

The Inner Workings of QoS for Wi-Fi7 Networks

CISCO Live !

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Distinguished Engineer

Webex App

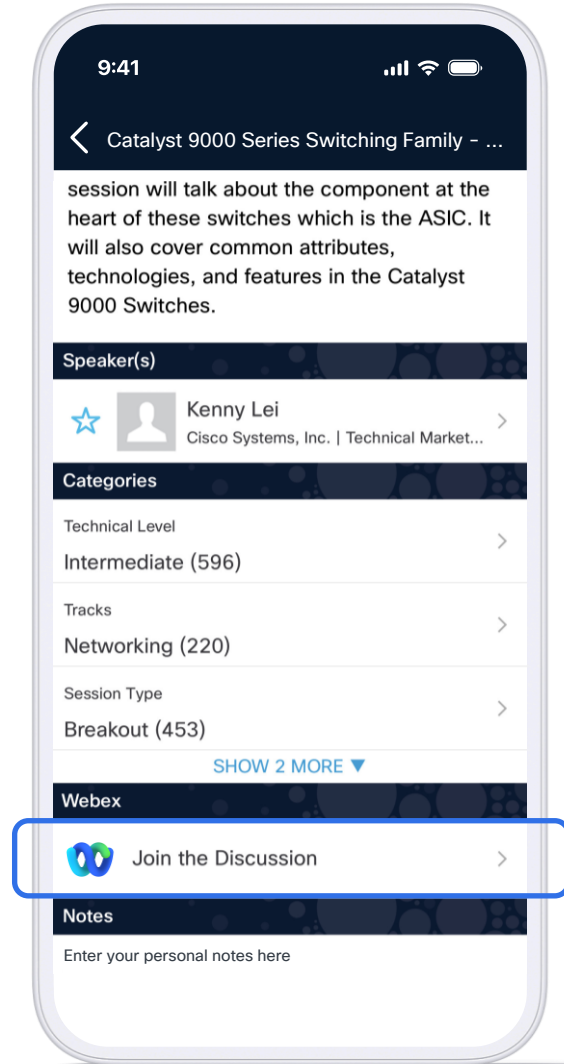
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- Agenda**
- 01 Understanding the Wireless QoS Problem**
 - 02 The Age of QoS Emerges**
 - 03 Recent History**
 - 04 An Introduction to Wi-Fi7**
 - 05 Wi-Fi7 QoS Principles**
 - 06 Wi-Fi7 QoS Deployment Considerations**
 - 07 Looking to the Future**

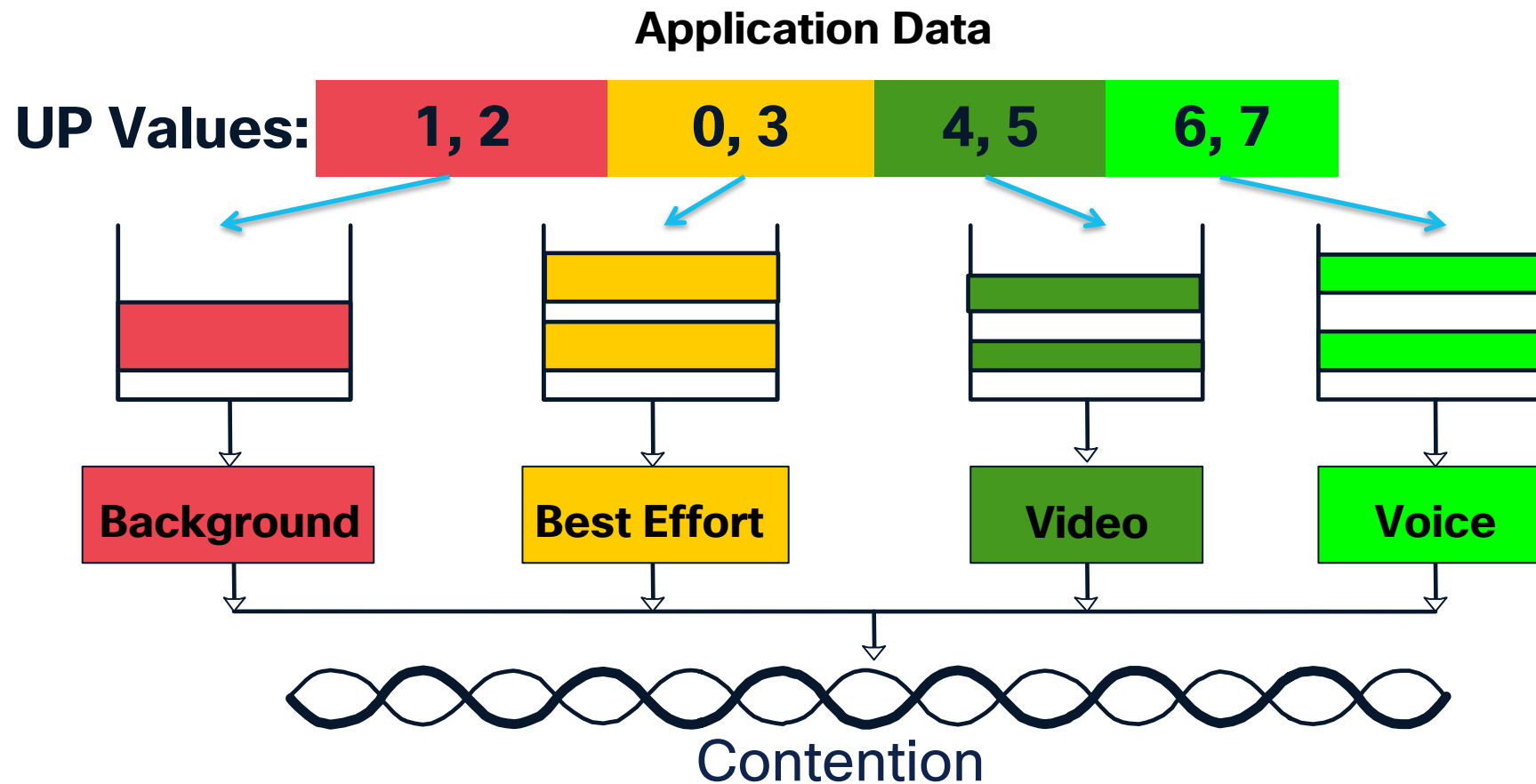
The Age of QoS Emerges

802.11e Introduced the Enhanced Distributed Channel Access (EDCA) Model in 2005

- 802.11e was tasked with bringing QoS to Wi-Fi
- EDCA was introduced by IEEE 802.11e in 2005, and has been adopted by the Wi-Fi Alliance as Wireless Multimedia (WMM)
- WMM is now a mandatory part of modern Wi-Fi
- 802.11a/b/g are based on DCF (no QoS)
- 802.11n/ac are based on EDCA (QoS is supported)

#1) EDCA Introduced Wireless Access Categories

- When wireless frames are transmitted, a 3-bit QoS value known as the **User Priority (UP)** is written into the 802.11 header
- Each AC gets different priority to transmit onto the medium



Default DSCP ↔ UP Mapping Table

Traffic Type	DSCP	802.11e UP / WMM	Access Category
Voice	46 (EF)	6	Voice
Interactive Video	34 (AF41)	5	Video
Call Signaling	24 (CS3)	3	Best Effort
Transactional / Interactive Data	18 (AF21)	3	Best Effort
Bulk Data	10 (AF11)	2	Background
Best Effort	0 (BE)	0	Best Effort



#2 Assign Backoff Timers for the Access Category

- EDCA manages the ACs in the following way:
 - Variable Arbitration Interframe Spacing (AIFS)
 - Variable CW_{min} and CW_{max} values depending on traffic type
 - Values shown are “slot times” – $9\mu s$ per slot in 802.11

EDCA / WMM AC	AIFS Number	CWmin	CWmax
Legacy DCF	DIFS > 2	15*	1023
Voice	2	3	7
Video	2	7	15
Best Effort	3	15	1023
Background	7	15	1023

*For 802.11a/g. 802.11b uses 31

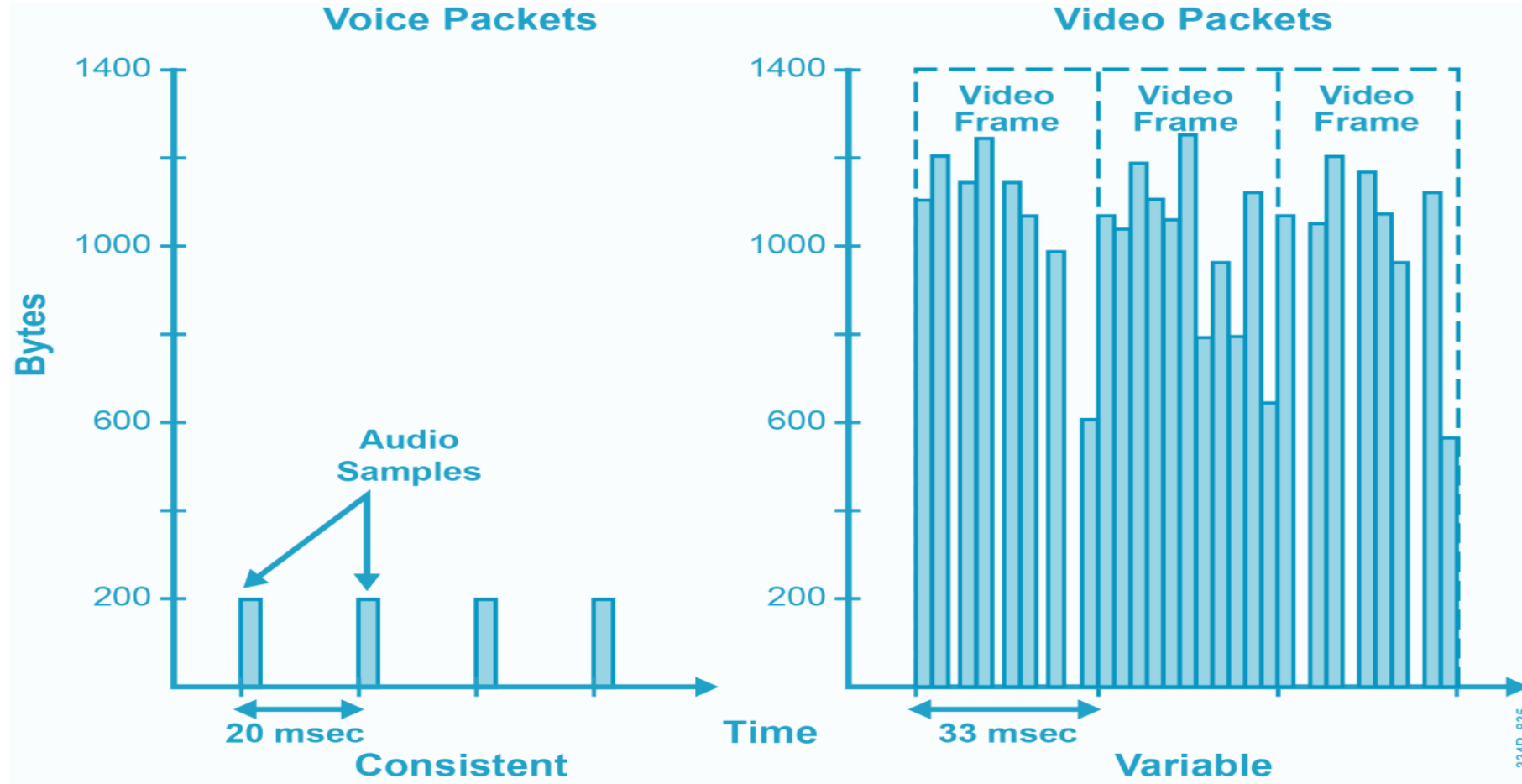
#3 Transmission Opportunity (TXOP)

- TXOP is a timer – a station keeps sending until it's TXOP timer counts down to zero
- DCF had no such thing – send one frame and then start again!
- Why is video smaller than the other TXOPs?

EDCA / WMM AC	TXOP (μ s)	TXOP (Units)
Voice	2080	65
Video	4096	128
Best Effort	2528	79
Background	2528	79

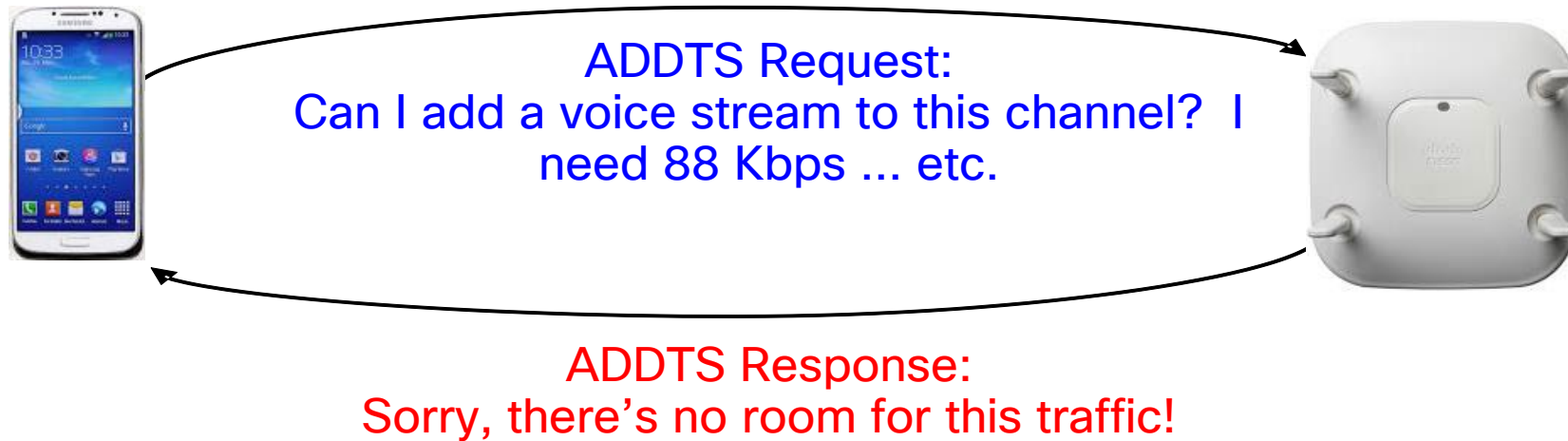
Real Time Voice vs. Real Time Video Traffic Profile

Traffic Profile Helps Model TXOP Timers



#4 Transmission Specification (TSpec)

- TSpec is basically Call Admission Control - management of the number of voice and video traffic flows per AP radio
- Client signals to AP to request its traffic stream be added to AP (ADDTS)
- TSpec includes data rate, packet size, number of stream & more



Summary: Four Key 802.11e QoS Enhancements

Enhanced Distributed Channel Access (EDCA):

1. Establishment of four Access Categories and 3-bit User Priority QoS field
2. New timers replacing legacy static DIFS and CW
3. Each AC get's its own Transmission Opportunity (TXOP)
4. Call Admission Control (CAC) with TSpec

