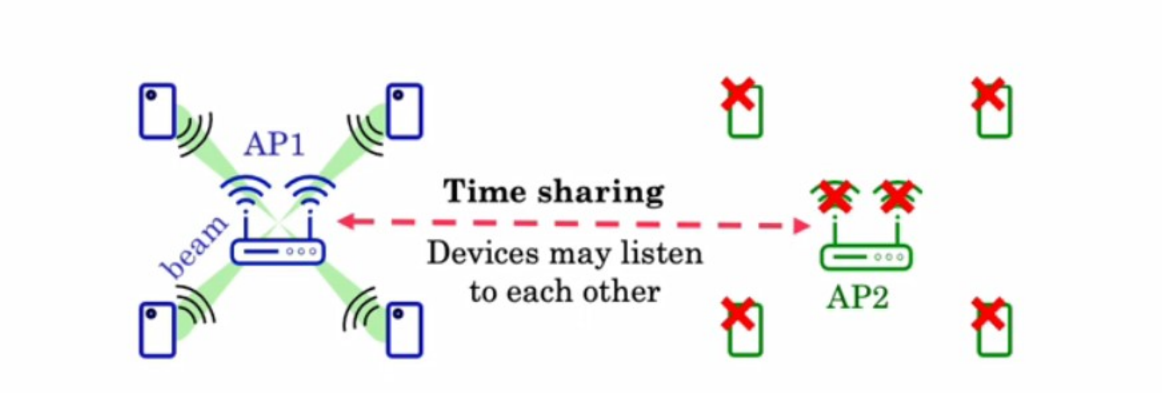


# Performance evaluation: Coordinated beamforming

System models: scenarios

1. Baseline system without PSR

- Spectrum shared according to CSMA/CA

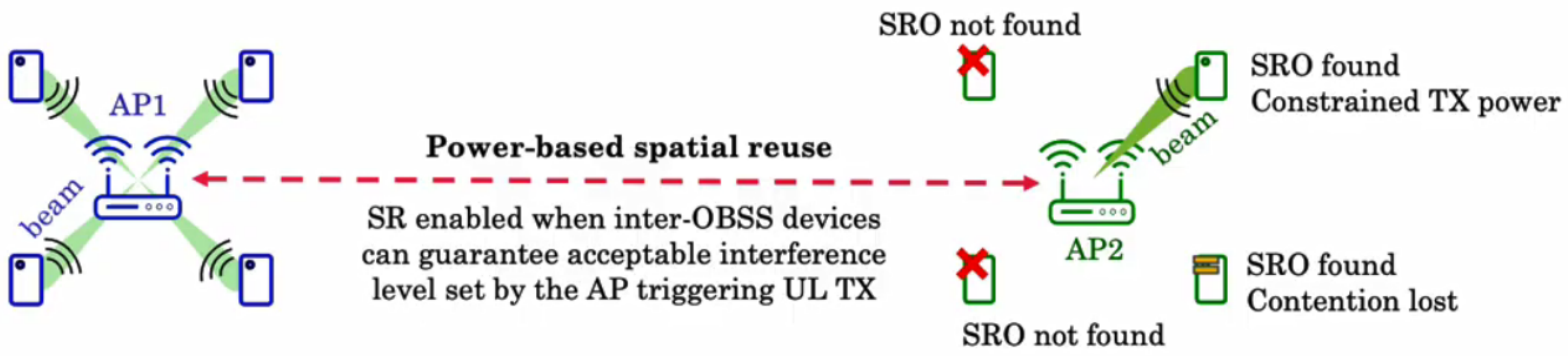


1. Baseline system without PSR

- Spectrum shared according to CSMA/CA

2. System with PSR

- When triggering uplink TX, APs may grant SROs to inter-BSS STAs



1. Baseline system without PSR

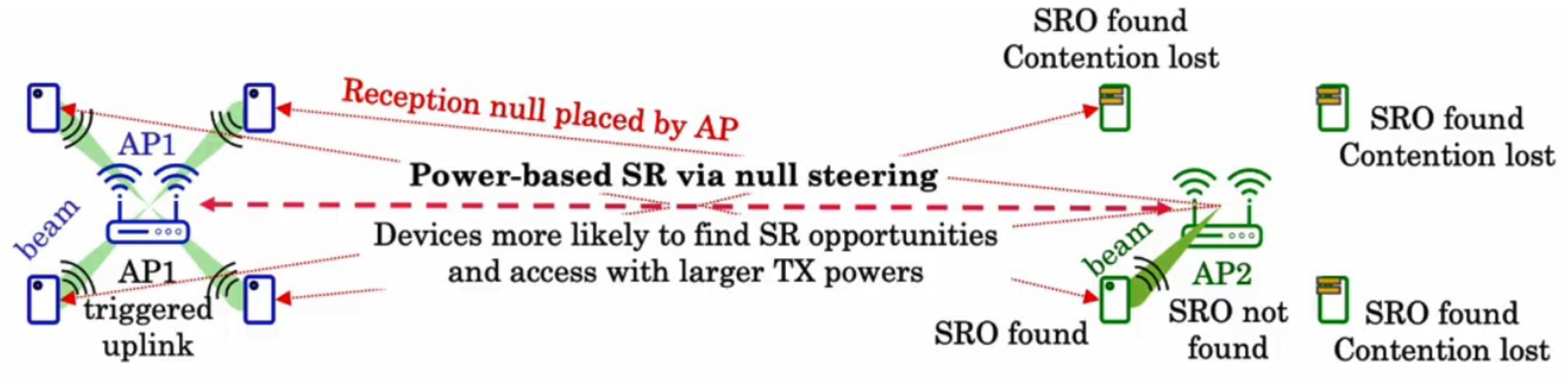
- Spectrum shared according to CSMA/CA

2. System with PSR

- When triggering uplink TX, APs may grant SROs to inter-BSS STAs

3. System with PSR and coordinated beamforming/null steering

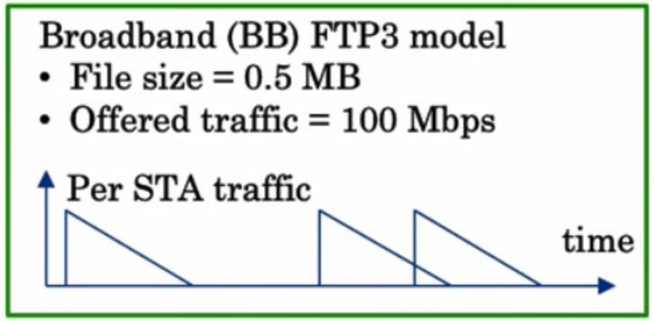
- When triggering uplink Tx, APs may steer radiation nulls and grant SROs to inter-BSS STAs

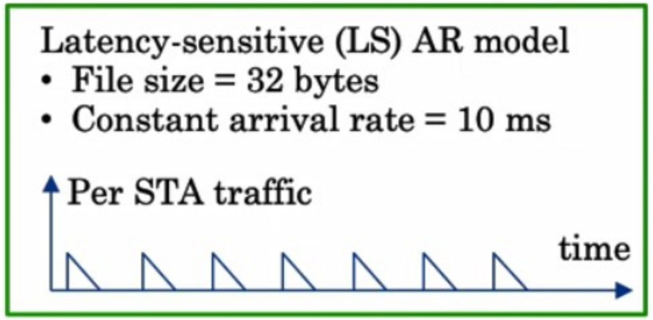


# System model: traffic and scheduling

- Traffic:
  - ➢ Uplink broadband FTP traffic
  - ➢ Uplink latency-sensitive AR traffic

- Scheduling:
  - ➢ When triggering uplink, APs spatially multiplex as many STAs as possible of a class per TXOP
  - ➢ Remaining spatial DoF suppress strongest interference from neighboring low-latency STAs



# System model: setup

| | |
