

CS/ECE 439: Wireless Networking

802.11ax - High Efficiency WLANs

Early Wi-Fi standards: 802.11a/b/g

802.11b

1999

2.4 GHz
Up to 11 Mbps
DSSS modulation

802.11a

1999

5 GHz
Up to 54 Mbps
OFDM
modulation

802.11g

2003

2.4 GHz
Up to 54 Mbps
ERP-OFDM
(backward-compat.
w/ DSSS)

Trade-offs between range, speed, and frequency bands



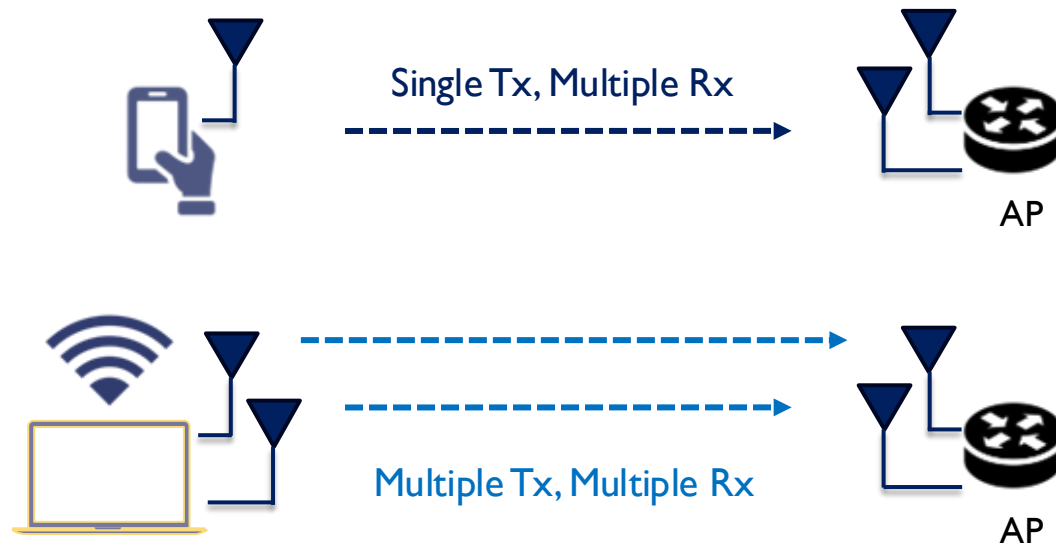
802.11n – Precursor to Modern Wi-Fi

- ▶ Introduced MIMO (Multiple input, Multiple output, SU-MIMO only)
- ▶ Dual-band operation on 2.4 GHz and 5 GHz
- ▶ Introduced channel bonding of 20MHz channels
- ▶ Theoretical max of 600 Mbps



MIMO

- ▶ Multiplies the capacity of a link using multiple Tx and Rx antennas



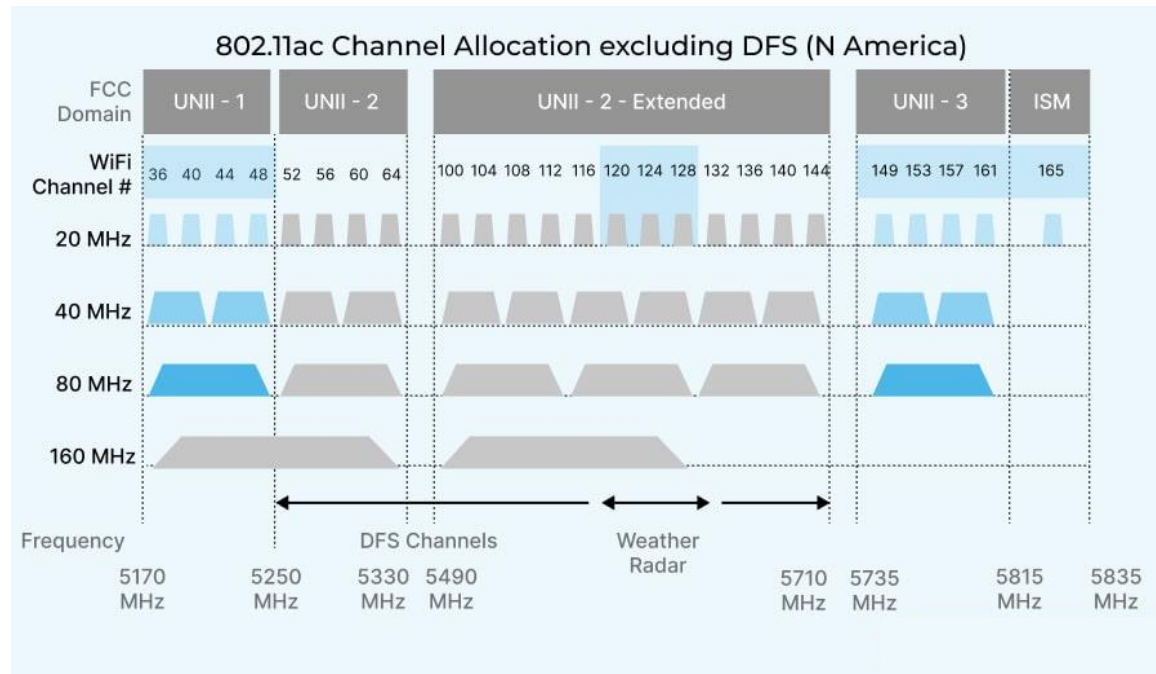
802.11ac – The Bridge to Wi-Fi 6

- ▶ Increased data rates to 3.5 Gbps
- ▶ Operates only in the 5 GHz band
- ▶ Expanded channel bonding to 80 MHz, 160 MHz, and 80+80 MHz
- ▶ DL MU-MIMO: Router transmits to multiple clients



802.11 Channel Bands

5 GHz band

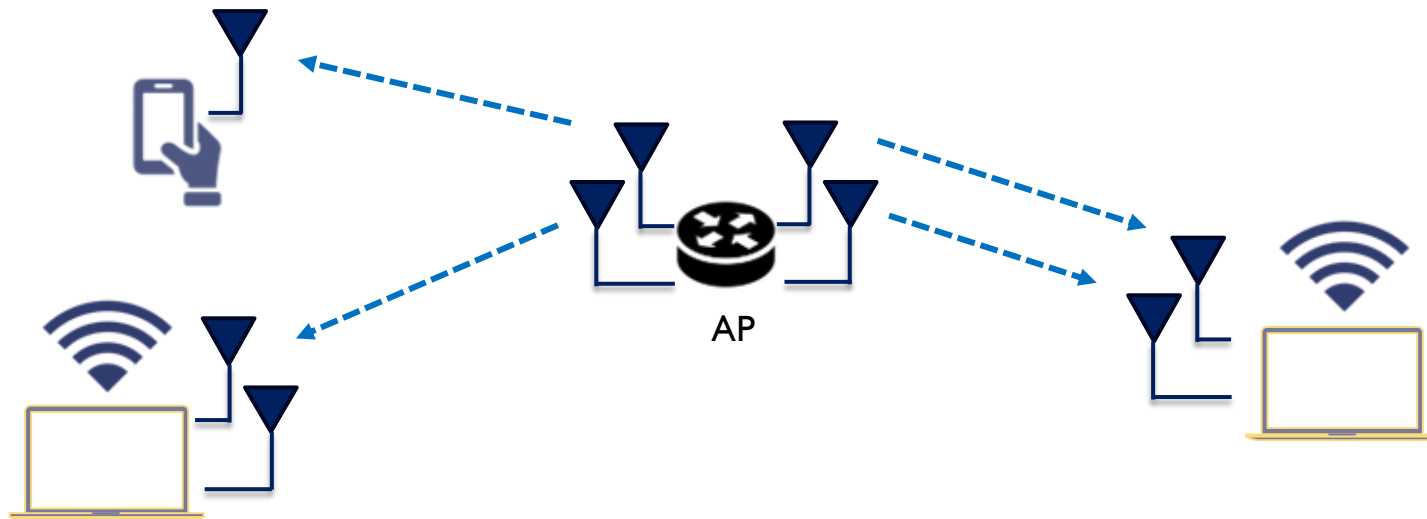


Wi-Fi 5 uses fixed bandwidth, but not all devices need it

<https://homeowner.com/connectivity/wifi-channel-width>

Downlink MU-MIMO

AP transmits separate spatial streams to multiple clients at once



DL MU-MIMO Constraints

- ▶ Only worked with up to 4 client devices
- ▶ Clients still need to take turns when transmitting
- ▶ Requires Channel State Information feedback from clients (management traffic overhead)
- ▶ No uplink synchronization



Limitations of Legacy Standards

- ▶ Multiuser scheduling only worked on the downlink
- ▶ Dense areas suffered from low throughput, interference
- ▶ High MAC layer overhead for short frames
- ▶ QoS for time-sensitive apps needed improvement



