Arista Wi-Fi 7 AP: Initial Findings on Wi-Fi 7 Features and Client Behavior

Introduction

Wi-Fi 7 offers numerous core improvements that boost the user experience by optimizing the performance of wireless connections. This article will share insights from early experiments on Wi-Fi 7 client behavior with Arista Wi-Fi 7 access points. We will primarily focus on MLO (Multi-Link Operation) and preamble puncturing behavior with popular clients.

Multi-Link Operation (MLO):

Multi-Link Operation (MLO) is a standout feature of Wi-Fi 7. Leveraging the dual-band or tri-band capabilities of most current APs and stations, MLO allows for packet-level link aggregation in the MAC layer across various PHY links. This enables load balancing based on traffic demands, resulting in significantly higher throughput, lower latency, and improved reliability in heavily congested networks.

MLO Modes:

802.11be defines the following different operational modes for MLOs.

Single Radio	**Single link E-MLSR** Single link enhanced multi link single radio	Able to Tx and Rx over one radio at a time
Single Radio	**Multi Link E-MLSR** Enhanced Multiple Link Single Radio	Enhanced MLSR with additional capability to listen on two links simultaneously
Multi Radio	**STR MLMR** Simultaneous Transmit & Receive Multiple Link Multiple Radio	Simultaneous Tx/Tx, Rx/Rx and Tx/Rx over multiple links
Multi Radio	**NSTR MLMR** Non-Simultaneous Transmit & Receive Multiple Link Single Radio	Simultaneous Tx/Tx and Rx/Rx over multiple links
Multi Radio	**E-MLMR** Enhanced Multi Link Multi Radio	Capabilities to dynamically reconfigure links

Before we delve into the single and multi-radio capabilities of MLO operating modes. Let's have a quick look at the primary differences between Wi-Fi 6 and Wi-Fi 7.

Feature	Wi-Fi 6 Single Channel Operation	Wi-Fi 7 Multi-Link Operation (MLO)
Channel Use	Single channel within a single frequency band	Multiple channels across different frequency bands simultaneously
Interference and Congestion	More susceptible to interference and congestion	Better management by spreading traffic across multiple links
Latency and Throughput	Limited by the capacity of a single channel, impacting latency and throughput	Higher aggregate throughput and lower latency due to concurrent multi-link operation
Dynamic Operation	N/A	Dynamic switching between channels and bands

Wi-Fi 7 introduces various configurations for single- and multi-radio systems, each with distinct capabilities and enhancements. Please refer to the Arista Data Processing Agreement for complete details.

Single Radio Configurations

Single Link E-MLSR (Enhanced Multi-Link Single Radio):
This configuration allows the device to transmit (Tx) and receive (Rx) over one radio at a time, providing enhanced single-link capabilities for better performance.

Multi-Link E-MLSR (Enhanced Multiple Link Single Radio):
Building on the single link E-MLSR, this configuration includes the additional capability to listen on two links simultaneously and then switches all chains to one link dynamically offering improved efficiency and versatility in handling multiple links.

Multi-Radio Configurations

STR MLMR (Simultaneous Transmit & Receive Multiple Link Multiple Radio):
This advanced configuration supports simultaneous transmission and reception over multiple links, whether it is Tx/Tx, Rx/Rx, or Tx/Rx. This capability ensures higher throughput and better utilization of available spectrum.

NSTR MLMR (Non-Simultaneous Transmit & Receive Multiple Link Single Radio):
Although this configuration does not support simultaneous transmit and receive operations, it still allows simultaneous Tx/Tx and Rx/Rx over multiple links. This feature enhances network performance by optimizing link usage.

E-MLMR (Enhanced Multi-Link Multi-Radio):
This is the most advanced configuration, offering the capability to dynamically reconfigure links. It provides flexibility and adaptability, ensuring optimal performance and reliability in various network conditions.

These configurations highlight the diverse capabilities of Wi-Fi 7 in managing multiple links and radios, ensuring enhanced performance, reliability, and user experience across different network environments.