Check the Wireless Sniffer Trace

```
Access Category - Background
  ACI/AIFSN: %00100111
    x... .. Reserved
    .01. .... ACI: Background
    ...0 .... ACM: Admission Control Not Mandatory
    .... 0111 AIFSN: 7
  ECW Min/Max: %10100100
    1010 .... ECW Max: 10 (CW Max: 1,023)
    .... 0100 ECW Min: 4 (CW Min: 15)
  TXOP Limit: 0

Access Category - Video
  ACI/AIFSN: %01000010
    x... .. Reserved
    .10. .... ACI: Video
    ...0 .... ACM: Admission Control Not Mandatory
    .... 0010 AIFSN: 2
  ECW Min/Max: %01000011
    0100 .... ECW Max: 4 (CW Max: 15)
    .... 0011 ECW Min: 3 (CW Min: 7)
  TXOP Limit: 94

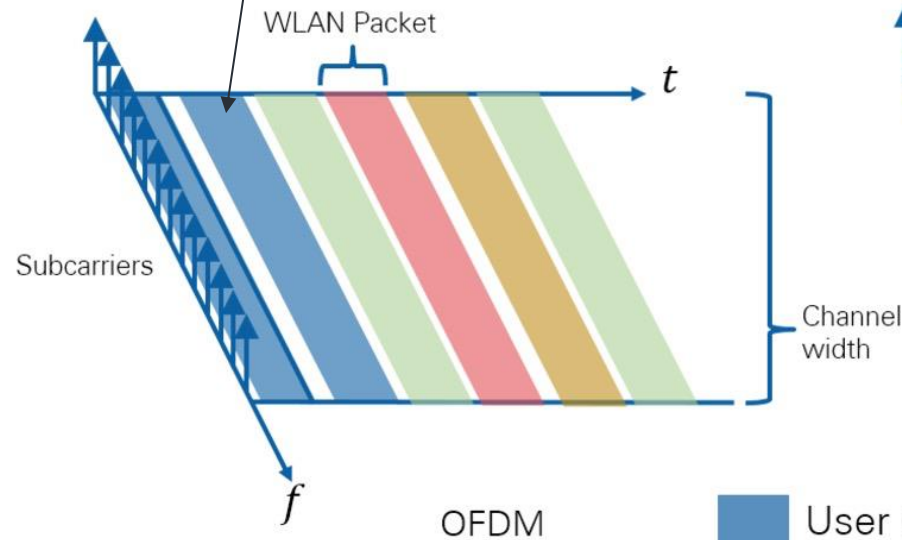
Access Category - Voice
  ACI/AIFSN: %01110010
    x... .. Reserved
    .11. .... ACI: Voice
    ...1 .... ACM: Admission Control Mandatory
    .... 0010 AIFSN: 2
  ECW Min/Max: %00110010
    0011 .... ECW Max: 3 (CW Max: 7)
    .... 0010 ECW Min: 2 (CW Min: 3)
  TXOP Limit: 47
```

- 1. Voice Access Category
- 2. Voice AIFSN = 2 slots
- 3. CWmin = 3 slots
CWmax = 7 slots
- 4. TXOP Limit = 47 units
(1.504 ms wait time)
- 5. Voice AC has Tspec
(ACM) turned on

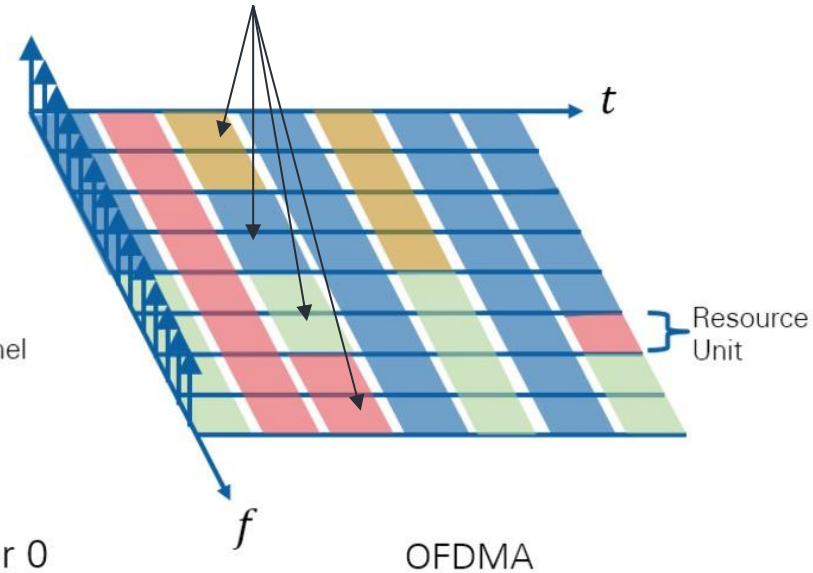
Recent History: Wi-Fi6 / 6E (802.11ax)

OFDMA (Orthogonal Frequency Division Multiple Access)

A Single Station Transmits in a Timeslot won by the contention algorithm (EDCA)



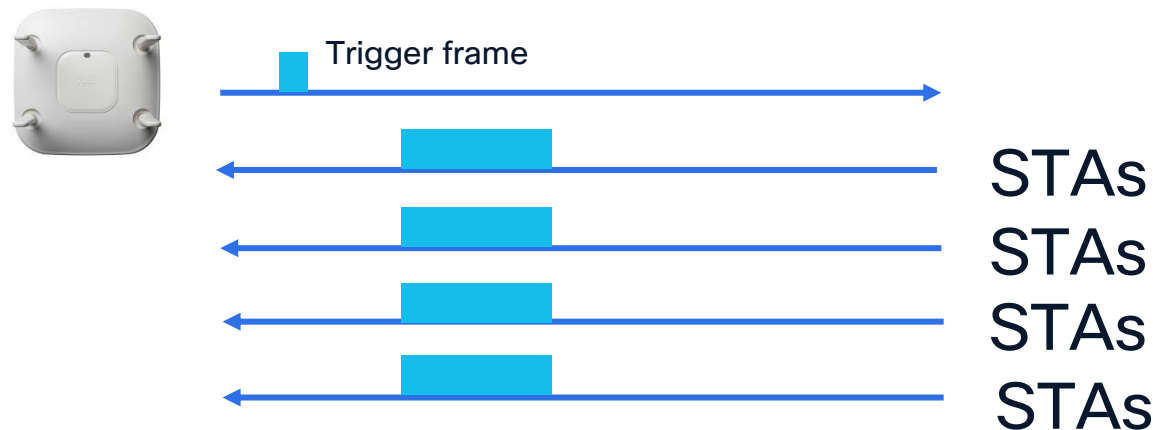
Multiple Stations Transmit in a scheduled Timeslot



- User 0
- User 1
- User 2
- User 3

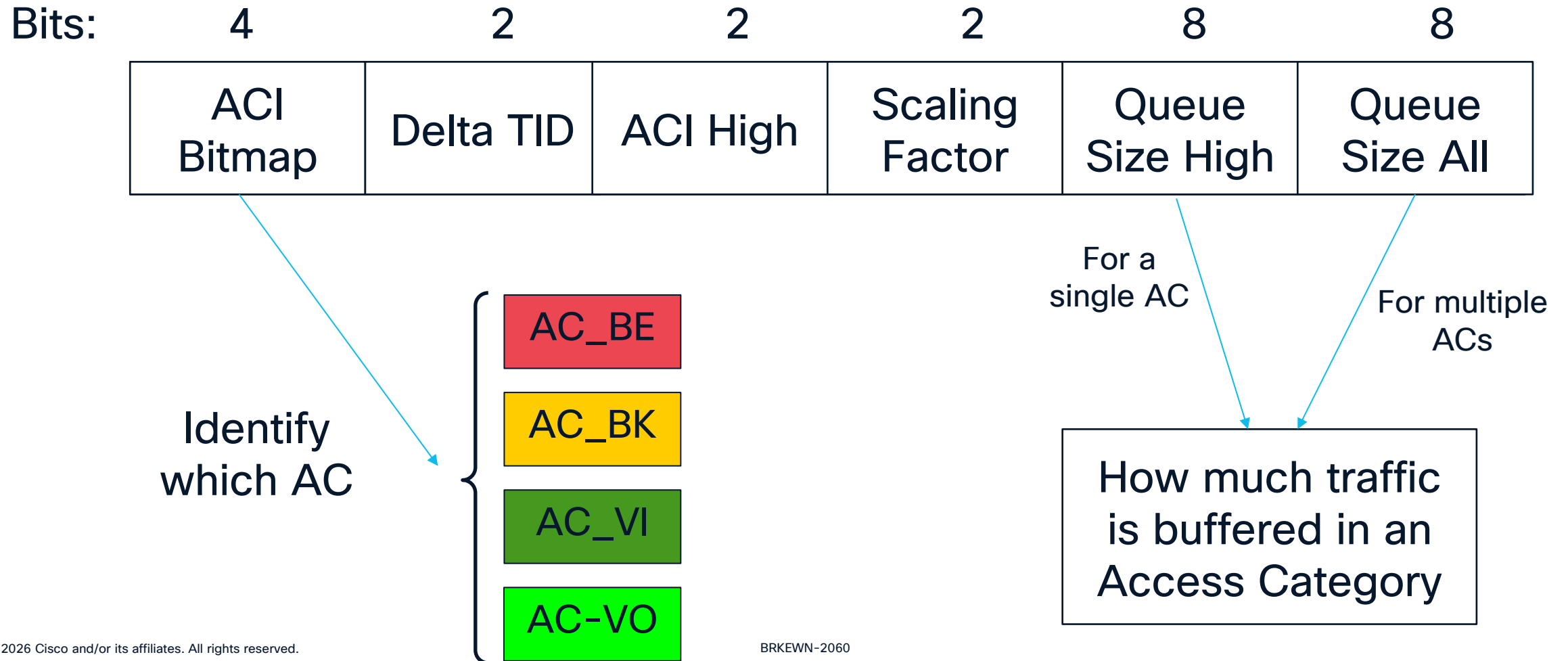
802.11ax Uplink (UL) MU-MIMO

- 802.11ac allows for downlink MU-MIMO
- 802.11ax adds uplink MU-MIMO
 - AP checks which STAs can send together
 - AP sends trigger frame and STAs respond all at the same time

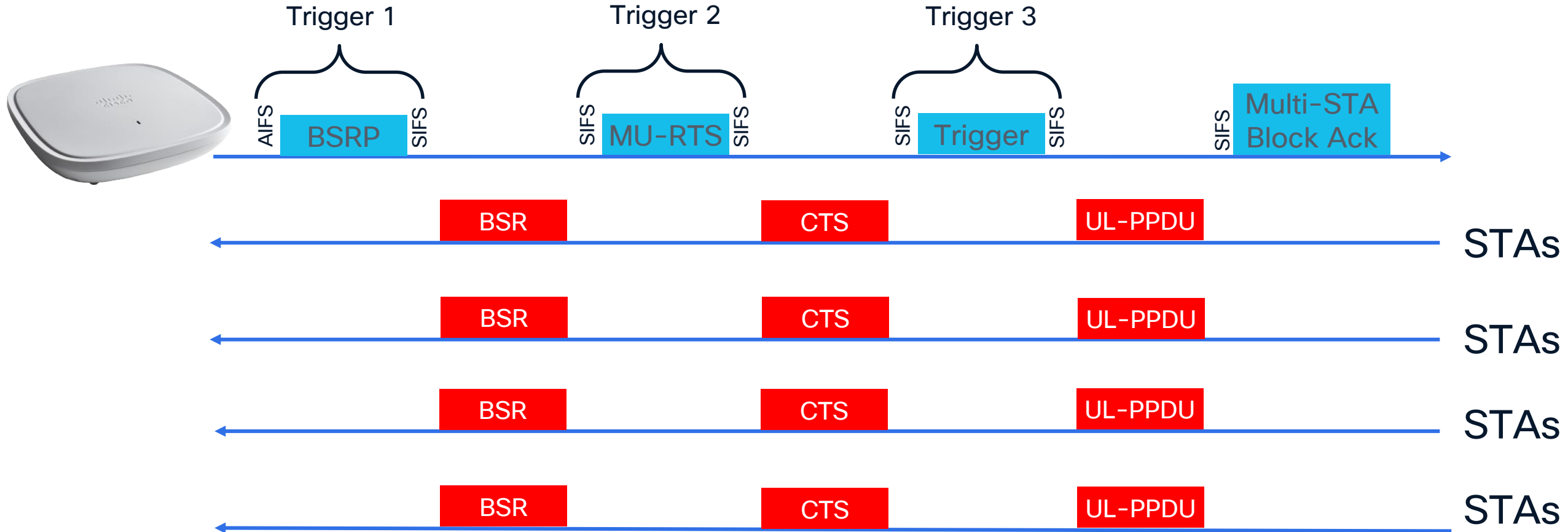


Buffer Status Reports (BSRs)

STAs may send QoS information in the **BSR Control subfield** of any frame



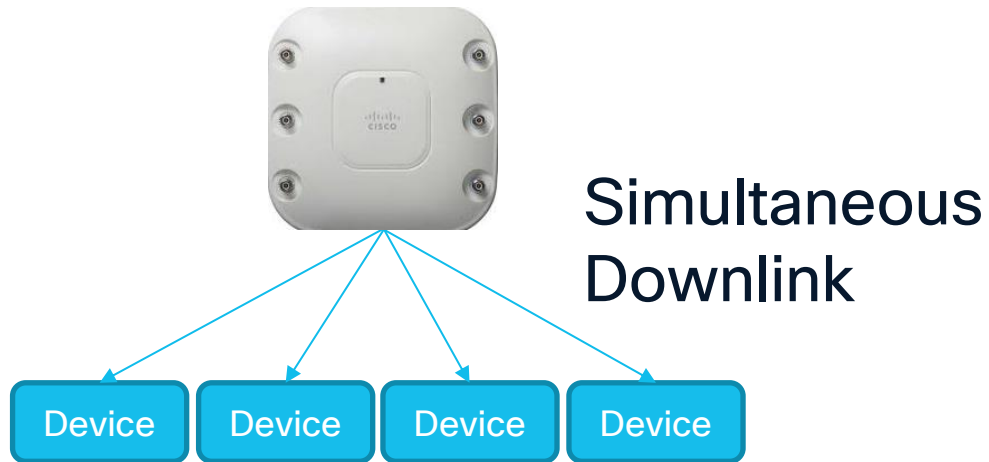
Buffer Status Report Polling (BSRP) (Figuring out how many RUs to Assign)



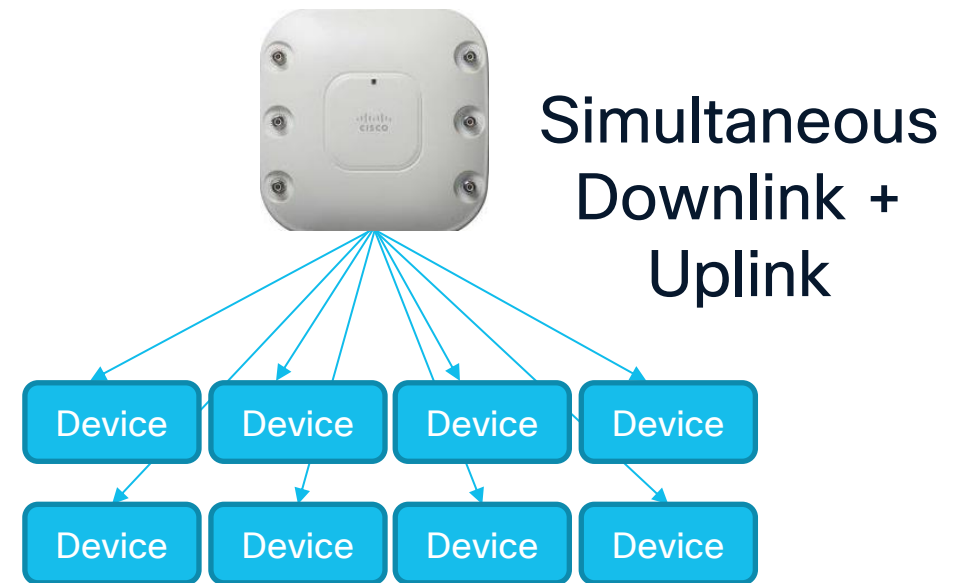
Downlink MIMO Spatial Streams

Note: Wi-Fi 7 Uses 8 SSs, same as Wi-Fi 6/6E

11ac (4 Spatial Streams)