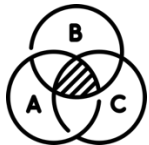
Key Features of 802.11ax



- ▶ Speed improvement of up to 9.6 Gbps
 - ▶ 1024-QAM
 - ▶ Uplink MU-MIMO



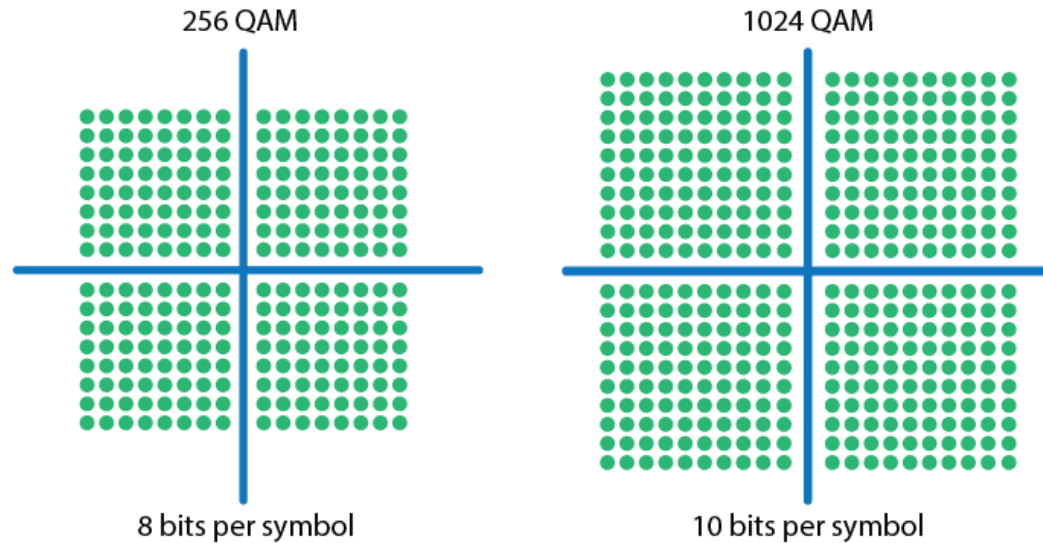
- ▶ Channel Efficiency improvements
 - ▶ OFDMA
 - ▶ Up to 160 MHz channels
 - ▶ Target Wake Time



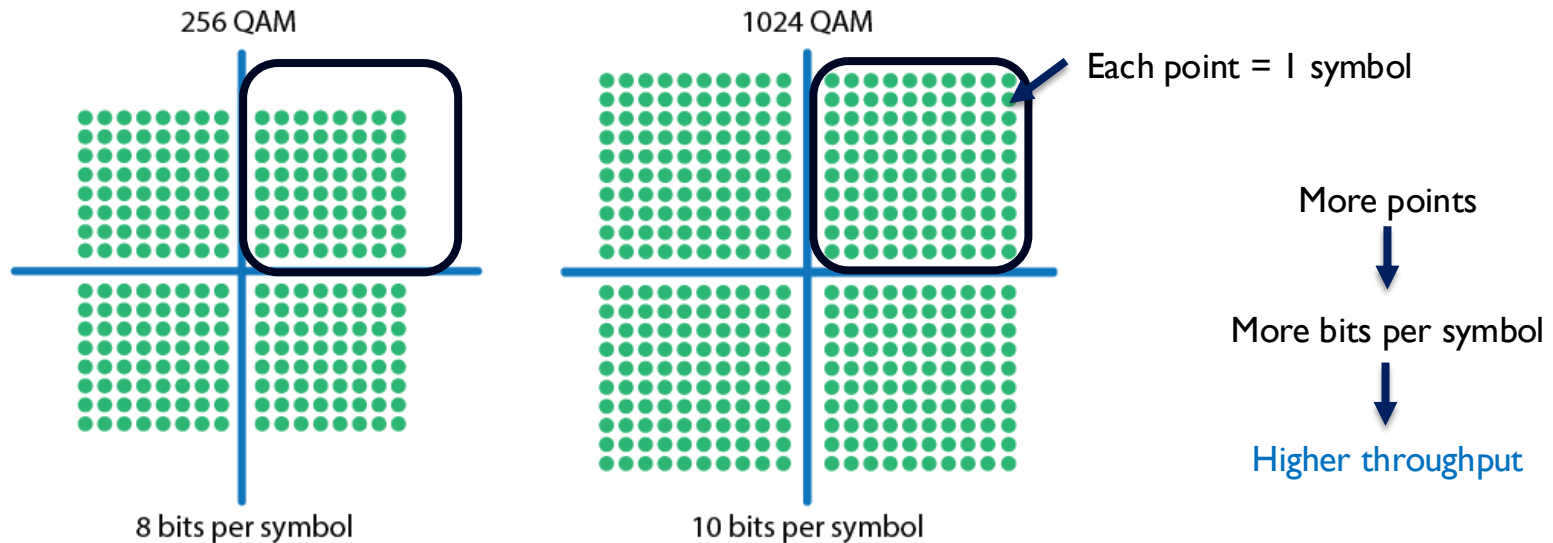
- ▶ Interference improvements
 - ▶ BSS Coloring



Modulation Enhancements



Modulation Enhancements



25% higher capacity per symbol

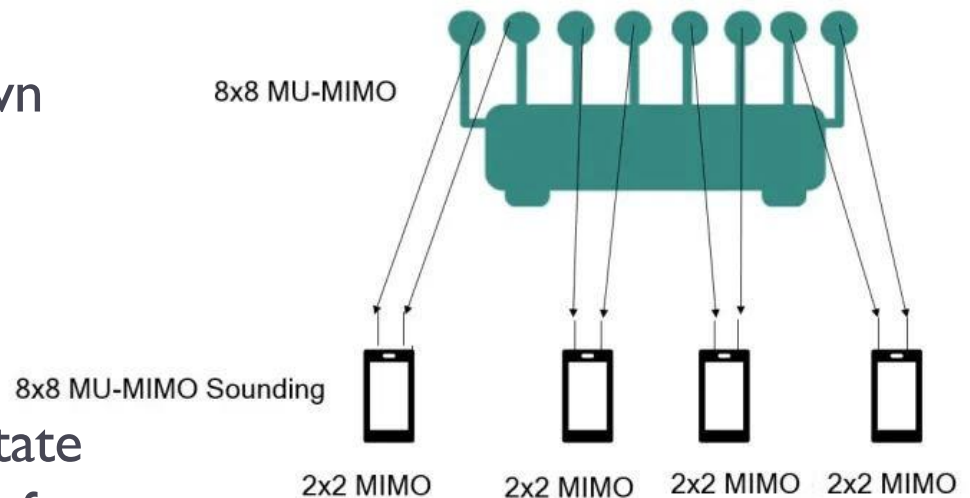
MU-MIMO Enhancements

- ▶ Increased from 4x4 (Rx:Tx antennas) in Wi-Fi 5 to 8x8 in Wi-Fi 6
- ▶ Supports simultaneous communication with multiple devices
- ▶ Enables both uplink and downlink MU-MIMO



MU-MIMO: Precoding

- ▶ Requires precoding at the AP
 - ▶ AP computes per-client spatial weights
 - ▶ Each client sees only its own stream
- ▶ Cost of MU-MIMO
 - ▶ Needs accurate Channel State Information (CSI) feedback from every client
 - ▶ AP needs more antennas than simultaneous streams being sent



Orthogonal Frequency Division Multiple Access - OFDMA

- ▶ Splits subcarriers (frequencies) into groups of bandwidths
- ▶ Shares the channel among multiple devices simultaneously
- ▶ Difference from MU-MIMO: divide bandwidth instead of different spatial streams



Resource Units



- ▶ RUs are the allocation blocks of bandwidth in OFDMA



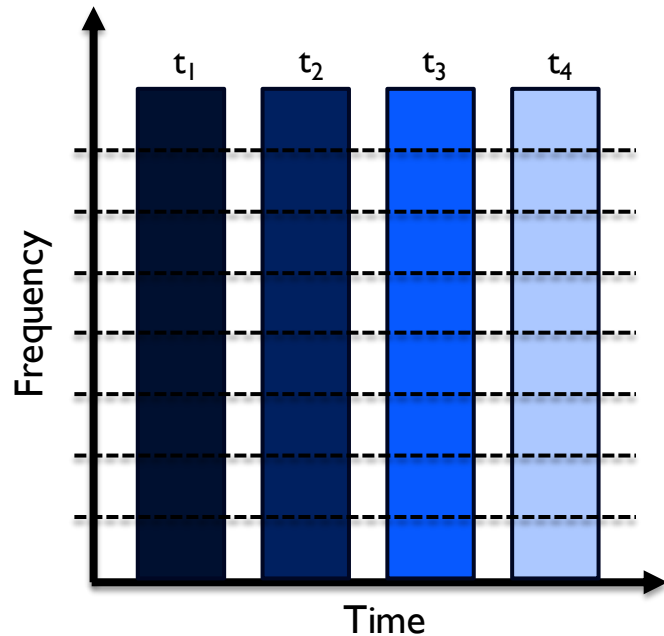
- ▶ Vary in size depending on channel width



- ▶ Adjacent subcarriers (tones) are grouped together into a resource unit (RU)

OFDM vs. OFDMA

OFDM (Previous generations)