Among all the available modes, clients predominantly use STR MLMR or E-MLSR. As of the date of this article, we have not observed any clients utilizing NSTR MLMR or E-MLMR operational modes.

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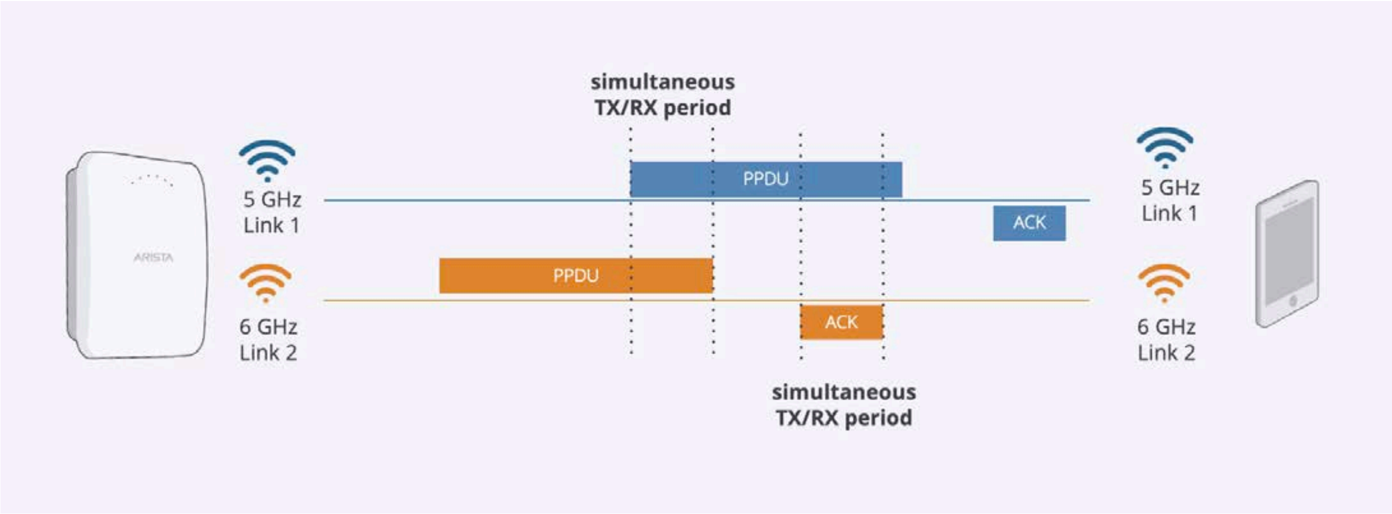
STR-MLMR: Concurrent Tx/Rx over Multiple Links

In STR-MLMR mode, Wi-Fi 7 clients can transmit and receive concurrently over multiple radios. Transmission on one link will not cause in-device interference to another link, preventing link retries or collisions.