11ax (8 Spatial Streams)

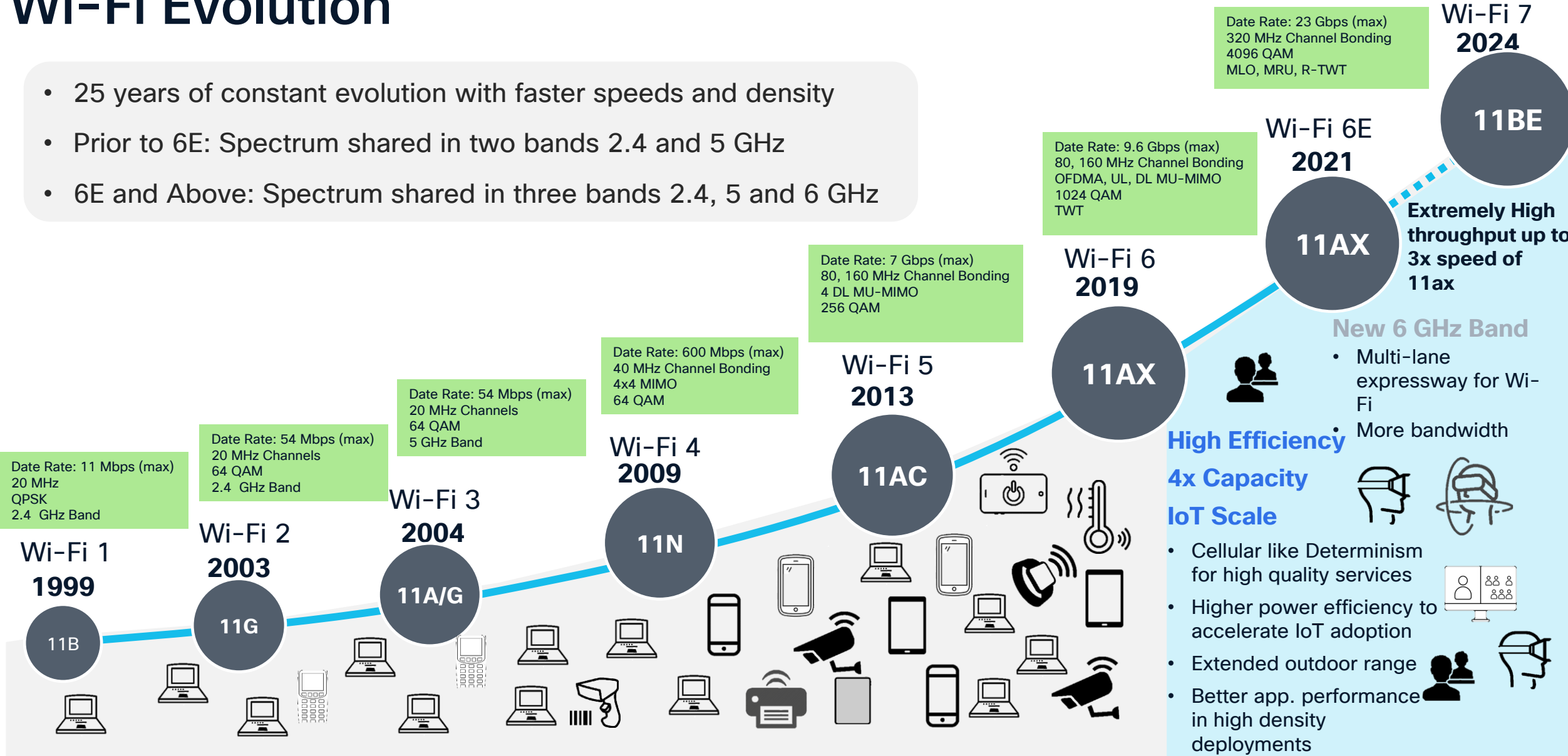


Spatial Streams enable Simultaneous Connections and now for both UL & DL

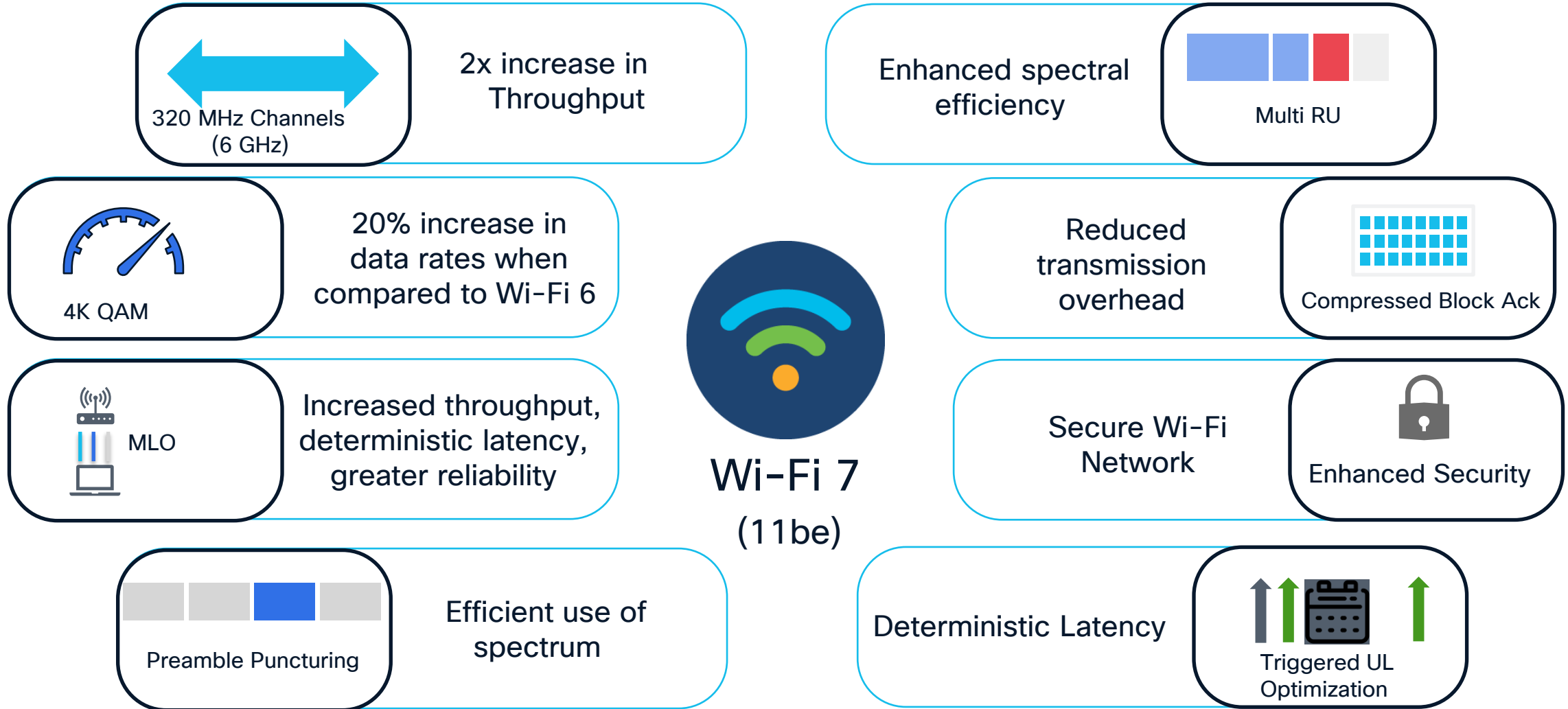
An Introduction to Wi-Fi7

Wi-Fi Evolution

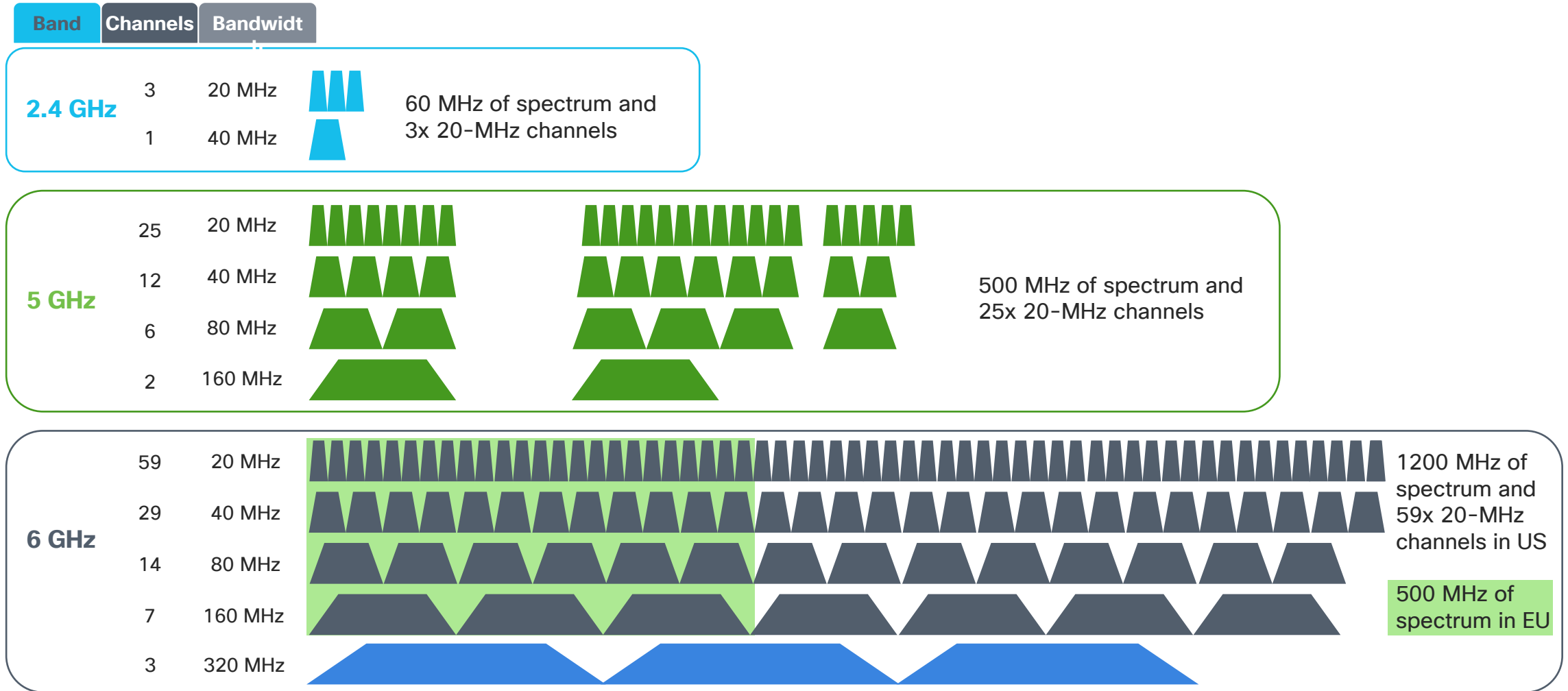
- 25 years of constant evolution with faster speeds and density
- Prior to 6E: Spectrum shared in two bands 2.4 and 5 GHz
- 6E and Above: Spectrum shared in three bands 2.4, 5 and 6 GHz



Wi-Fi 7 Key Innovations



Wi-Fi7 Operates in all Traditional Wi-Fi Spectrums



Wi-Fi 7 Preamble Puncturing

Without Preamble Puncturing:



With Preamble Puncturing:



Puncturing allowed for 80 MHz channel width or wider

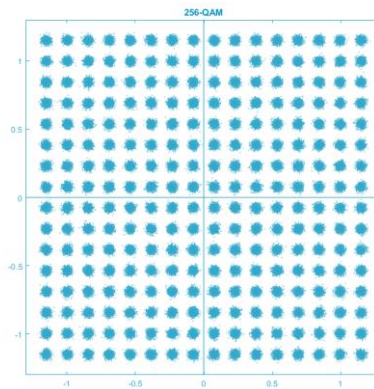
Channel Width	Allowed Puncturing
80 MHz	20 MHz
160 MHz	20 or 40 MHz
320 MHz	40 or 80 MHz (or) 40 + 80 MHz

Wi-Fi 7: Evolution to 4K QAM

QAM – Quadrature Amplitude Modulation

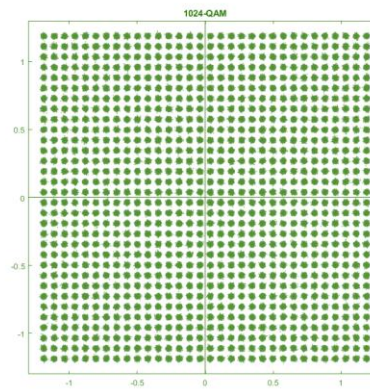
Data rate (Modulation density) or (how many Bit's per Radio Symbol)

Wi-Fi 5



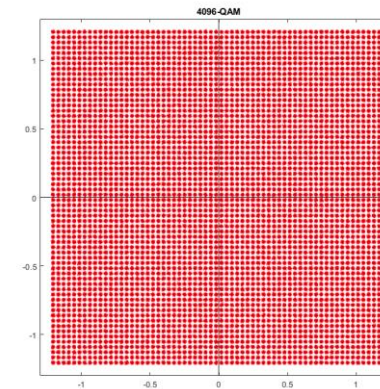
256 QAM

Wi-Fi 6/6E



1024 QAM

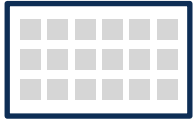
Wi-Fi 7



4096 QAM

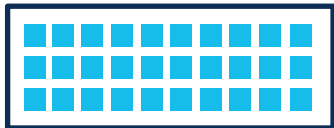
Wi-Fi 7 - 512 Compressed Block Ack

Wi-Fi 6/6E



- Aggregation of up to **256** MPDUs in a single frame.
- Acknowledgement up to **256** MPDUs in a single Block Ack Frame

Wi-Fi 7



- Aggregation of up to **512** MPDUs in a single frame.
- Acknowledgement up to **512** MPDUs in a single Block Ack Frame

Reduces Protocol Overhead. Improve transmitter's performance at higher rates

What Problem Does MLO Solve?