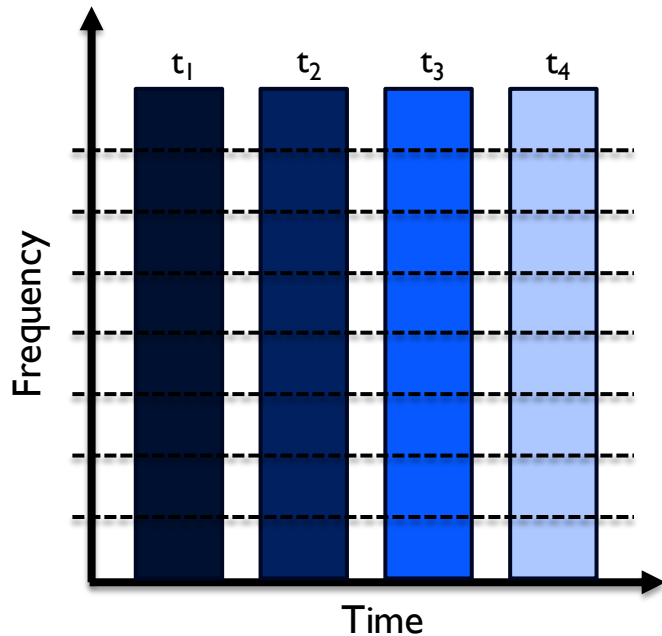


Previous standards have clients use the **entire channel** to transmit data



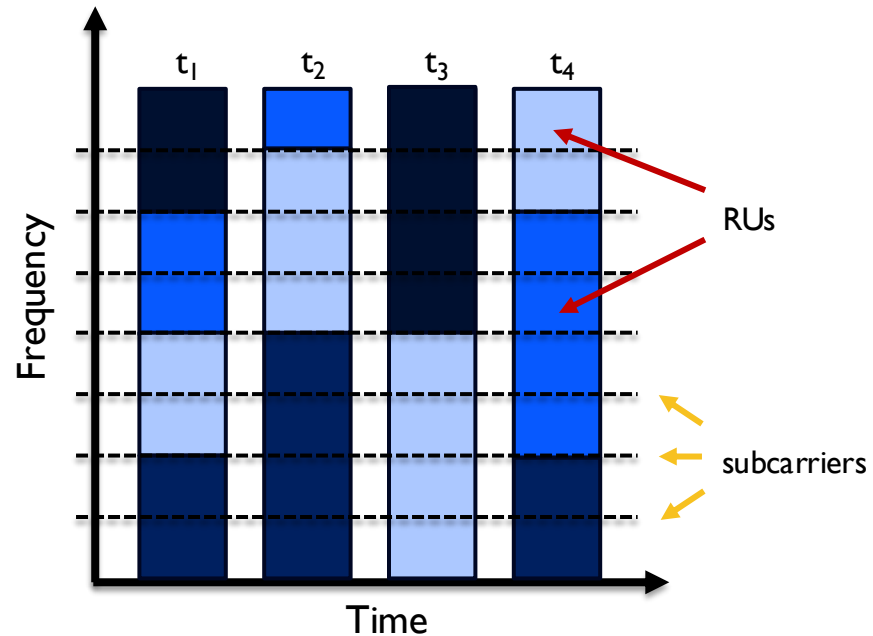
OFDM vs. OFDMA

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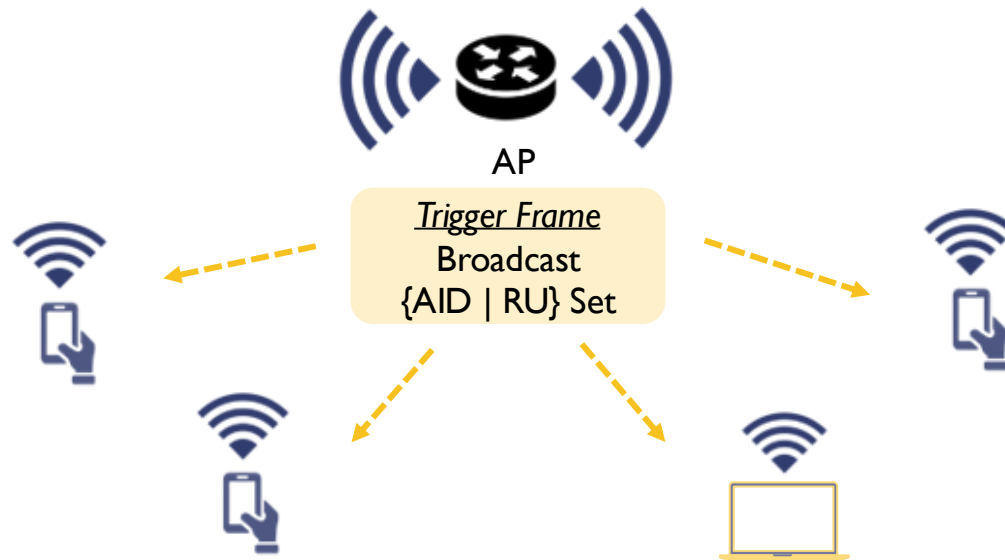
OFDMA (Wi-Fi 6)



OFDMA configures traffic for **multiple user packets per time segment**, increasing spectrum efficiency