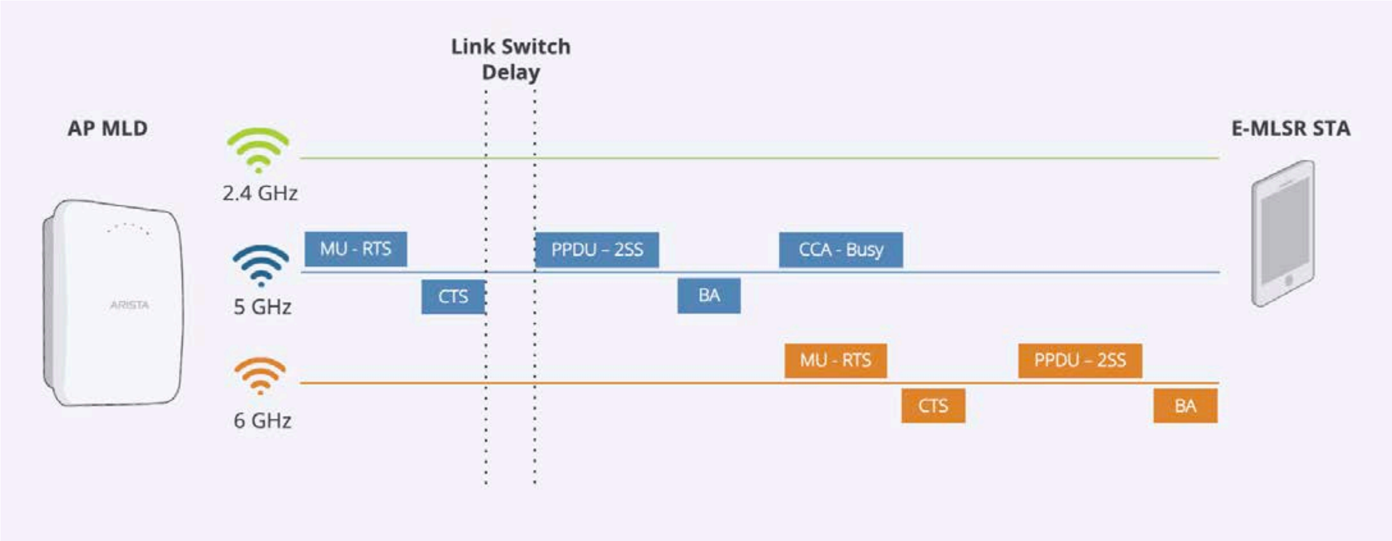
Higher Throughput:
STR-MLMR mode allows for simultaneous transmission and reception over multiple links, significantly increasing the overall data throughput.

Reduced Latency:
By enabling concurrent data flows, this mode reduces the latency associated with waiting for transmission slots, leading to faster and more responsive network performance.

Improved Spectrum Efficiency:
STR-MLMR mode makes better use of available spectrum by leveraging multiple radios and links concurrently, optimizing bandwidth usage.

These advantages make STR-MLMR mode a significant enhancement in Wi-Fi 7, contributing to improved performance, efficiency, and user experience in various networking scenarios.

E-MLSR: Dynamic Steering across Multiple Links



Multi-Link EMLSR: A multiple-chain client splits its Rx chains to listen on two links simultaneously and then switches all chains to one link dynamically. An MU-RTS/CTS exchange precedes the actual data frame from the AP.

Simultaneous Listening on Multiple Links:
Multi-Link EMLSR allows a client to listen on two links simultaneously, increasing the chances of successfully receiving data from multiple sources.

Dynamic Switching:
The ability to dynamically switch all chains to one link enhances flexibility and ensures optimal link utilization based on current network conditions.

Improved Reliability:
By listening on multiple links, Multi-Link EMLSR reduces the likelihood of missed transmissions, thus improving the reliability of data reception.

MU-RTS/CTS Exchange:
The use of MU-RTS/CTS exchanges before data frames helps to manage and coordinate transmissions, reducing the chances of collision and improving the efficiency of data transfer.

These advantages make Multi-Link EMLSR a valuable feature in Wi-Fi 7, contributing to enhanced network performance, reliability, and user experience.

MLO Network Selection by MLO Capable Clients

During our early testing, we found that most popular clients on the market don't perform STR-MLMR when the SSID is configured in the 5 GHz and 6 GHz bands. However, they do perform STR-MLMR in the 2.4 GHz and 5 GHz or 2.4 GHz and 6 GHz bands, with a preference for the 2.4 GHz and 6 GHz configurations.

E-MLSR in the 5 GHz and 6 GHz bands is often preferred over STR-MLMR due to the ability to manage in-device coexistence and minimize interference effectively. This approach ensures better performance, reliability, and efficiency, making it a practical choice for many Wi-Fi clients.