Object in Signal Path	Signal Attenuation Through Object
Plasterboard wall	3 dB
Glass wall with metal frame	6 dB
Cinderblock wall	4 dB
Office window	3 dB
Metal door	6 dB
Metal door in brick wall	12 dB
Phone and body position	3 - 6 dB
Phone near field absorption	Up to 15 dB



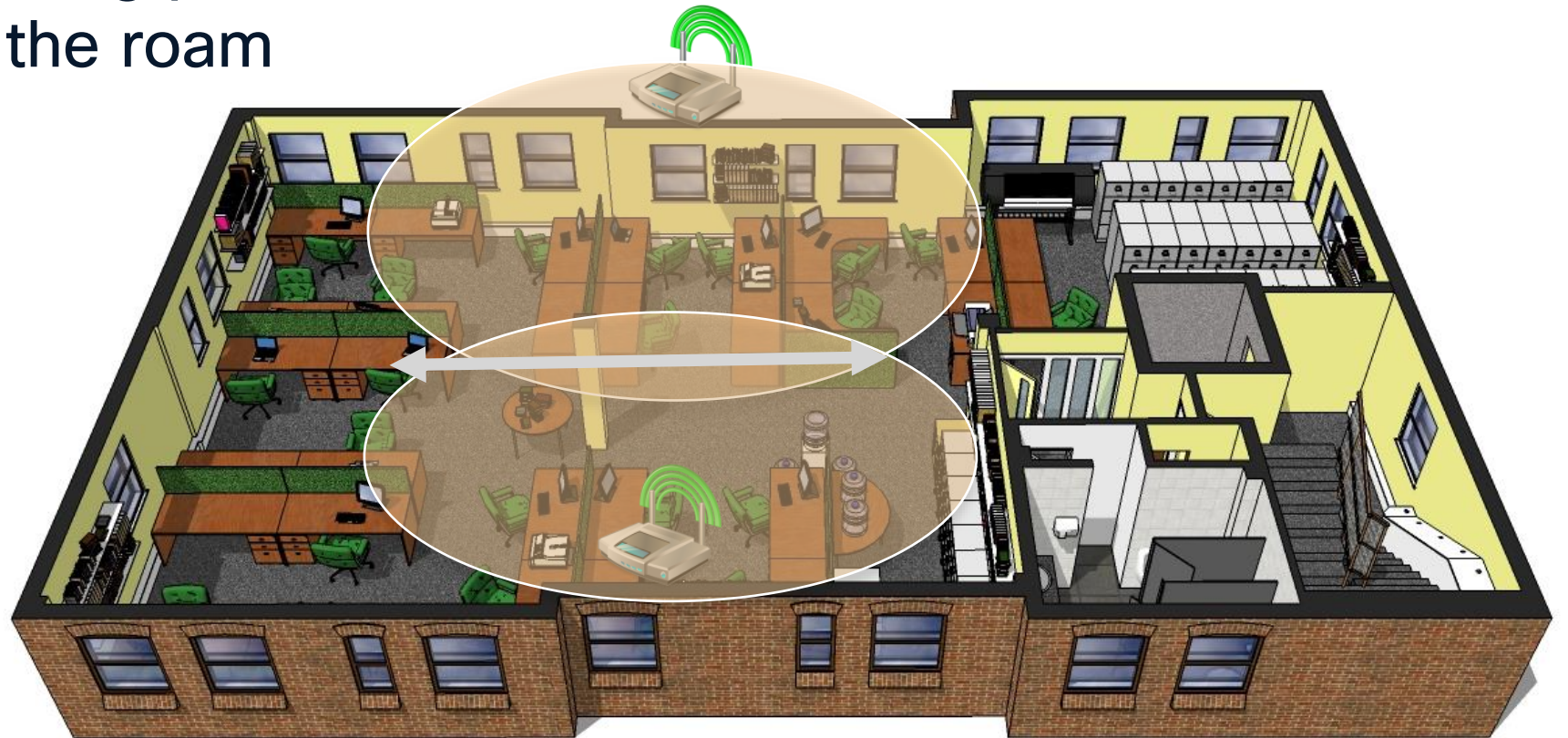
There can be a 20 dB difference between these photos



MLO Helps Avoid Ping Pong Zones

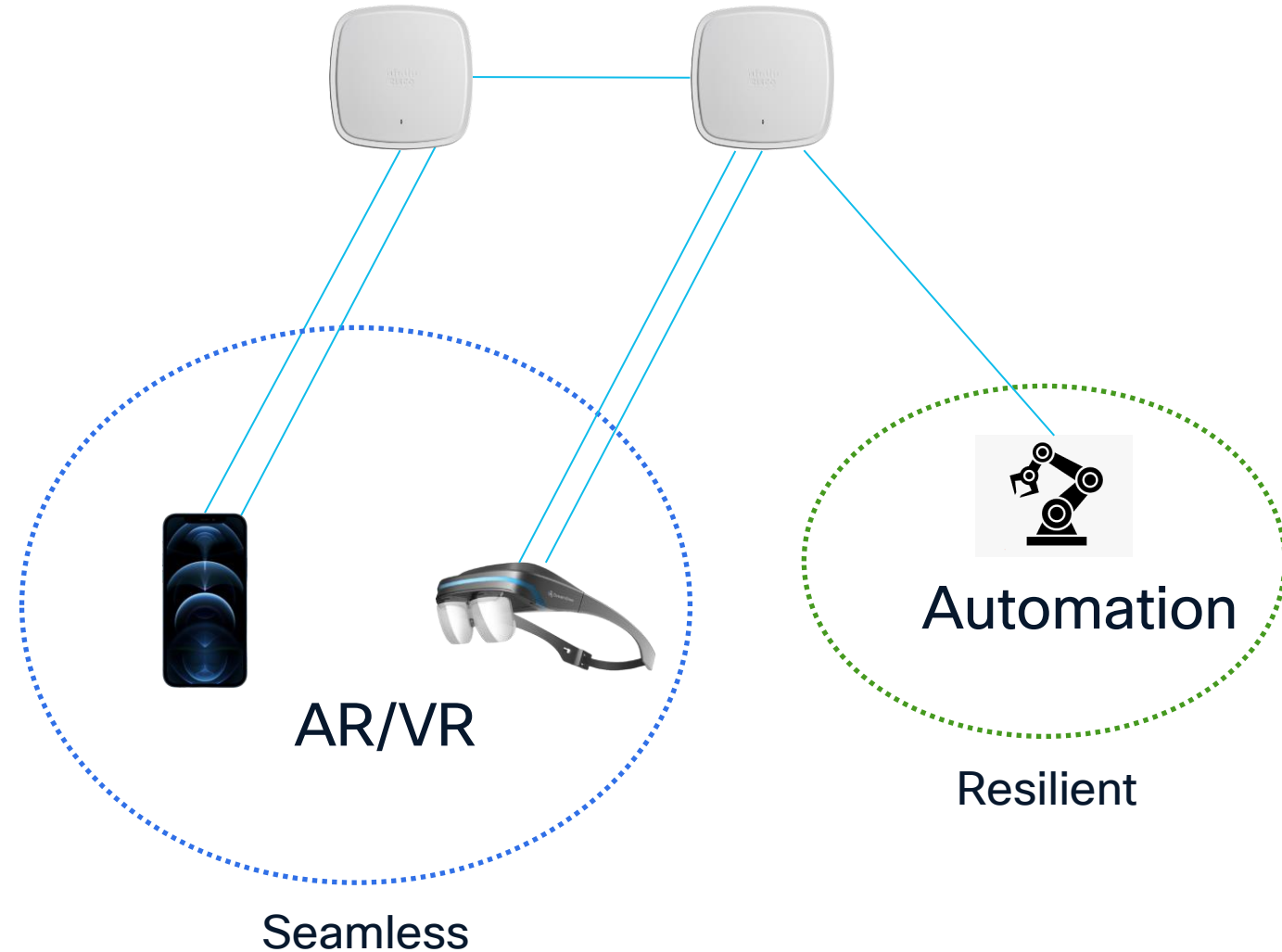
Ping Pong zone recipe:
Set overlap along pacing path
Let user head force the roam

“Pacing
back and
forth” zone

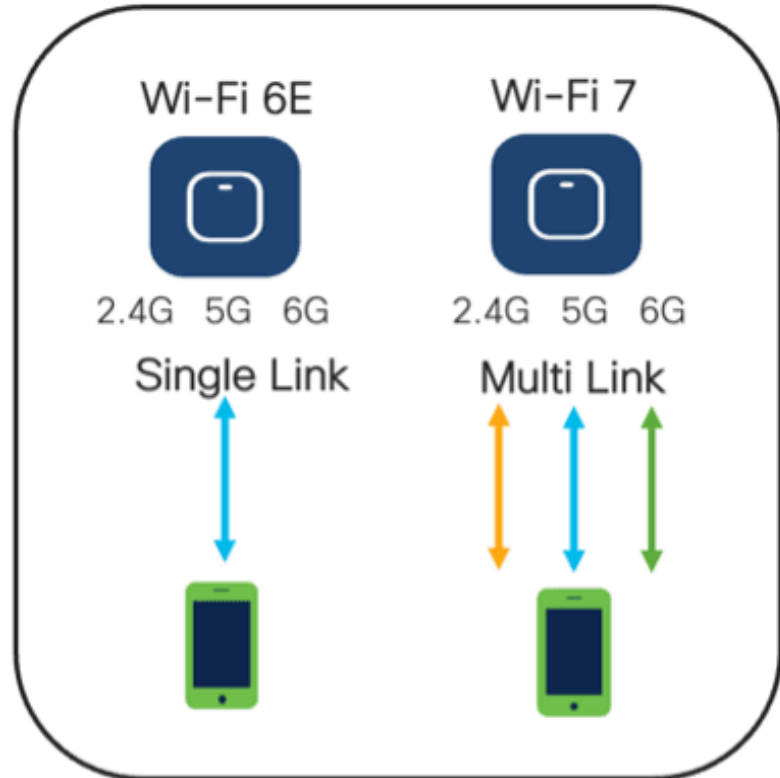


MLO Applications (present and future)

- Improve Resilience
 - Ability to Tx and Rx on multiple channels
 - QoS-based link selection/steering
- Enhanced QoS Capabilities
 - Stream Classification Service (SCS)
 - SLA-based KPI support (latency, jitter, etc.)

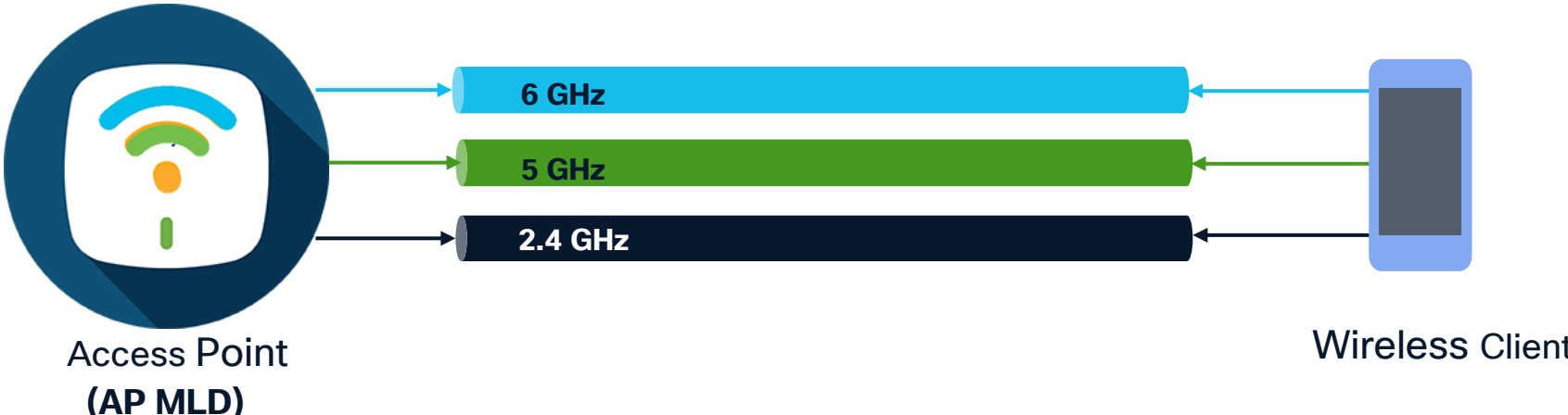


Multi-Link Capabilities – the Basics

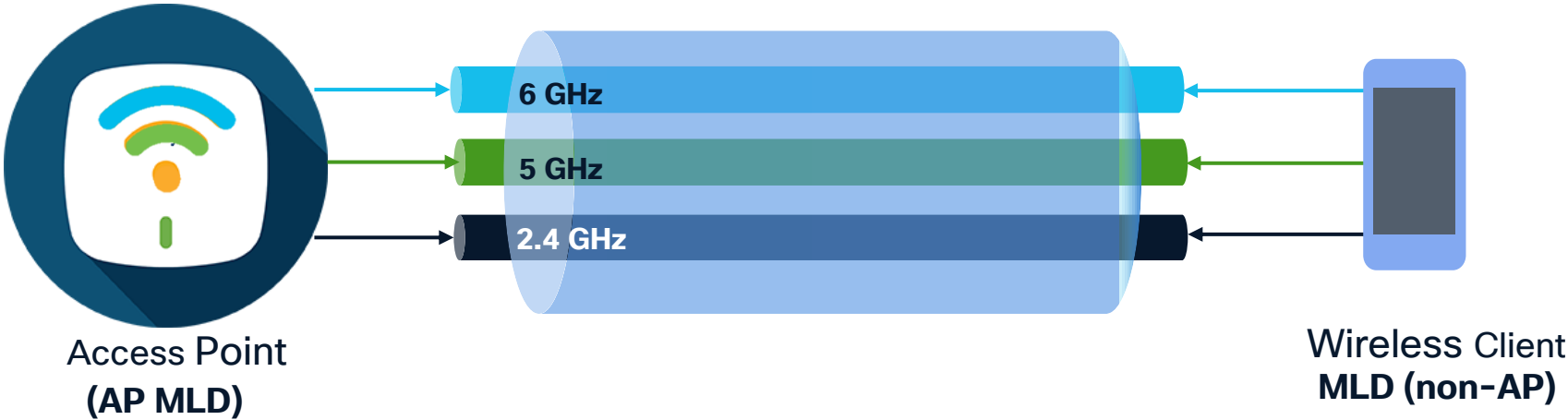


- **Existing Wi-Fi generations** allow the association and exchange of data in **one band only**.
- Multi-Link Operation is an aggregation of multiple bands or channels.
- With MLO, the **Wi-Fi 7 wireless client devices capable of multi-link** are referred to as **multi-link devices (MLDs)**
- Can **associate and simultaneously exchange traffic** on multiple bands (or multiple channels in the same band if the access point has a dual 5 GHz radio)