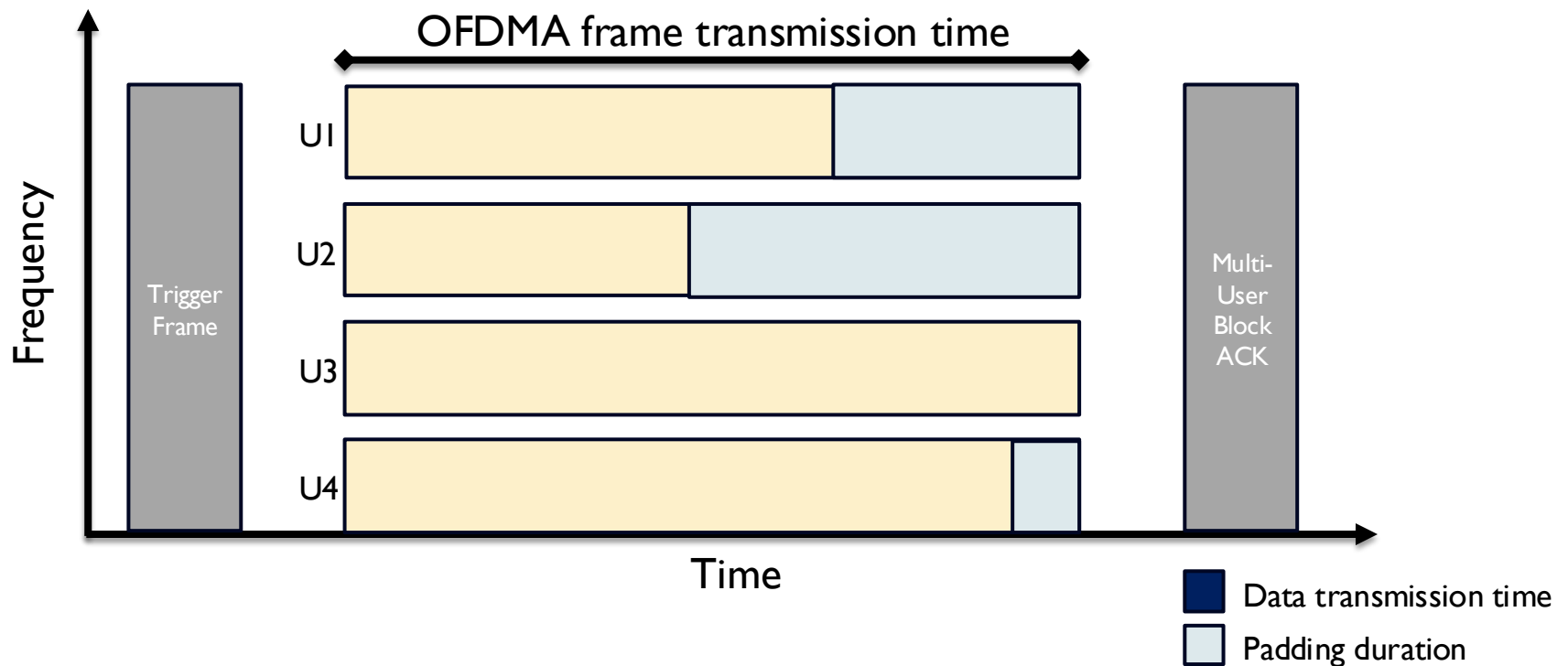
Assigning Bandwidths to Devices

- ▶ RUs are allocated by the AP, determined by traffic demand

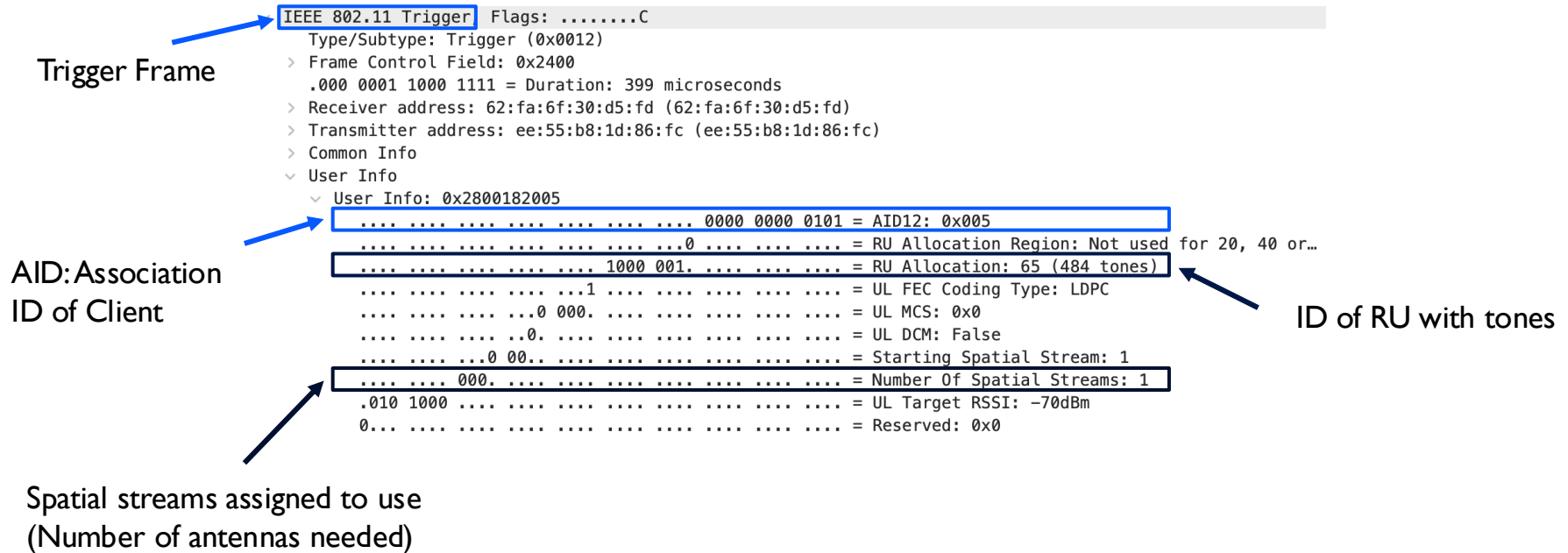


Trigger Frames define the RUs that devices can use

Transmission Time Utilization

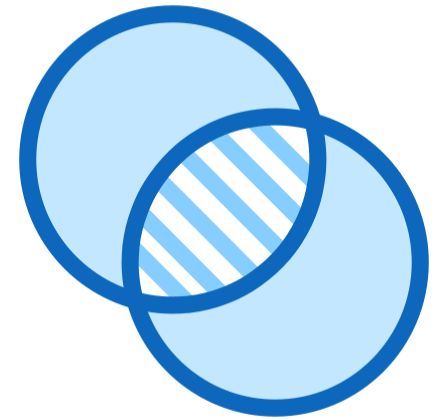


Assigning Bandwidths to Devices

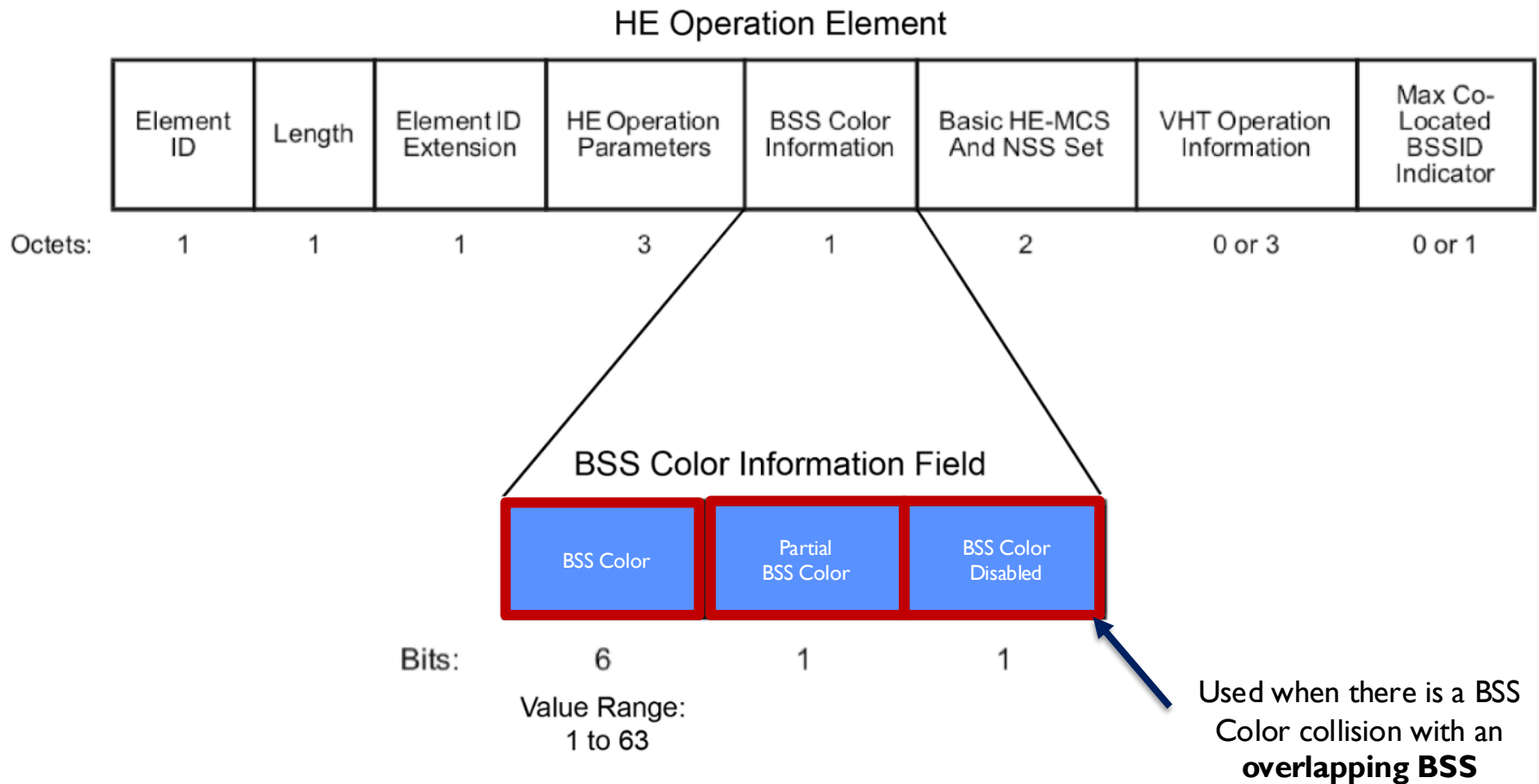


BSS Coloring

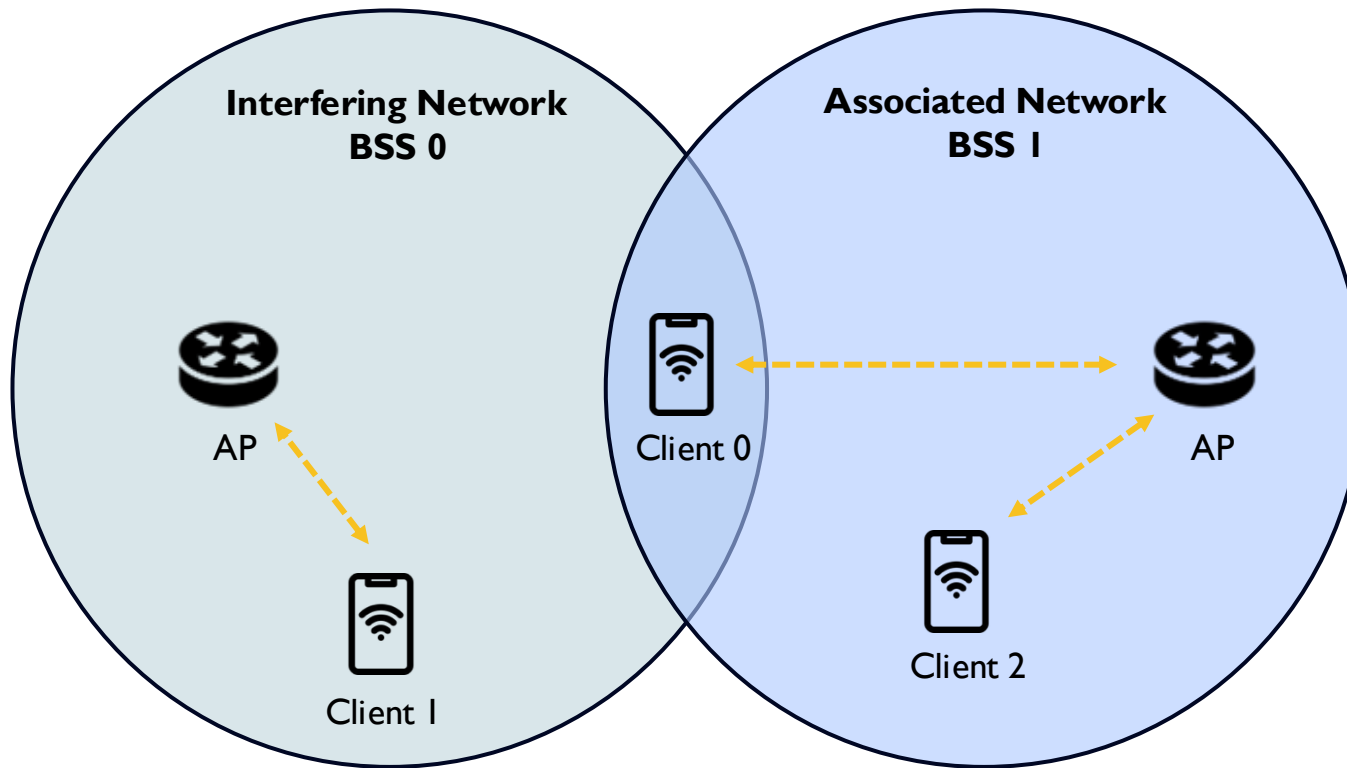
- ▶ Reduces interference from nearby APs
- ▶ Improves coexistence between multiple APs in dense deployments