|---|---|
| **Carrier / bandwidth** | 5.18GHz / 80MHz (1 channel) |
| **AP deployment** | 2 ceiling-mounted APs \| Inter-AP distance = 15 m \| AP height = 3 m |
| **STA deployment** | 16 broadband STAs uniformly distributed at height = 1 m<br>8 low-latency STAs uniformly distributed at height = 1 m |
| **AP RF** | 4x2 antenna array (0.5λ separation) \| AP max. Tx power = 24 dBm \| omni antenna elements \| NF = 7 dB |
| **STA RF** | STA max. Tx power = 15 dBm \| 1 omni antenna \| NF = 9 dB |
| **Channel model** | 3D spatial channel model (3GPP TR38.901 – InH) |
| **MAC configuration** | Max. # radiation nulls = 4 \| IP/MAC header overhead considered \| No EDCA \| No RTS/CTS \| Max. TXOP = 4 ms \| SNR-driven MCS selection |
| **PHY configuration** | PHY header overhead considered \| Spatial filter = ZF (w/ and w/o nulls) \| Omni PLCP header \| 11ax MCSs |

# Latency performance

- 11axw/ or w/o SR capabilities:
- ➢ latency<3 ms half the time, but
- ➢ in some cases, latency>200 ms
- 11be w/ CBF reduces worst-case latency by an order of magnitude:
- ➢ more aggressive spectrum access
- ➢ inter-BSS interference mitigation
- 11be W/ CDF also ~preserves the throughput* of broadband STA