Wi-Fi 7 Multi Link Capability



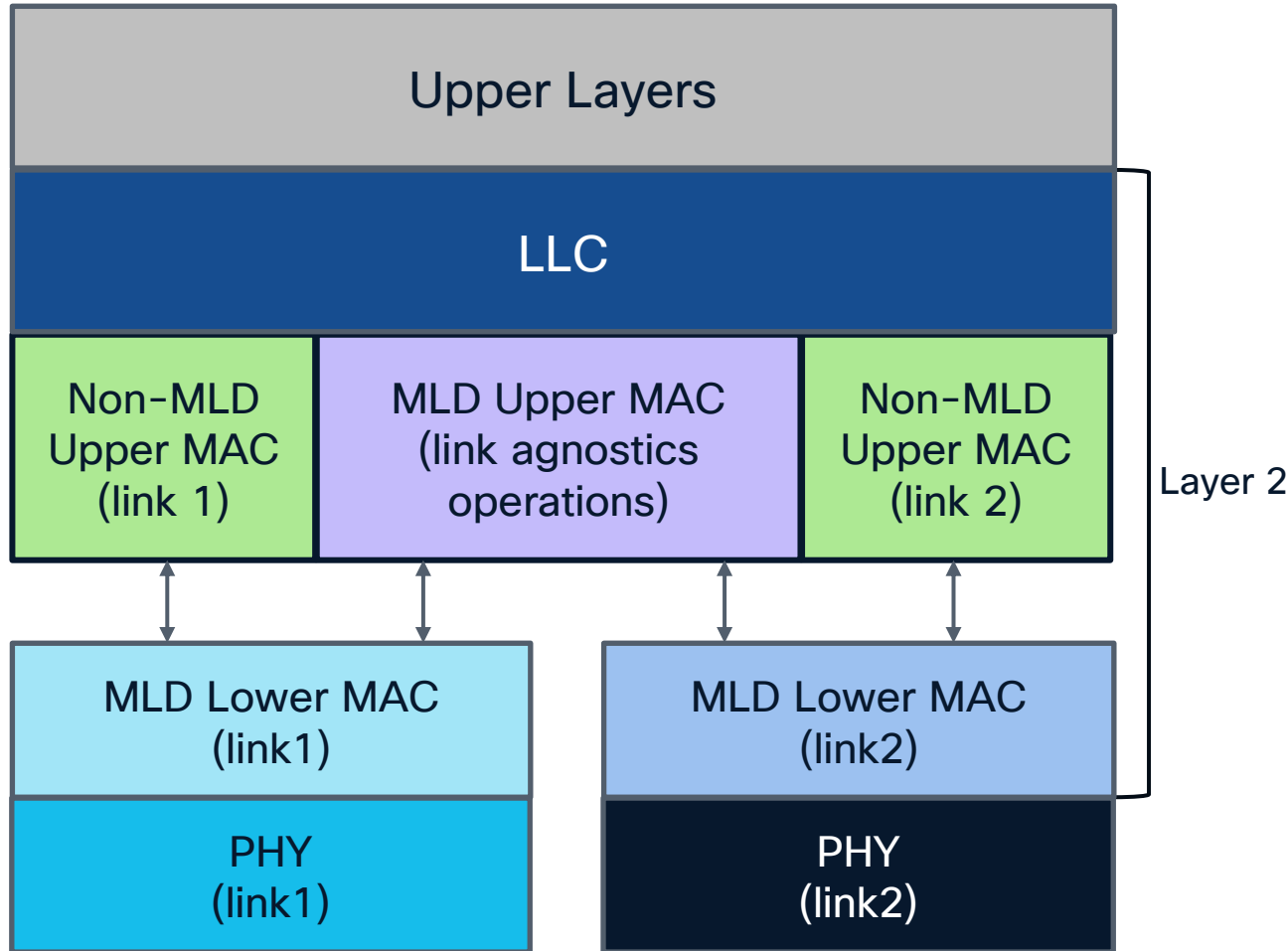
Wi-Fi 7 Multilink Operations (not Bundling)



Method	Benefit
Aggregation	Throughput
Steering	Lower Latency
Redundancy	Reliability

*MLD:
Multi-Link
Device*

Wi-Fi 7 Multi-Link-Device (MLD) MAC Layers



MLD Upper MAC Layer functions :

- Auth, (Re)Association
- Security association
- SN assignment for unicast & groupcast frames
- Encryption/Decryption of unicast frames
- Power save buffering of unicast frames
- MLD level management frames
- Unified Block Ack scoreboard
- Packet re-ordering, replay detection
- Selection of MLD lower MAC for Tx

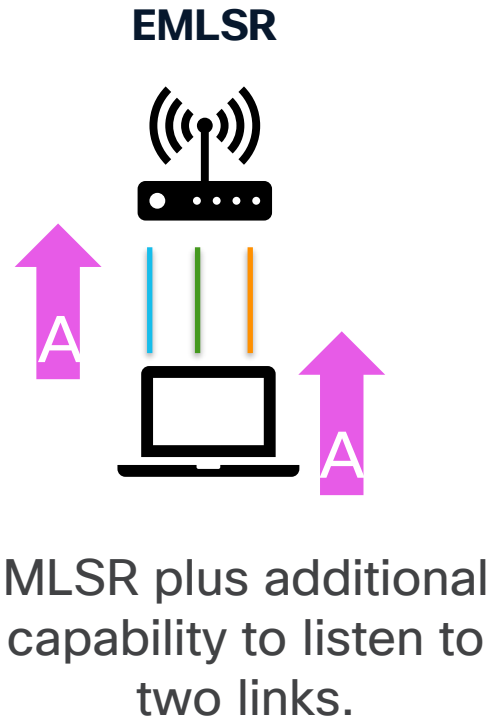
Non-MLD Upper MAC Layer functions:

- Non-MLO peer operation (above MLD lower MAC)
- Link specific group keys
- Link specific encryption/decryption of groupcast
- Power save buffering of groupcast frames

MLD Lower MAC Layer functions:

- Link specific mgmt. frames (beacons)
- Control Frames (RTS, CTS, Ack,...)
- Power save state and mode
- Per-link Block Ack scoreboard

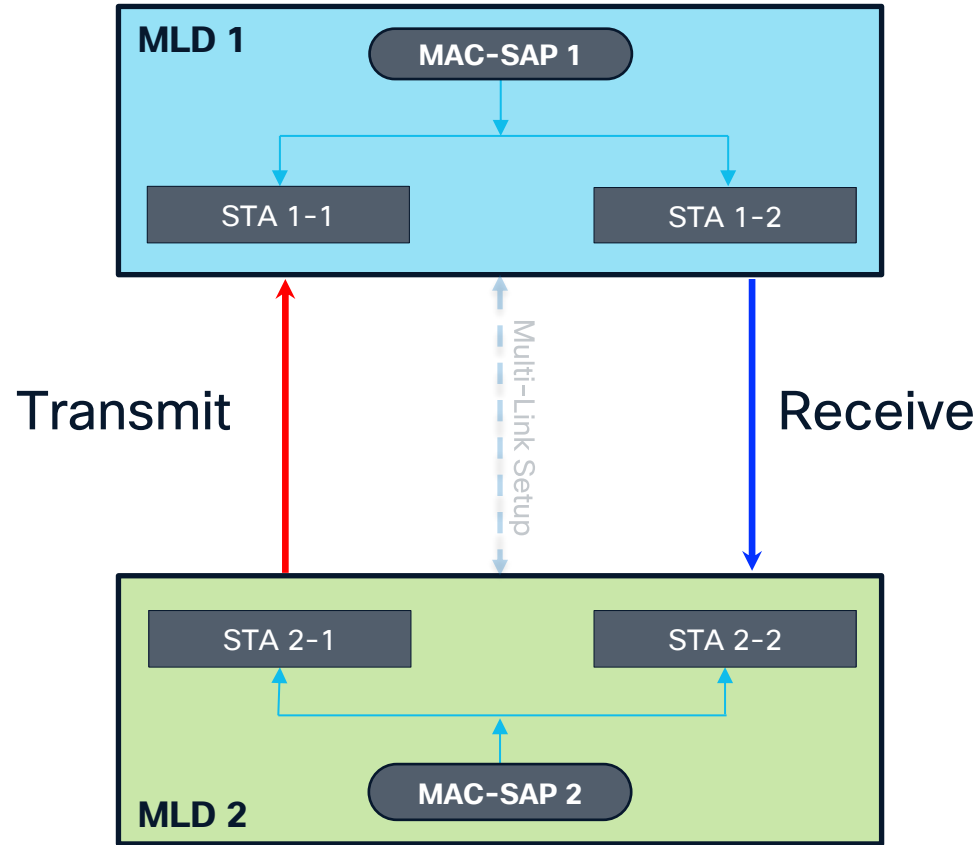
Single Radio MLO (eMLSR)



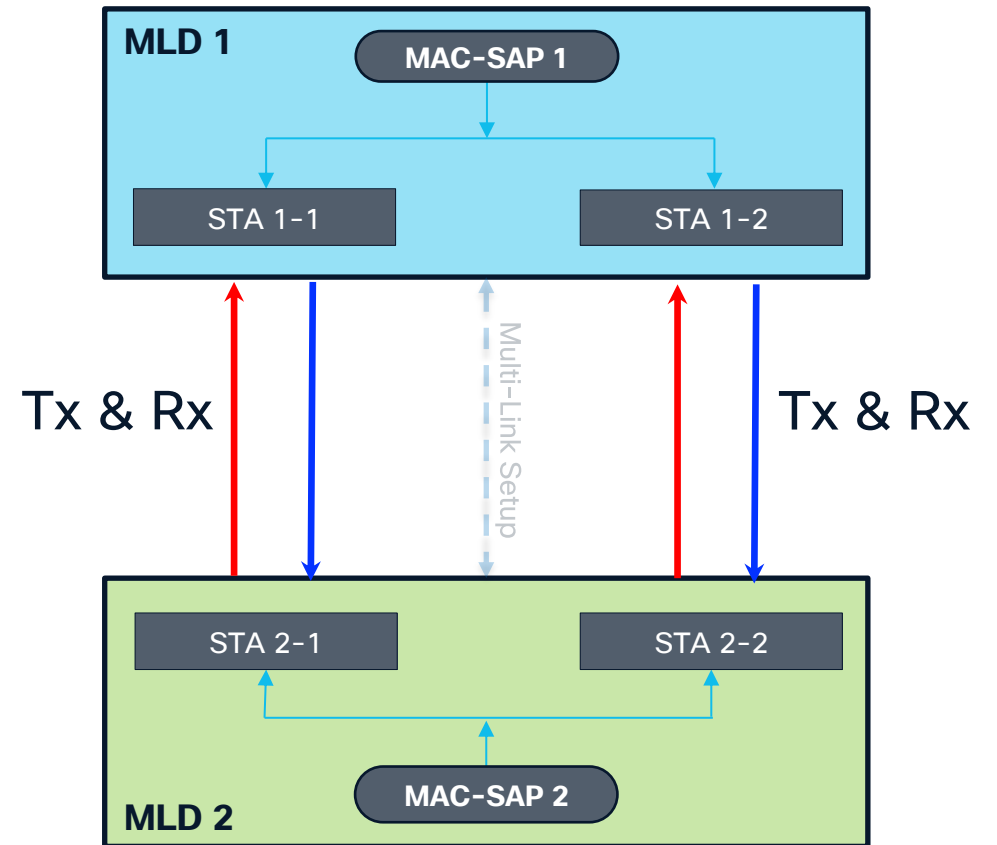
Enhanced Multi Link Single Radio (eMLSR):

Allows a client to swap over to another radio seamlessly (e.g. a client listens to 5 GHz and 6GHz, waiting for transmit opportunity)

Multi-Link Operation (MLO) Uplink and Downlink



STR Mode (Simultaneous Tx and Rx)
Essentially Full-Duplex

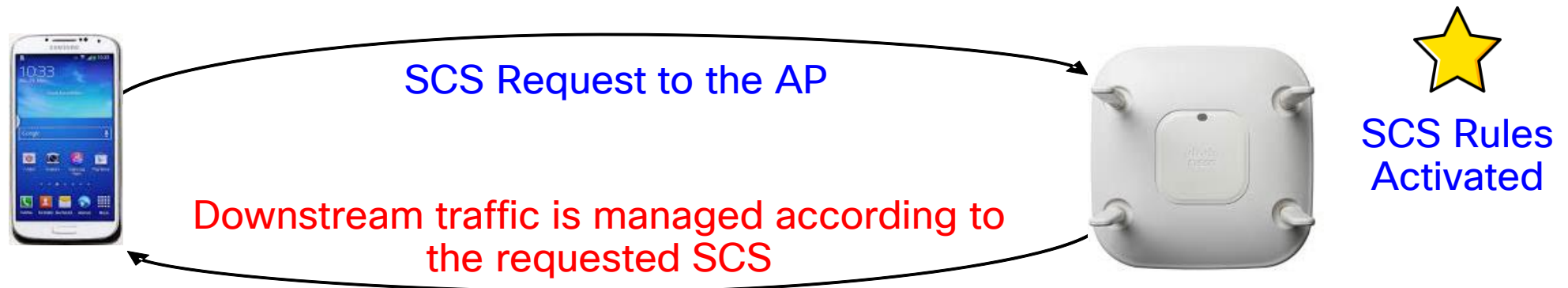


NSTR Mode (Non-Simultaneous Tx and Rx)
Load balanced traffic across multiple links

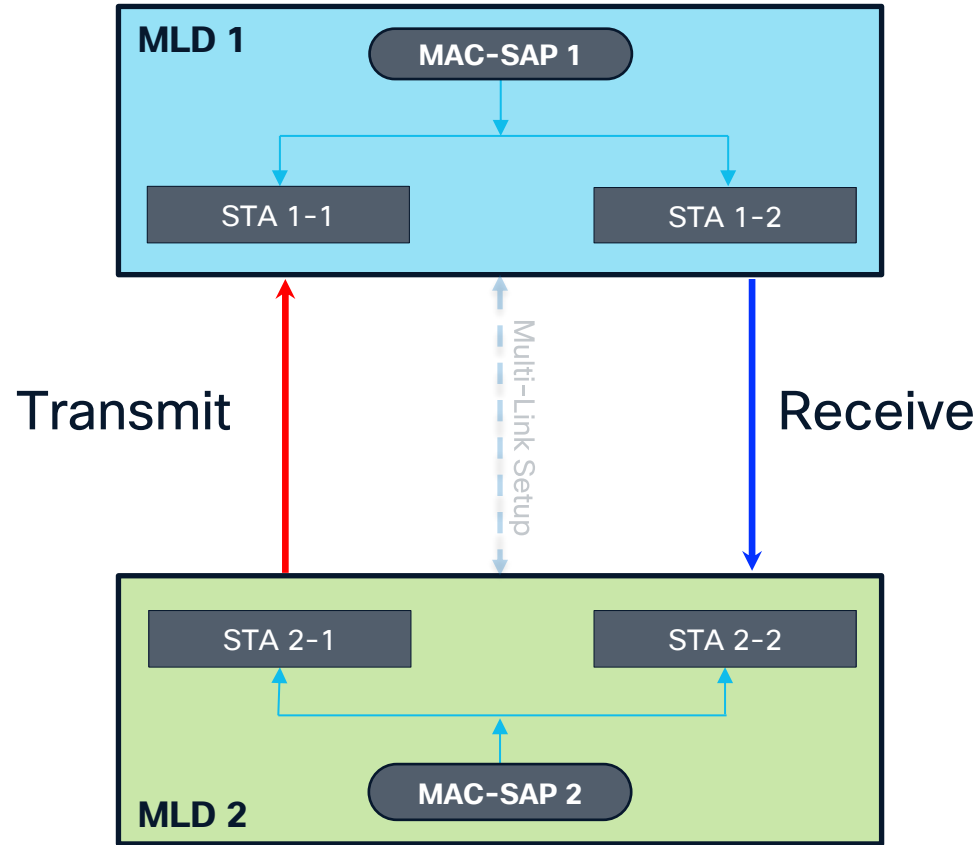
Wi-Fi7 QoS Principles

A New QoS Paradigm: Stream Classification Service (SCS)

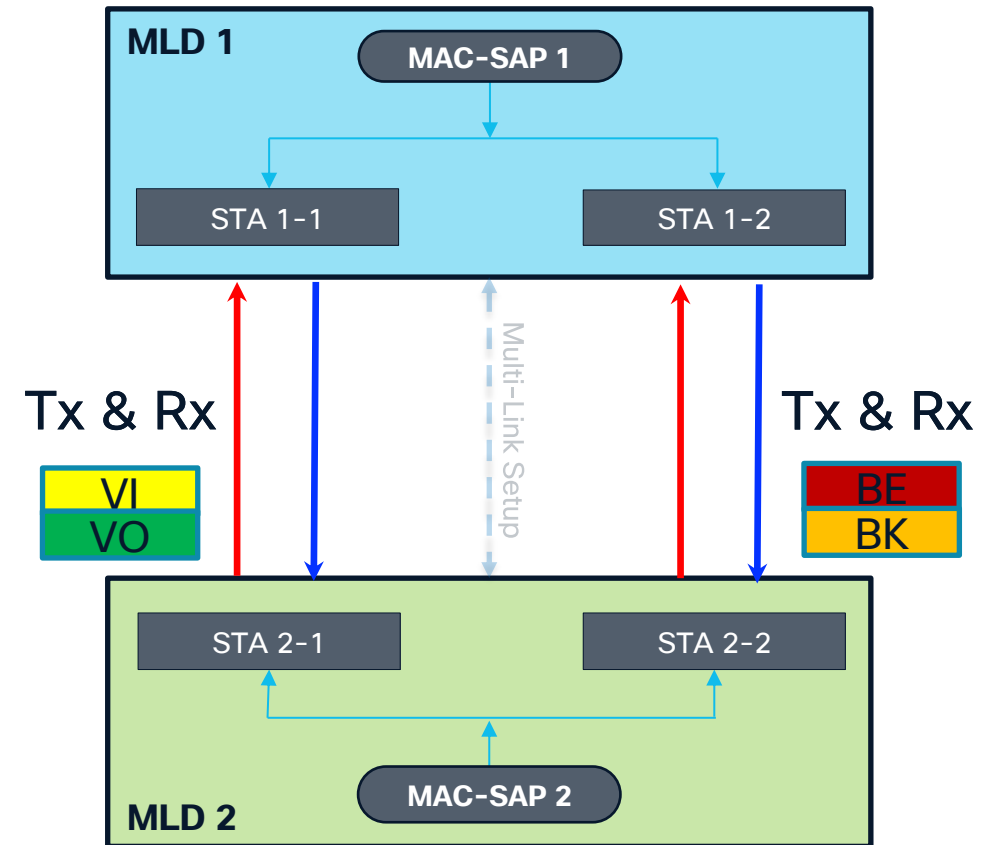
- SCS (Stream Classification Service) specifies traffic flows using an SCS request frame (a QoS Information Element / IE)
- The AP derives QoS rules by monitoring the corresponding uplink flows
- Allows the STA to explicitly provide traffic classifiers and priority for each downlink flow using Traffic Identifiers (TIDs), a 4-bit field based on the UP value, that can be used to select a variety of link characteristics (burst interval, which link to use, delay, reliability, etc.)