BSS Coloring

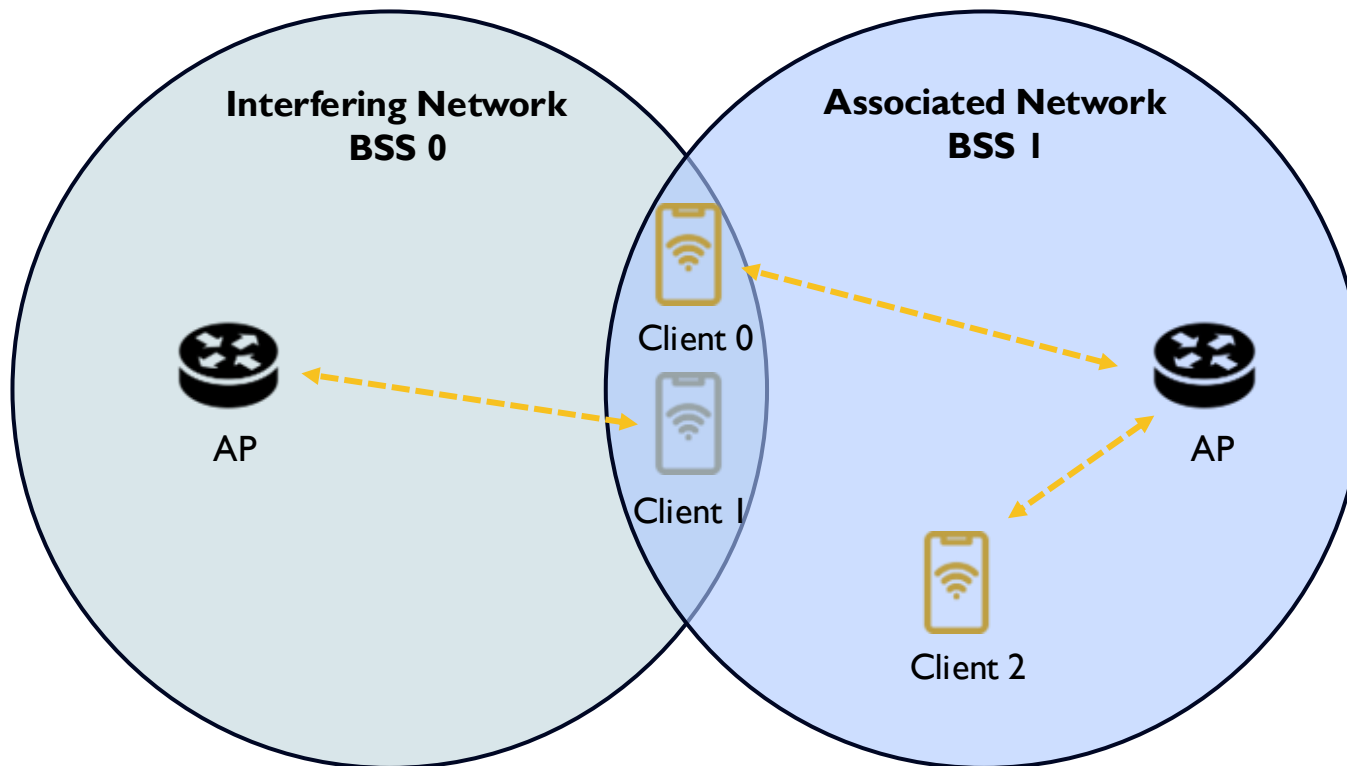


BSS Coloring Example



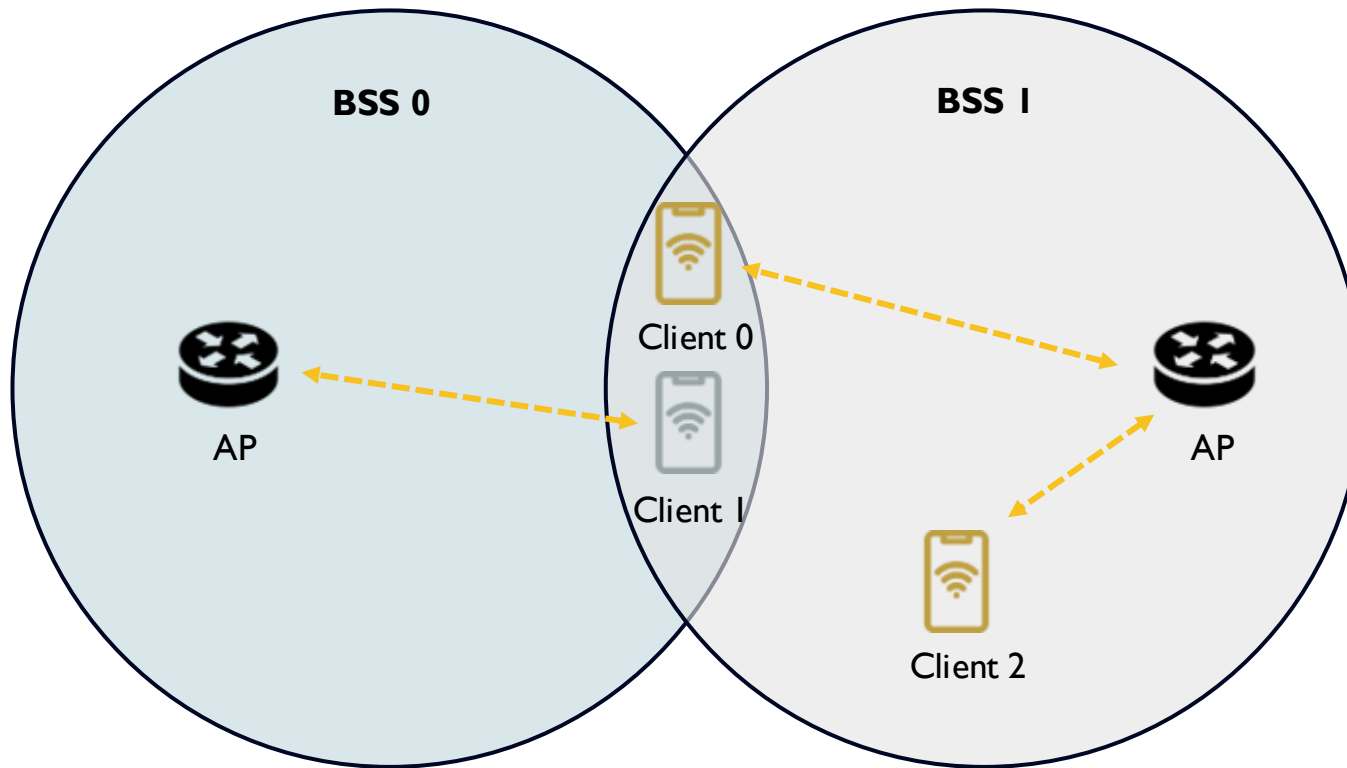
In range of
interfering AP
signal, so
check
preamble bits

BSS Coloring Example



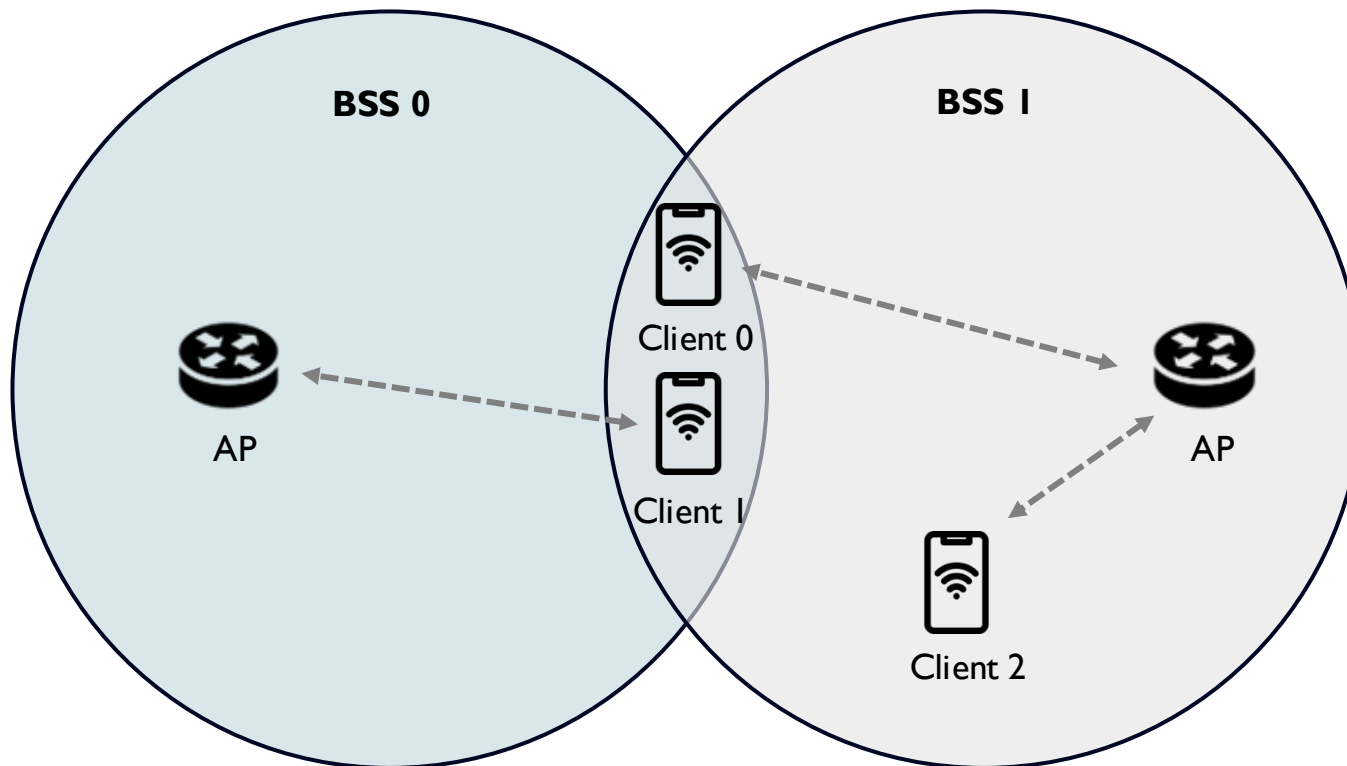
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BSS Coloring Example



Problem!
Both BSS
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same color, a
color collision