Multi-Link Operation (MLO) Enables new QoS Capabilities



STR Mode (Simultaneous Tx and Rx)
Essentially Full-Duplex



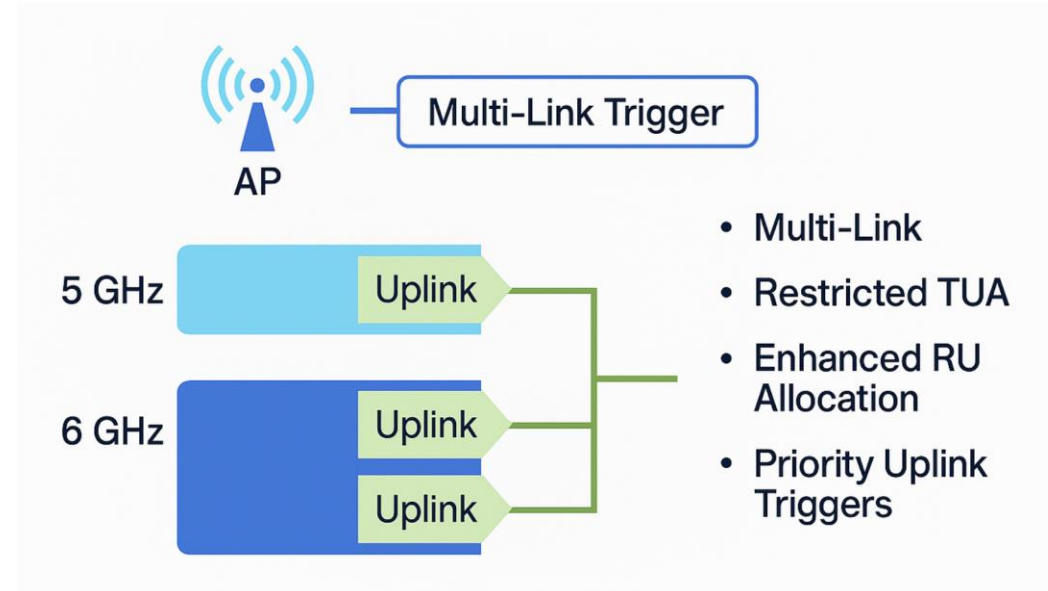
NSTR Mode (Non-Simultaneous Tx and Rx)
Load balanced traffic across multiple links

Legend

BE
BK
VI
VO

Triggered Uplink Access (TUA) + MLO

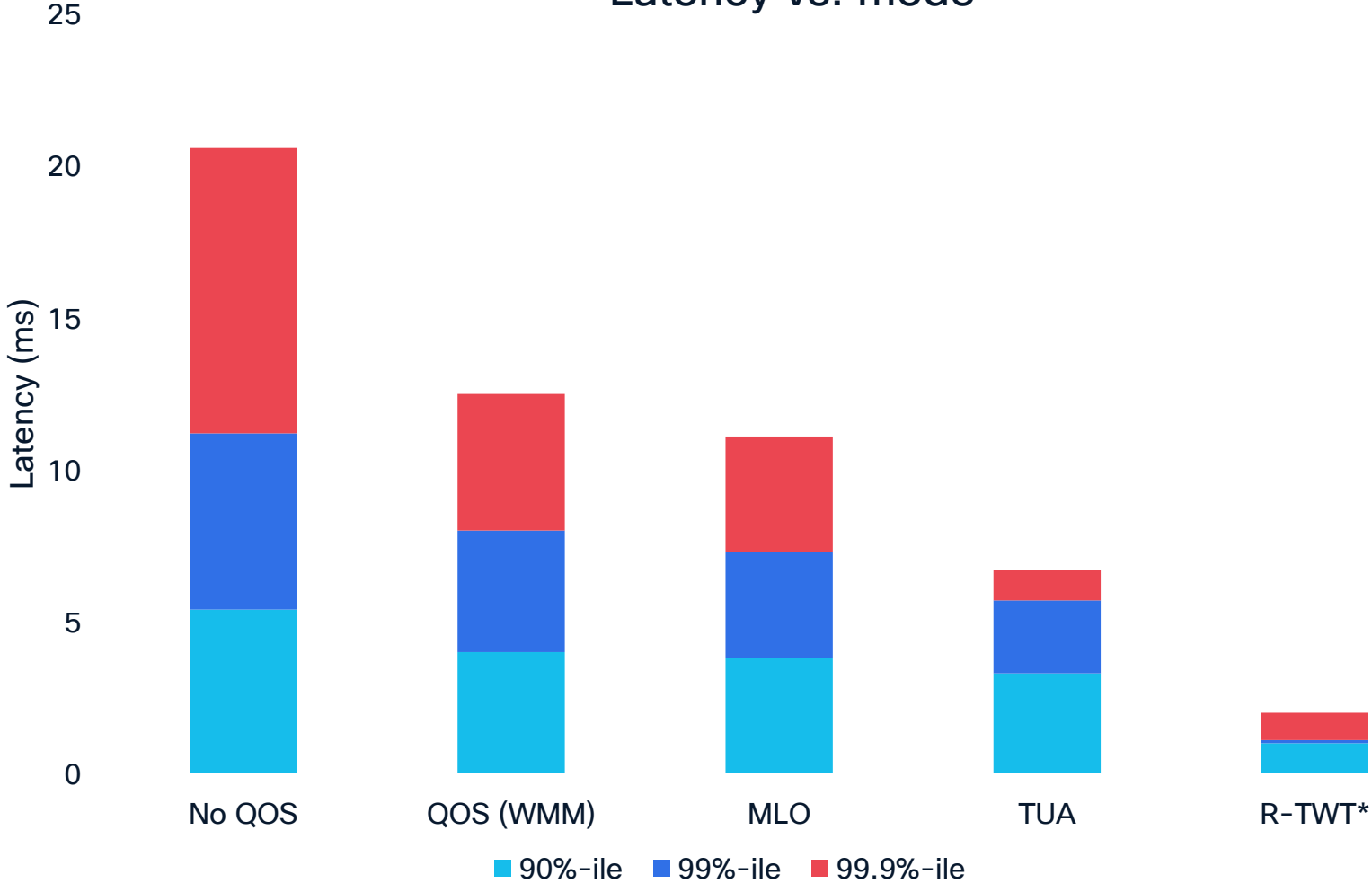
- The AP can issue a multi-link trigger directing the STA to send uplink data on one or more links concurrently.
- Wi-Fi 7 allows triggered uplink pre-emption: high-priority traffic (like voice) can interrupt lower-priority traffic.
- APs can issue granular and flexible RU assignments (including puncturing for non-contiguous spectrum).



Wi-Fi 7 Latency improvements

- Avg. 50% CU
- 40MHz
- TUA needed to meet 10ms

Latency vs. mode

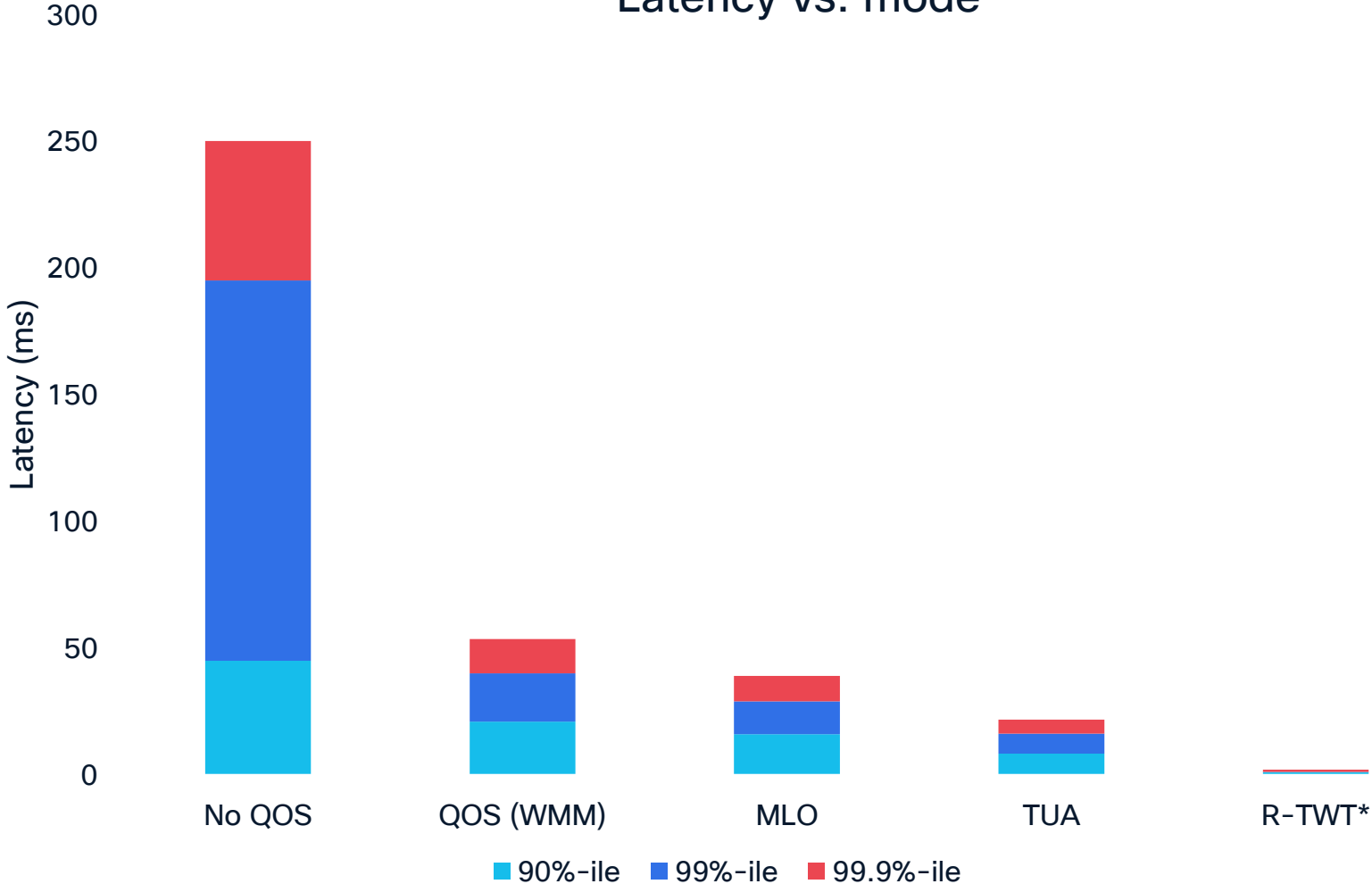


*from WTSN PoC
CU Channel Utilization

Wi-Fi 7 Latency improvements

- Avg. 90% CU
- 40MHz
- WMM Won't meet 10ms
- R-TWT required for 1mS 99.9%

Latency vs. mode



*from WTSN PoC
CU - Channel Utilization

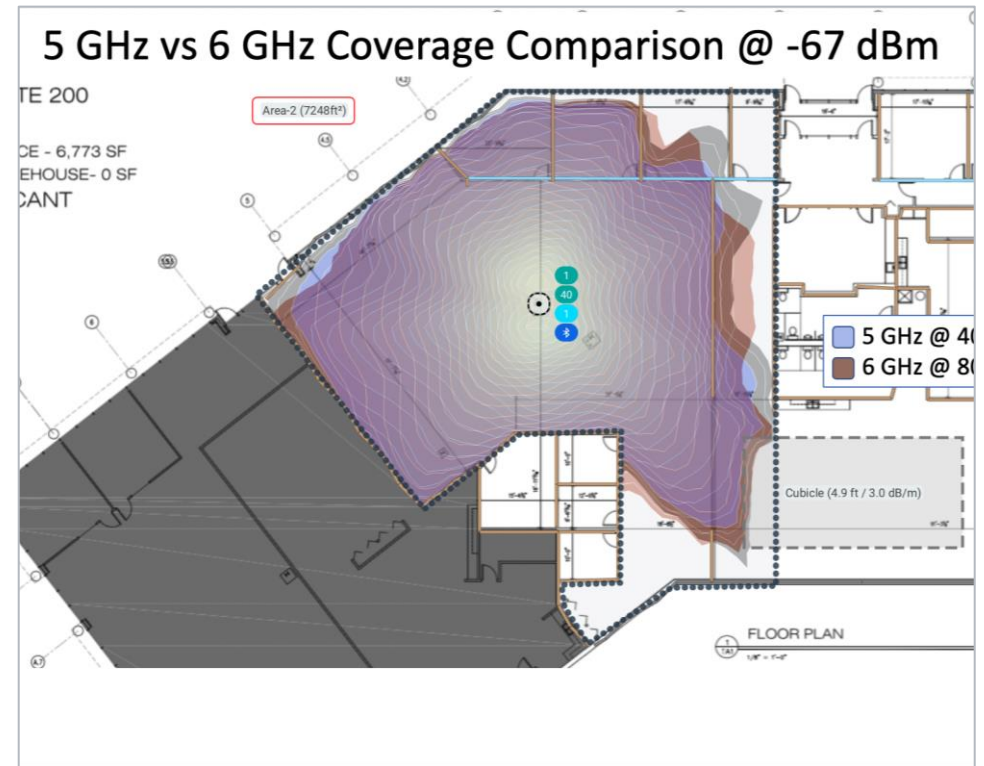
Wi-Fi7 Deployment Considerations

Designing for Wi-Fi 7

Wi-Fi 7 coverage area will be similar to the previous generations for the same minimum data rate, channel bandwidth and so on.

Design considerations:

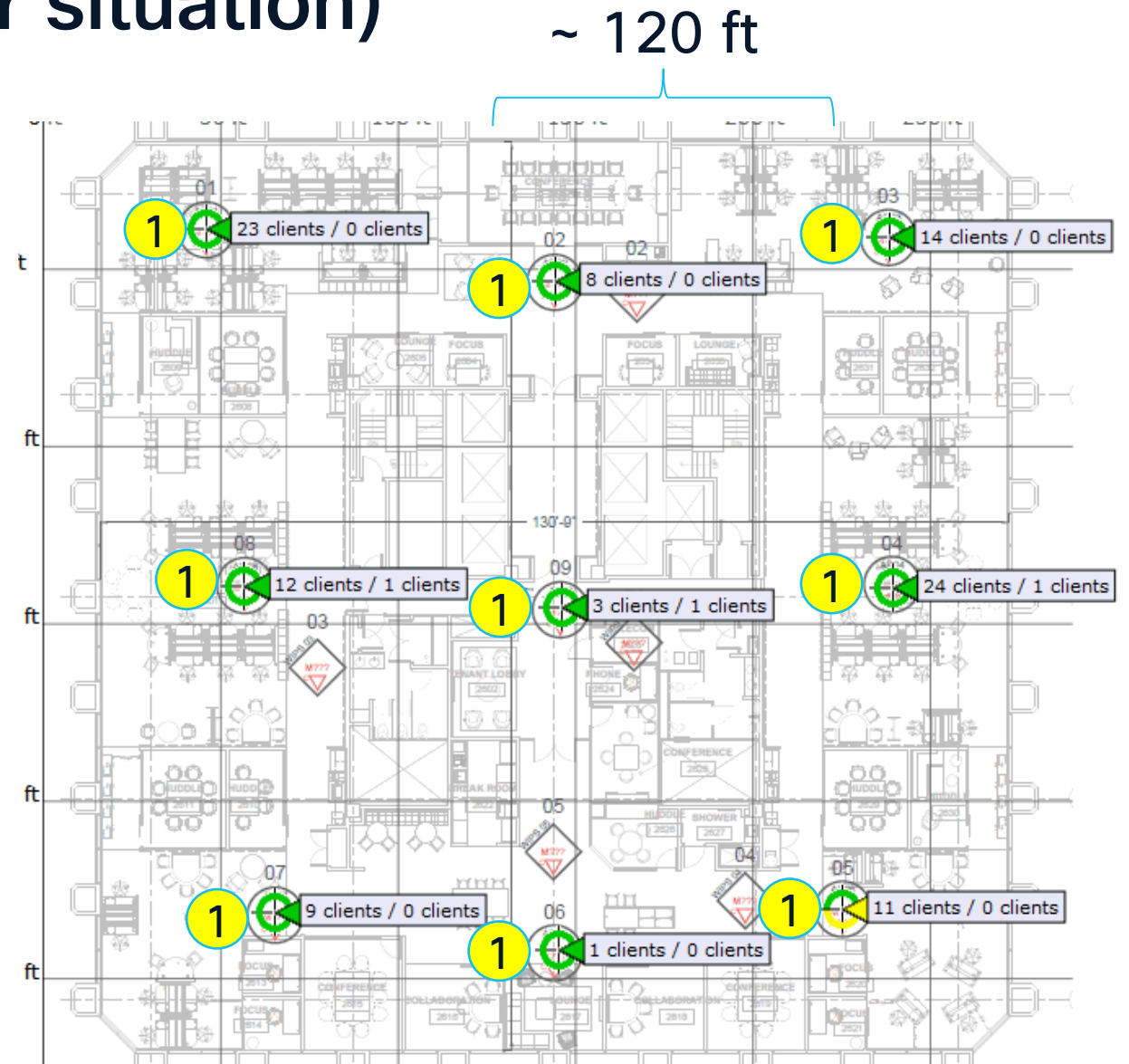
- 320 MHz channel width
- MLO



Wi-Fi 7 site planning is very much like Wi-Fi 6E (6 GHz) or Wi-Fi 6 (5 GHz)

Imagine This Scenario (based on an actual customer situation)

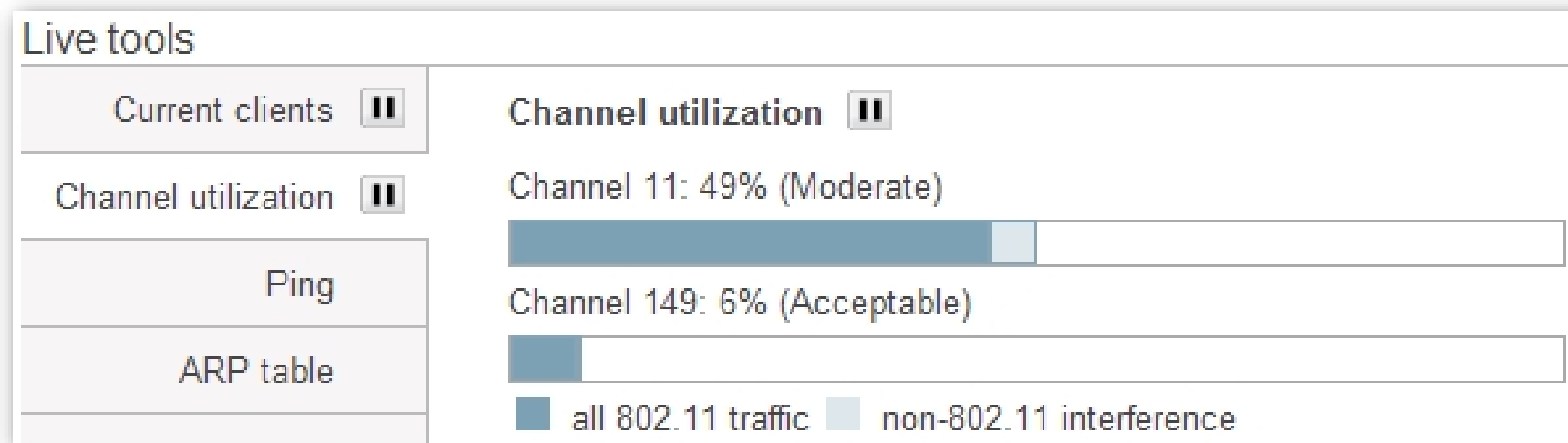
- Customer moved to first Wi-Fi only building (including voice and video)
- DISASTER! Wi-Fi was Terrible!!
- Investigation revealed all APs at max power (power level 1)



Monitor Channel Utilization in MLO Deployments

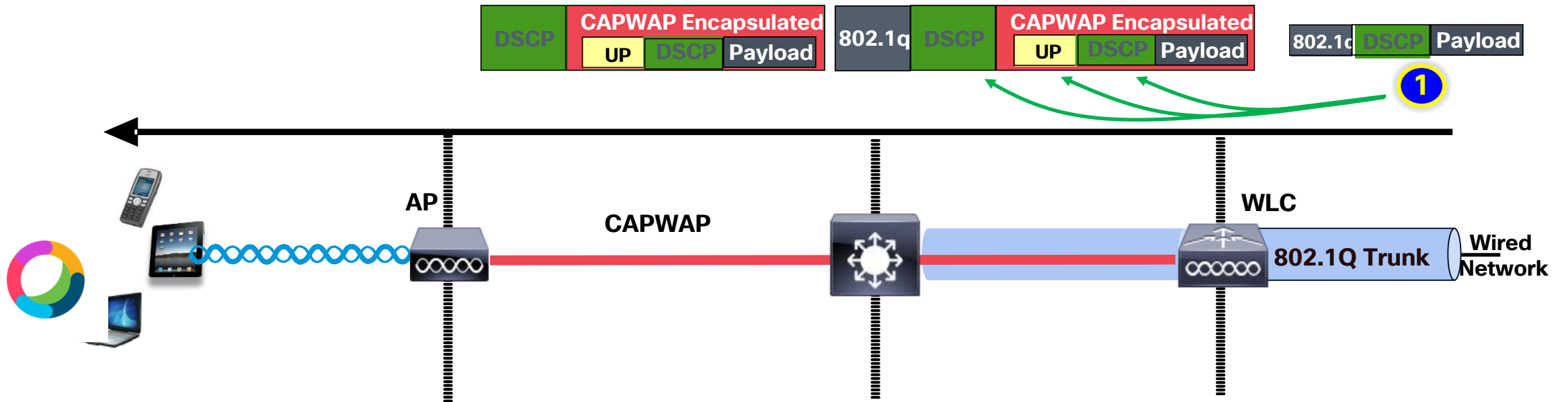
This is how busy the channel looks from the AP's perspective

- High Channel Utilization indicates high levels of contention
- **50% Channel Utilization** is the “gaping threshold” for performance
- Poor CU = poor link quality, poor performance



The Meraki Live Channel Utilization Measurement Tool

Catalyst 9800 Downstream QoS Model

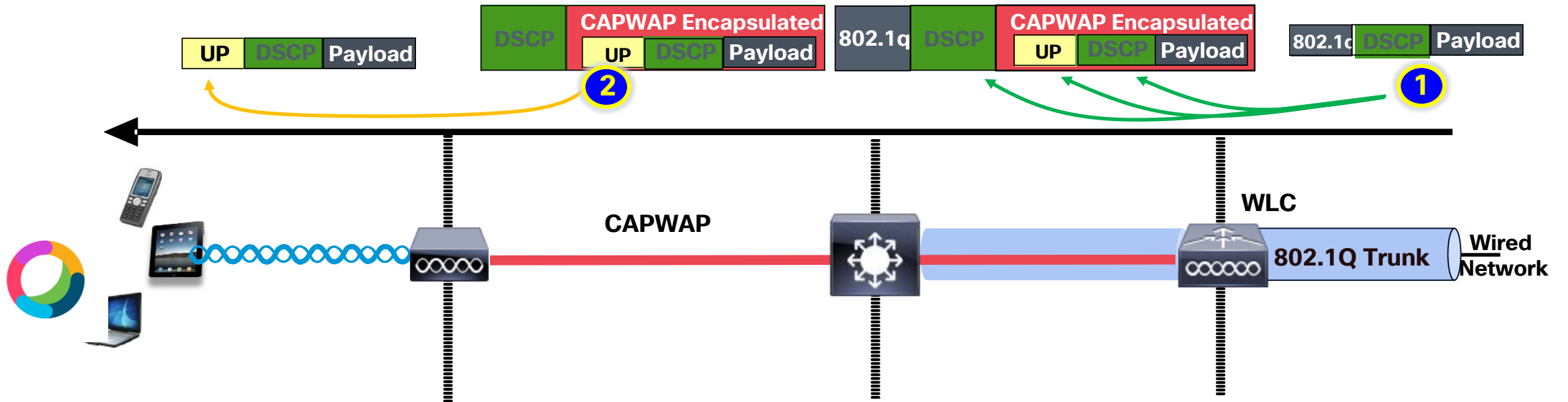


1

The client packet is received over an 802.1q trunk by the WLC. The WLC uses the DSCP value of the original IP packet and maps it to the outer DSCP of the CAPWAP tunnel (assuming no ceiling value is applied via Metal QoS at the WLC). It also maps DSCP to UP and set it in the inner 802.11e header

Note: class of Service (CoS) tagging is not supported in 9800 (supported but not recommended in AireOS)

Catalyst 9800 Downstream QoS Model

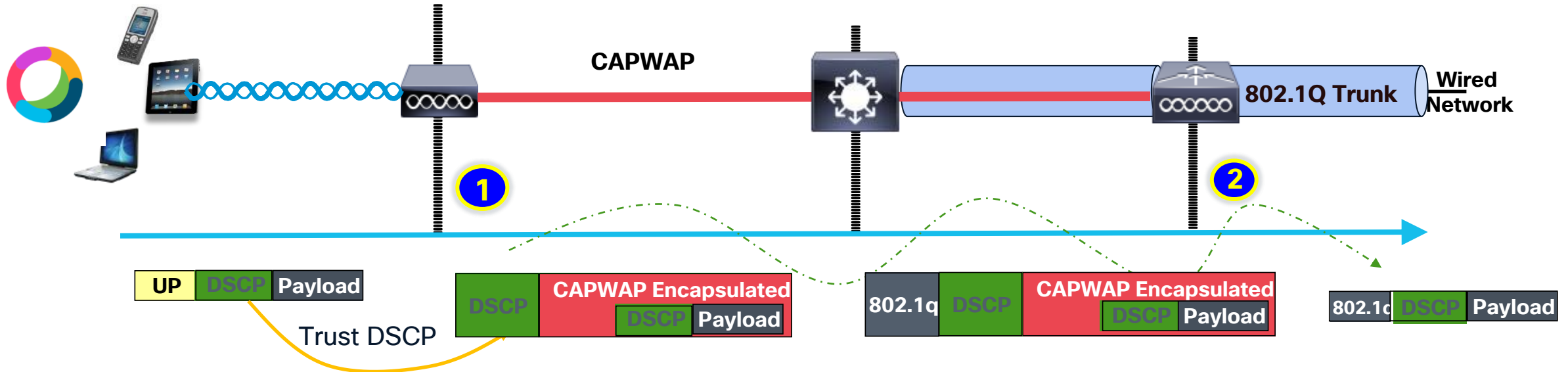


- 1** The client packet is received over an 802.1q trunk by the WLC. The WLC uses the DSCP value of the original IP packet and maps it to the outer DSCP of the CAPWAP tunnel (assuming no ceiling value is applied via Metal QoS at the WLC). It also maps DSCP to UP and set it in the inner 802.11e header
- 2** The AP leverages the inner UP value received from the WLC for internal QoS processing and queuing. The 802.11e UP value is also copied in the egress wireless 802.11 frame to the client, over the air

Catalyst 9800 Upstream QoS Model

1

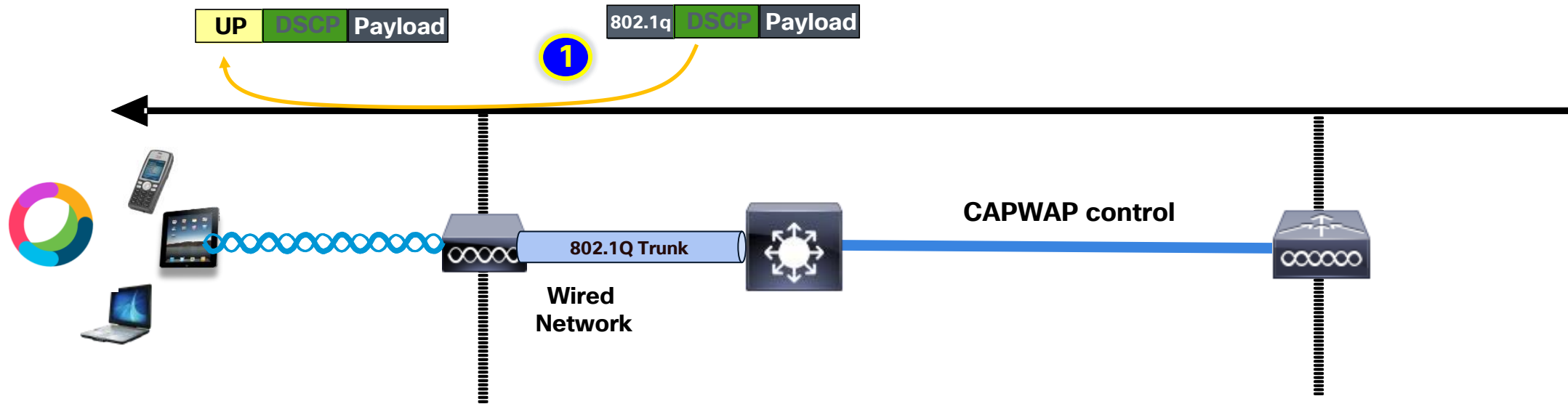
The client 802.11e frame is received by the AP. The AP utilizes the DSCP value in the original packet for internal QoS processing and then maps it to the outer CAPWAP IP header, (assuming no ceiling value is applied via Metal QoS at the WLC)(*))