BSS Coloring Example



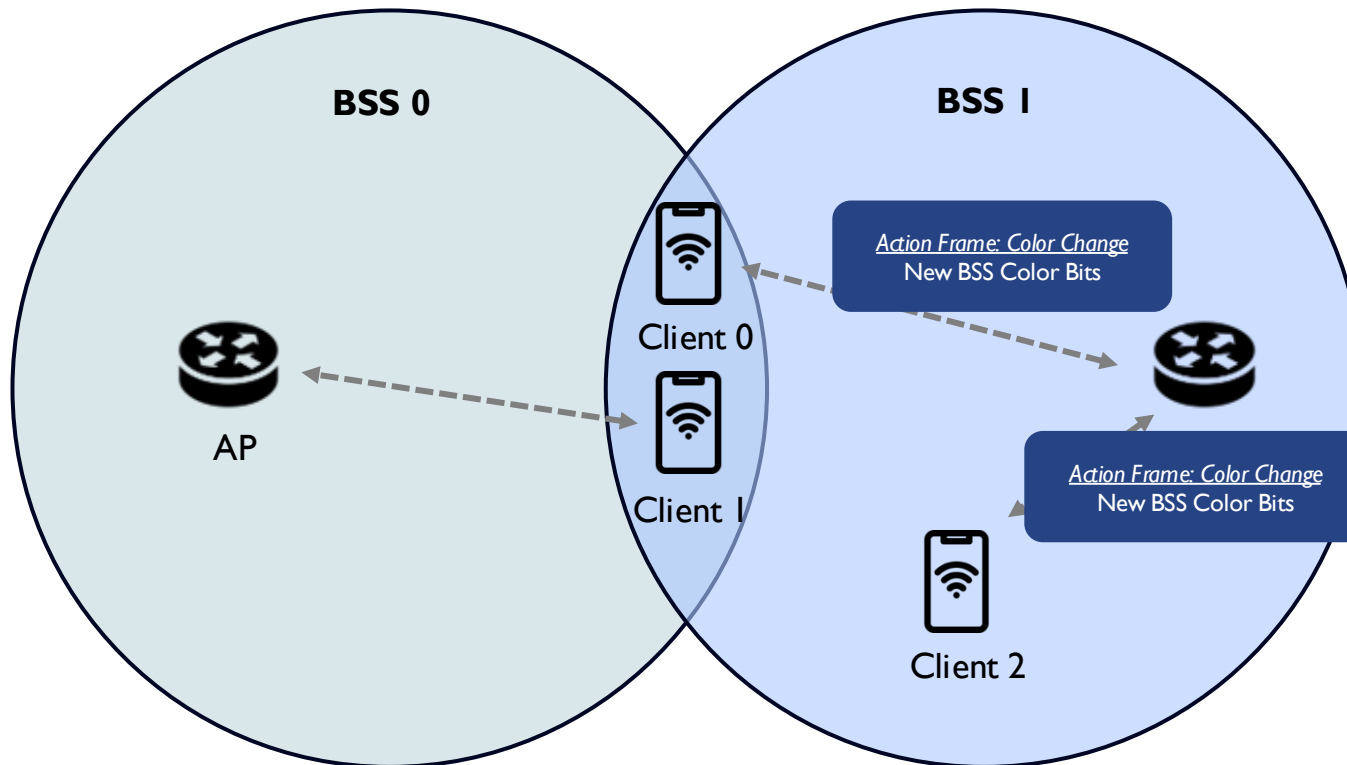
Problem!

Both BSS networks use the same color, a **color collision**

Solution:

Turn off the color, but **fall back to legacy medium access**

BSS Coloring Example



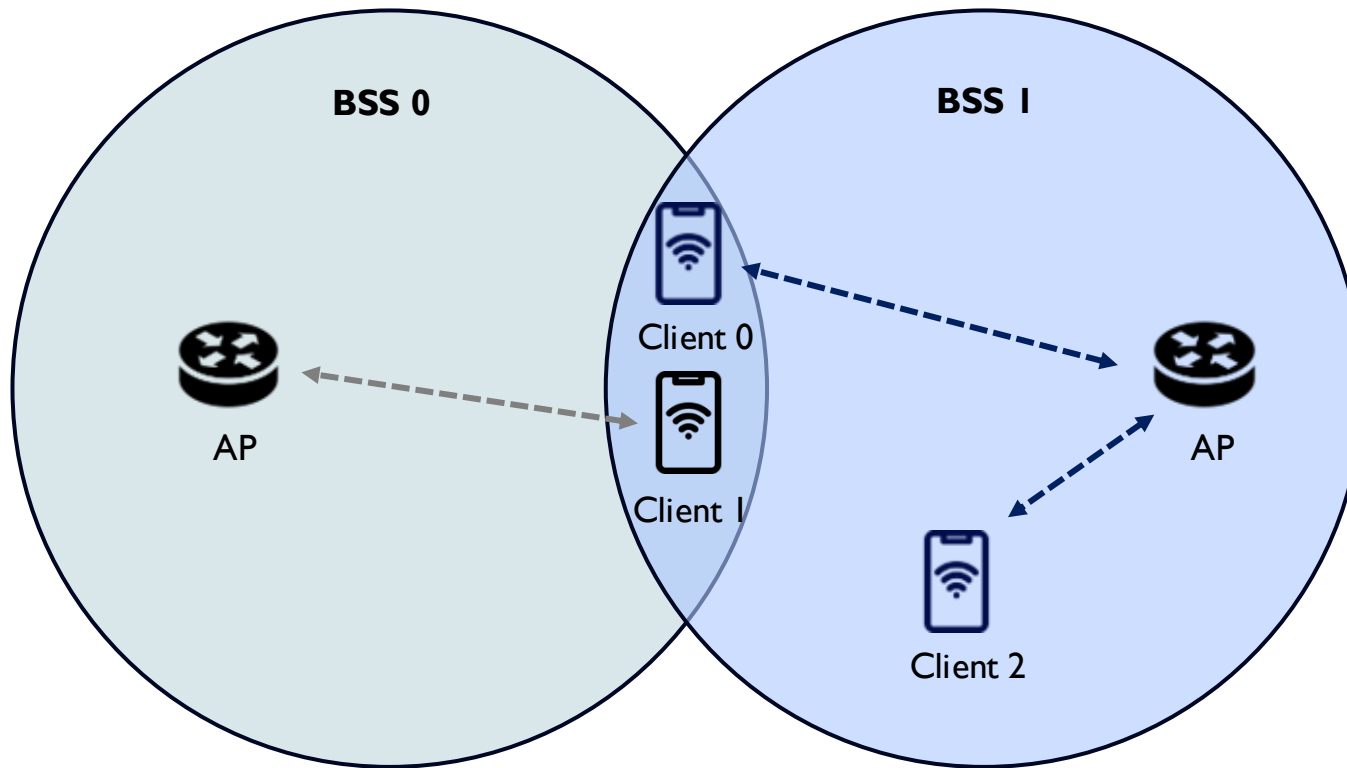
Problem!

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Better Solution:

Use a **Color Change Announcement**

BSS Coloring Example



Problem!

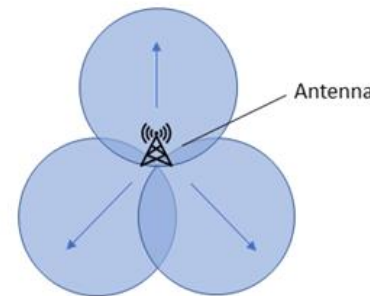
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Better Solution:

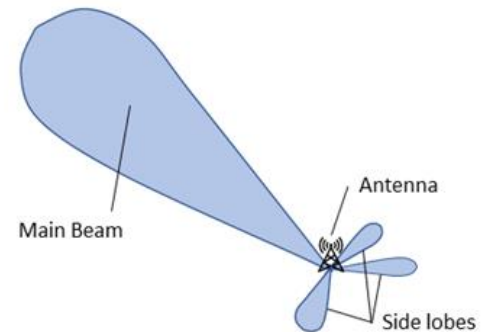
Use a **Color Change Announcement**

Beamforming

- ▶ Idea: instead of radiating a signal equally in all directions, weight the phase/amplitude at each transmit antenna
 - ▶ Signal copies combine constructively at the receiver
 - ▶ ...and destructively in other directions
- ▶ Requires Channel State Information (CSI)
 - ▶ Transmitter needs to know how the channel distorts the signal to that specific client, then pre-compensates