2

This allows preservation of the DSCP value from the client all the way through the network, emerging untouched from the WLC (assuming no Metal QoS or AVC policy is applied to remark DSCP)

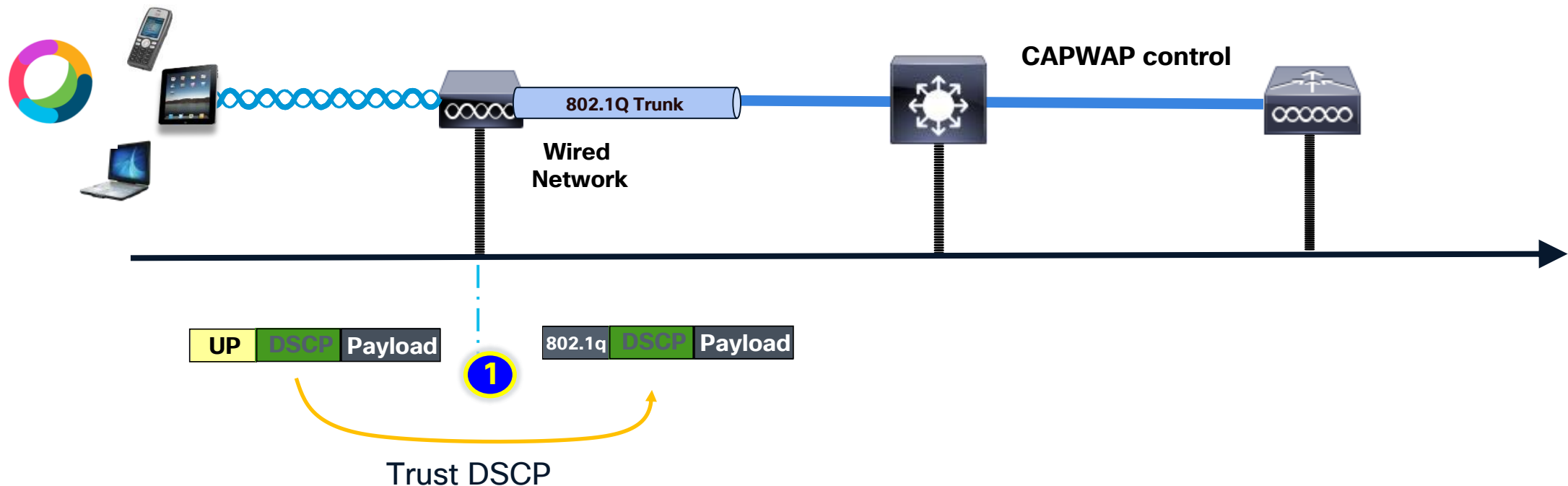
Downstream QoS Variant 1: Flex Local Switching



- 1 Once the Ethernet frame is received, the AP takes the DSCP value of the IP packet, process any QoS policy (e.g., AVC policy), maps it to the 802.11e UP value on the wireless frame and queue the frame accordingly. The frame is then sent to the client.

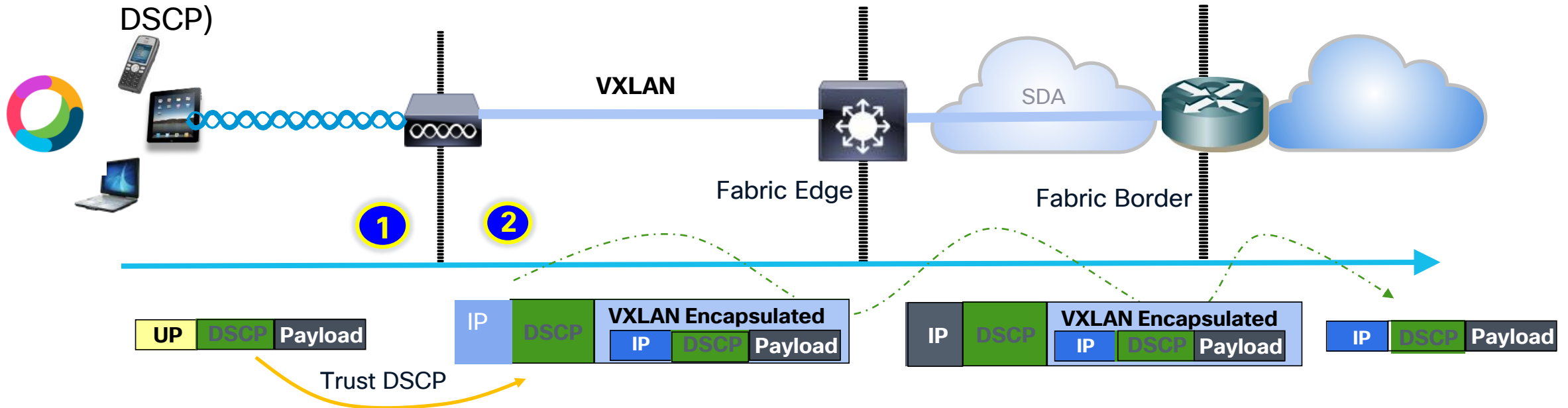
Upstream QoS Variant 1: Flex Local Switching

- 1 The client 802.11e frame is received by the AP. The AP looks at the original packet DSCP to apply any QoS policy before sending the packet onto the wire



Upstream QoS Variant 2: SDA Fabric

- 1 The client 802.11e frame is received by the AP. The AP utilizes the DSCP value in the original IP packet for internal QoS processing and then maps it to the outer VXLAN header(*)
- 2 This allow preservation of the DSCP value from the client all the way through the network, emerging untouched from the Border (assuming no Metal QoS or AVC policy is applied to remark DSCP)



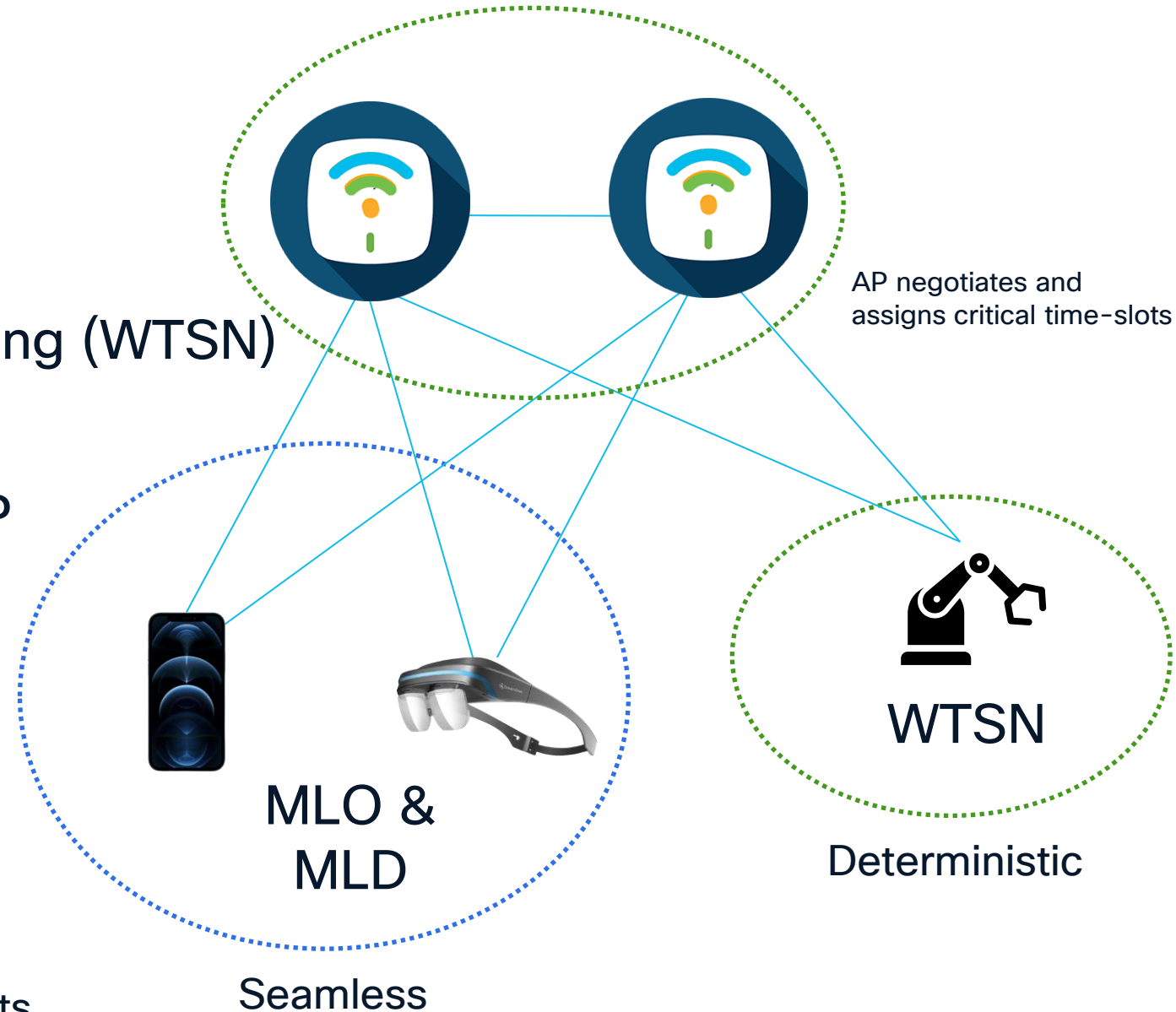
(*) Before release 17.4, you need to explicitly configure “qos-map trust-dscp-upstream” under the AP join profile. If this setting is not there, the AP will use the UP value in the received frame to derive the outer DSCP value of the VXLAN header

Looking to the Future: 802.11bn (Wi-Fi8)

Deterministic scheduling

- MAPC (Multi-AP Co-ordination)
- High-speed roaming
- Wireless Time Sensitive Networking (WTSN)
- AI/ML-Assisted Scheduling
- Determinism among APs and P2P

Reduce collisions and interference
Improve spectrum reuse
Enable **deterministic scheduling** (low latency, guaranteed airtime)
Increase throughput in high-density deployments



Wi-Fi8 Sneak Peek / 802.11bn Ultra High Reliability (UHR) WLAN

1. Ultra High Reliability – expanding MLO to multiple APs
2. Multi-AP Communication (MAPC)
3. Peer-to-Peer (P2P) communication
4. Ambient Power Wi-Fi Devices (AMP)
5. Standardization of randomized MAC addresses (802.11bi)
6. Make-before-break-roaming (ideally, zero packet loss)
7. Target Wake Time ++

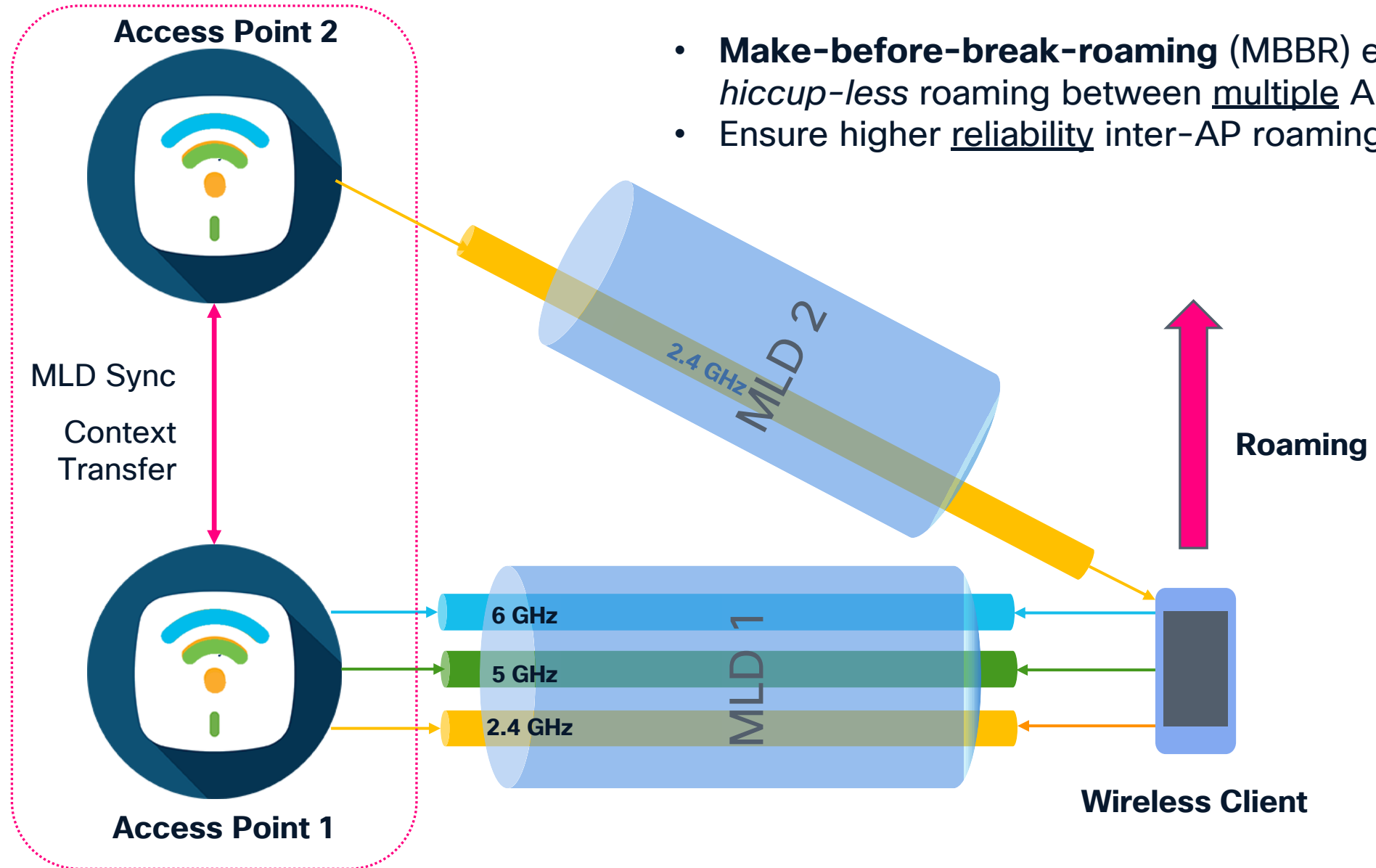
TODAY - Wi-Fi 7 - Multilink Operations -> MLO



- Roaming in Wi-Fi has typically been “best effort” or ***break-before-make-roaming (BBMR)***
- Wi-Fi 7 MLO improves “roaming” within a single AP (But between radios/bands)
- But time-sensitive/deterministic apps *still* experience *hiccups* roaming between AP’s

Wi-Fi 8 – Multilink Operations 2.0

Seamless
Mobility
Domain
(SMD)



- **Make-before-break-roaming** (MBBR) enables *hiccup-less* roaming between multiple AP's
- Ensure higher reliability inter-AP roaming

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Thank you

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