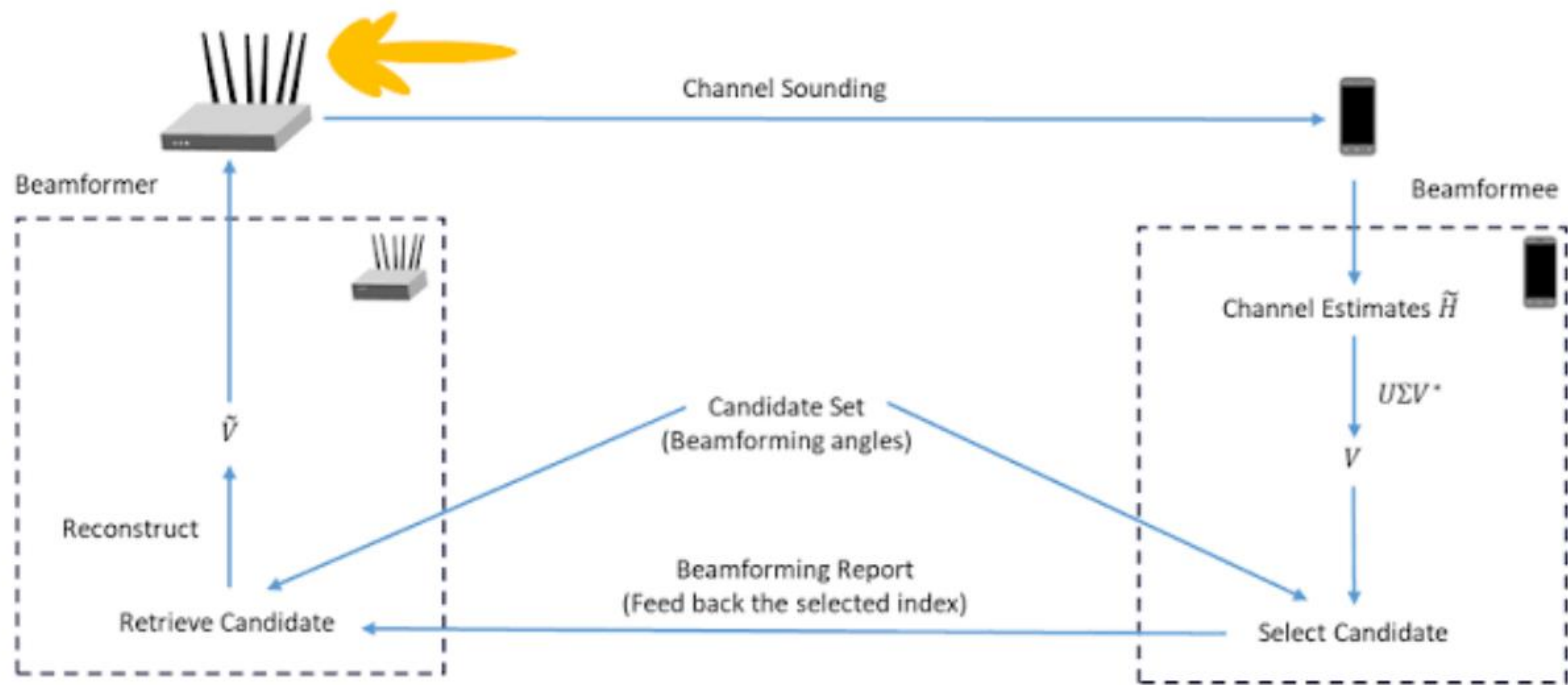
Sectored Antenna Array



Beamforming Antenna Array

Beamforming

- ▶ 802.11ac/ax explicit beamforming procedure
 - ▶ AP sends a sounding frame
 - ▶ Client measures the channel, feeds back a compressed CSI matrix
 - ▶ AP computes per-antenna beamforming weights from the feedback

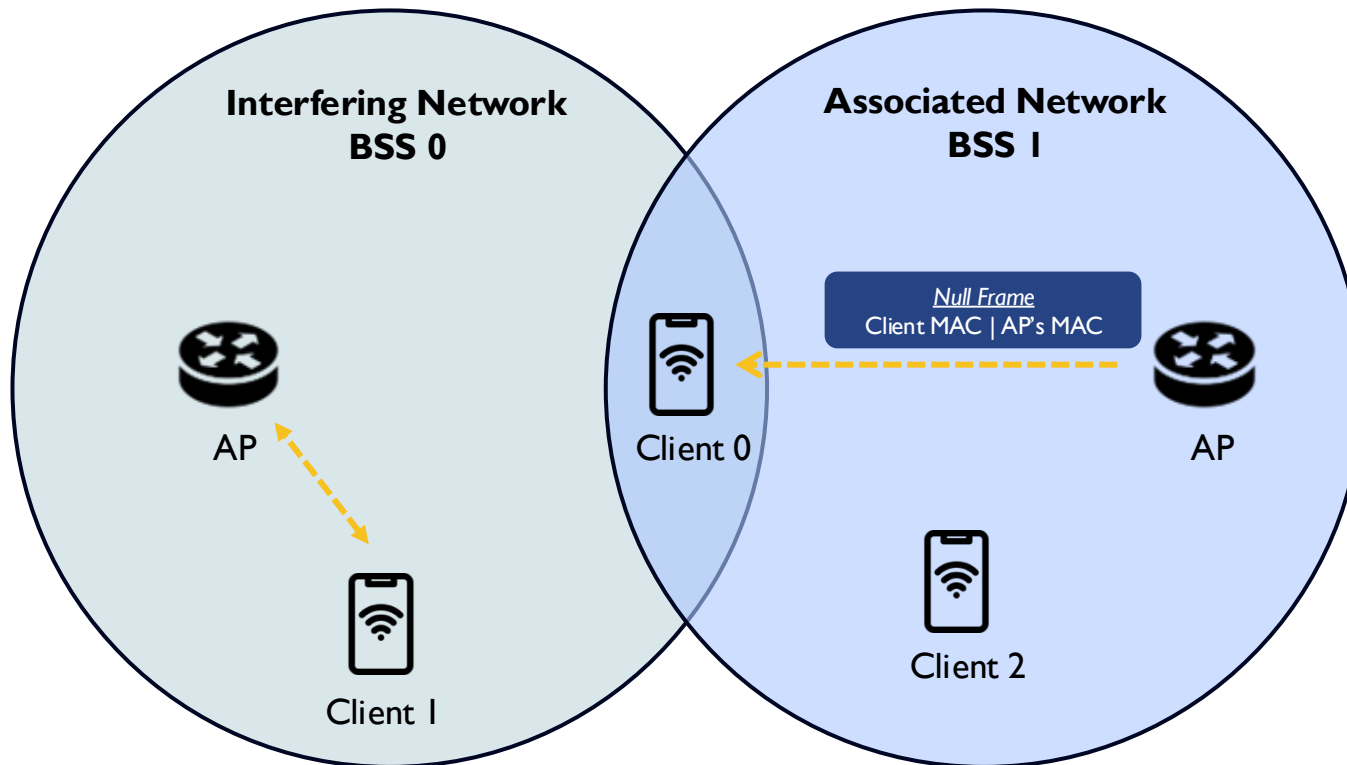


Beamforming

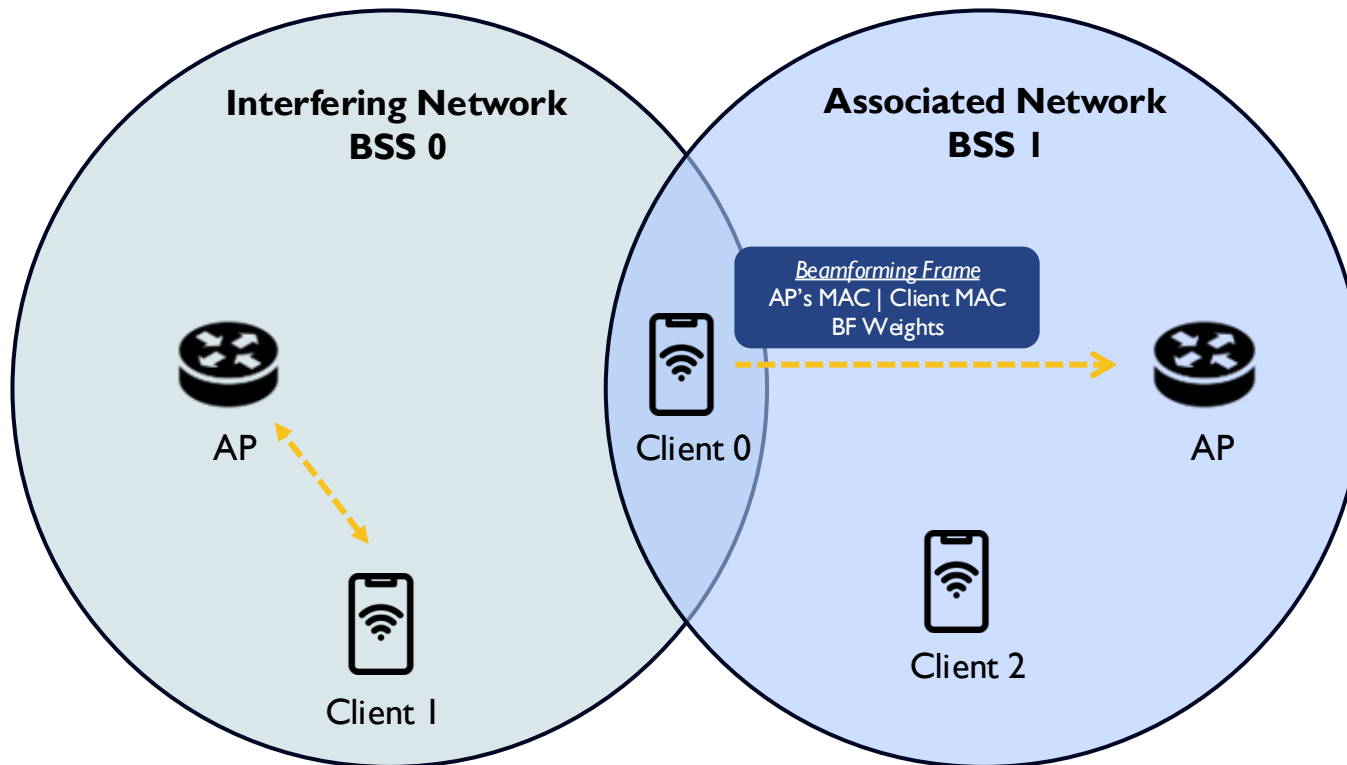
- ▶ Enables dynamic adjustment of the wireless signal direction
- ▶ Minimizes interference from nearby networks using BSS coloring



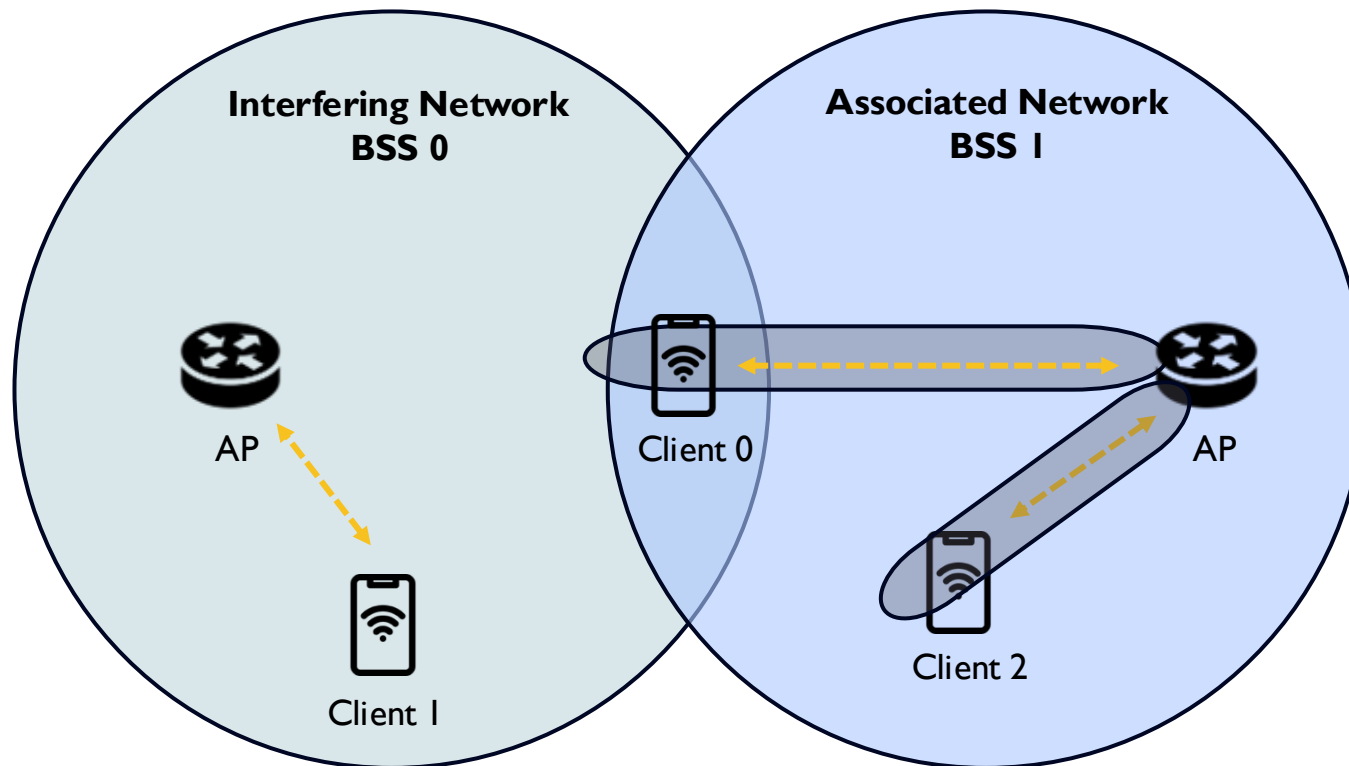
Beamforming Example



Beamforming Example

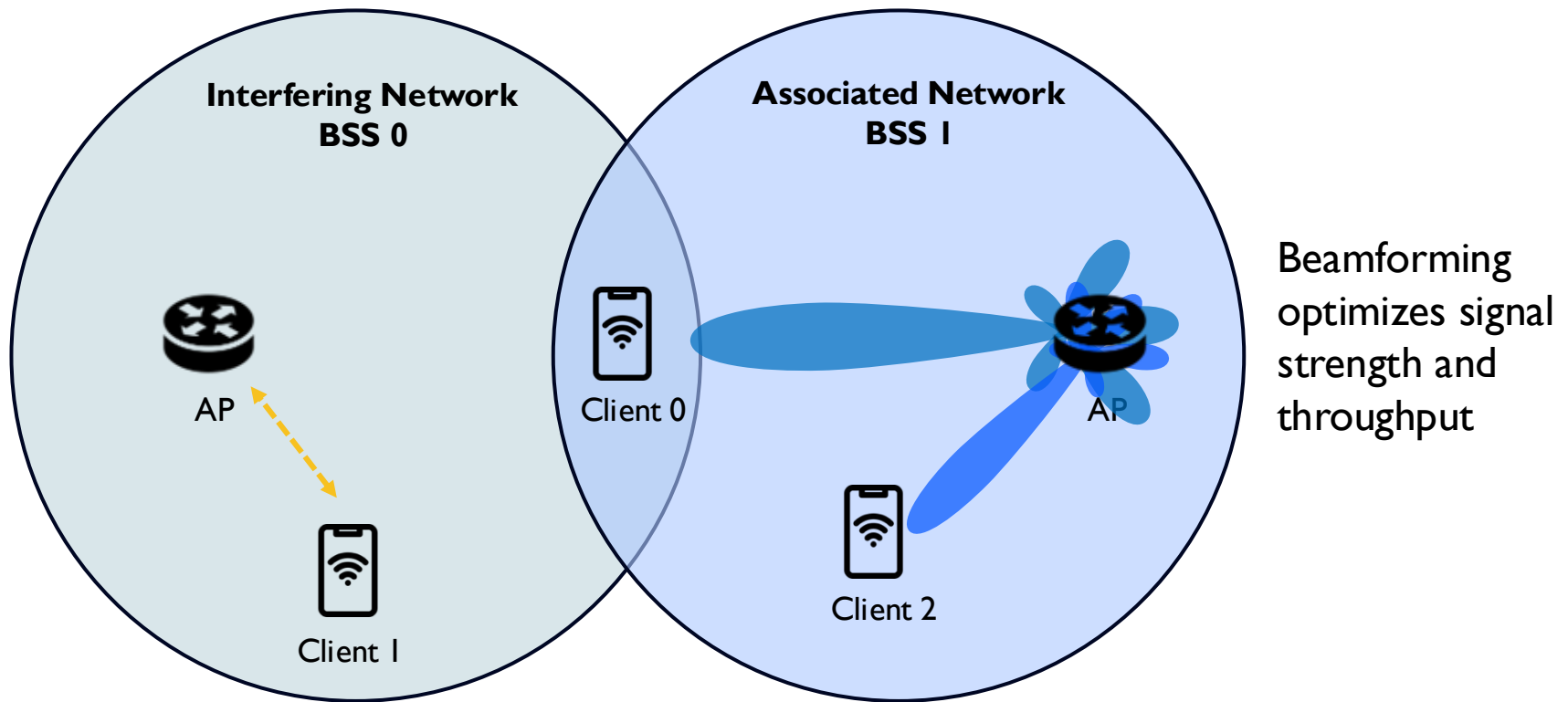


Beamforming Example



Beamforming optimizes signal strength and throughput

Beamforming Example



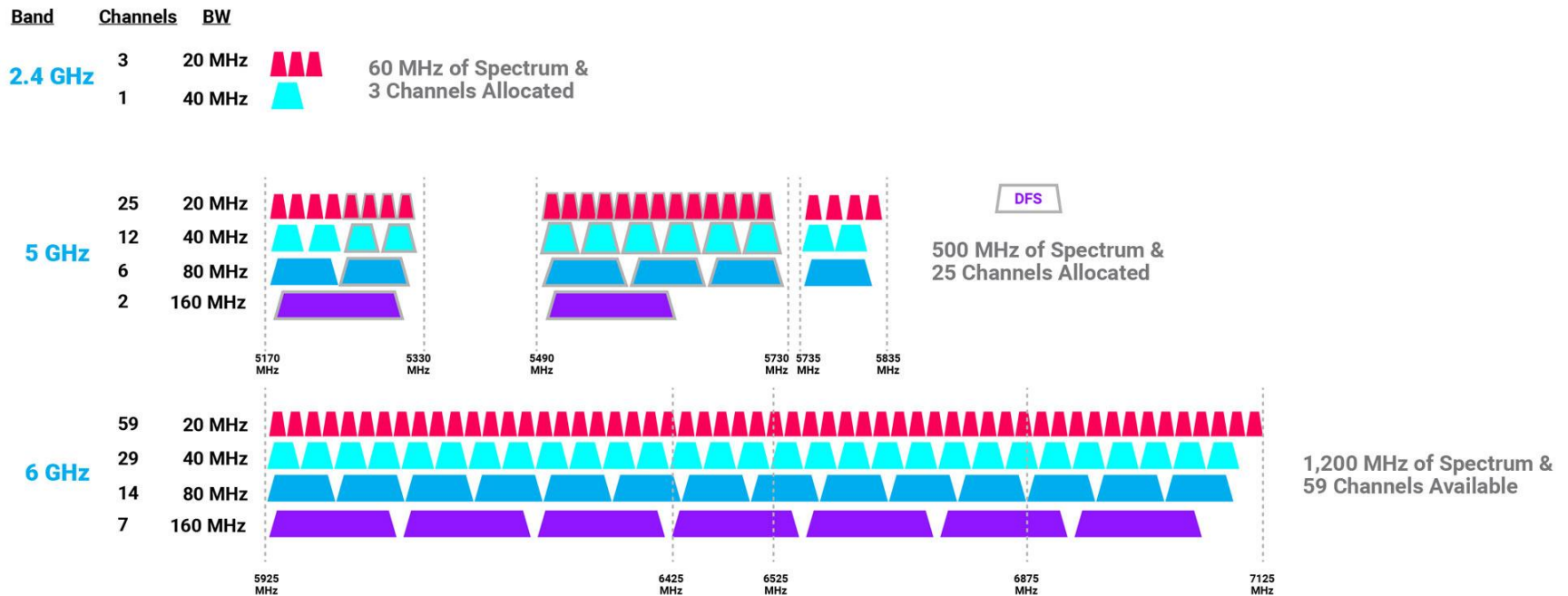
Wi-Fi 6E: Expanding to 6 GHz

- ▶ Introduces a new 6 GHz band
 - ▶ Uses OFDM for management frames, OFDMA for data
- ▶ Provides additional 1,200 MHz of bandwidth
- ▶ Allows for faster data rates and lower latency
- ▶ Offers more channels, reducing congestion in high-density areas



Wi-Fi 6E: Expanding to 6 GHz

Wi-Fi 6E



<https://engeniustech.com/wi-fi-6e-how-the-unlicensed-6-ghz-spectrum-will-drive-innovation/>