Device Capabilities

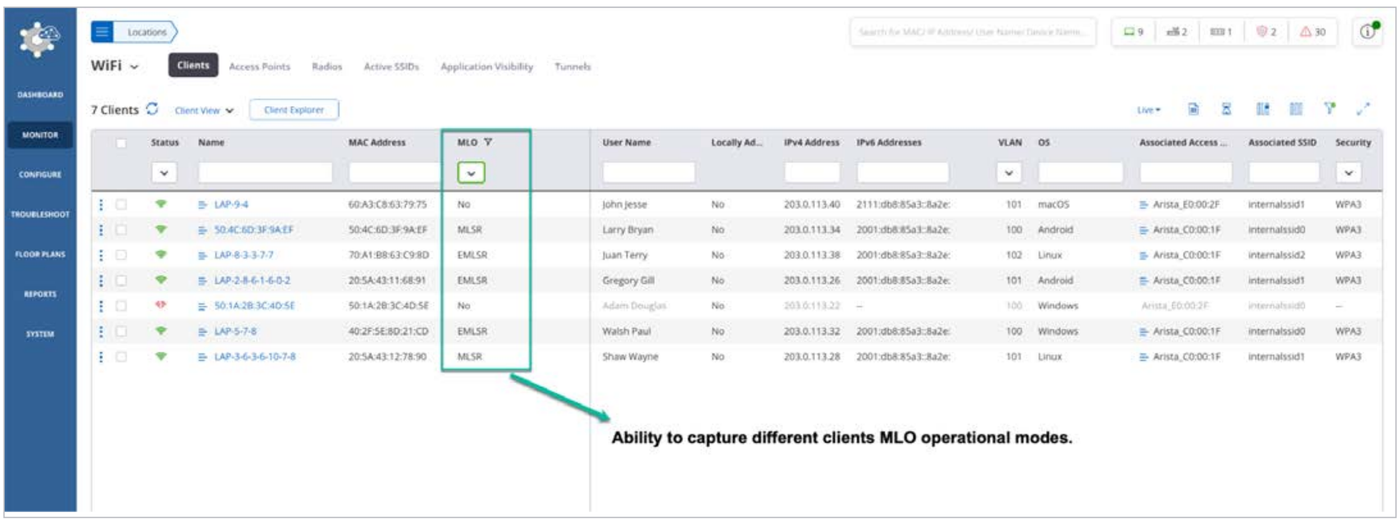
Device	SSID with 2.4+5+6 GHz enabled	SSID with only 5 & 6 GHz enabled
Google Pixel 8	2.4 + 5 GHz STR-MLMR 2.4 + 6 GHz STR-MLMR	5 + 6 GHz E-MLSR
Samsung S24	2.4 + 5 GHz STR-MLMR 2.4 + 6 GHz STR-MLMR	SLO
One Plus 11	2.4 + 5 GHz STR-MLMR 2.4 + 6 GHz STR-MLMR	STR-MLMR* (Data flow only in 6 GHz)
Intel BE200	2.4 + 5 GHz E-MLSR 2.4 + 6 GHz STR-MLSR 5.0 + 6 GHz E-MLSR	Dynamic switching between channels and bands
Qualcomm FastConnect 7800 Wi-Fi ref adapter	2.4 + 5 GHz STR-MLMR 2.4 + 6 GHz STR-MLMR 5.0 + 6 GHz STR-MLMR	5.0 + 6 GHz STR-MLMR

We tested with popular Wi-Fi 7 devices such as the Google Pixel 8, Samsung S24, OnePlus 11, Intel BE200, and Qualcomm Fast Connect 7800 Wi-Fi 7 Reference Adapter. When the SSID was configured on all three radios (2.4 GHz, 5.0 GHz, and 6.0 GHz bands), the above clients always successfully formed STR-MLMR in either the 2.4 GHz and 5.0 GHz bands or the 2.4 GHz and 6.0 GHz bands. However, when the SSID was only in the 5 GHz and 6 GHz bands, different client devices behaved differently—some performed E-MLSR, while many did not work with either STR-MLMR or E-MLSR.

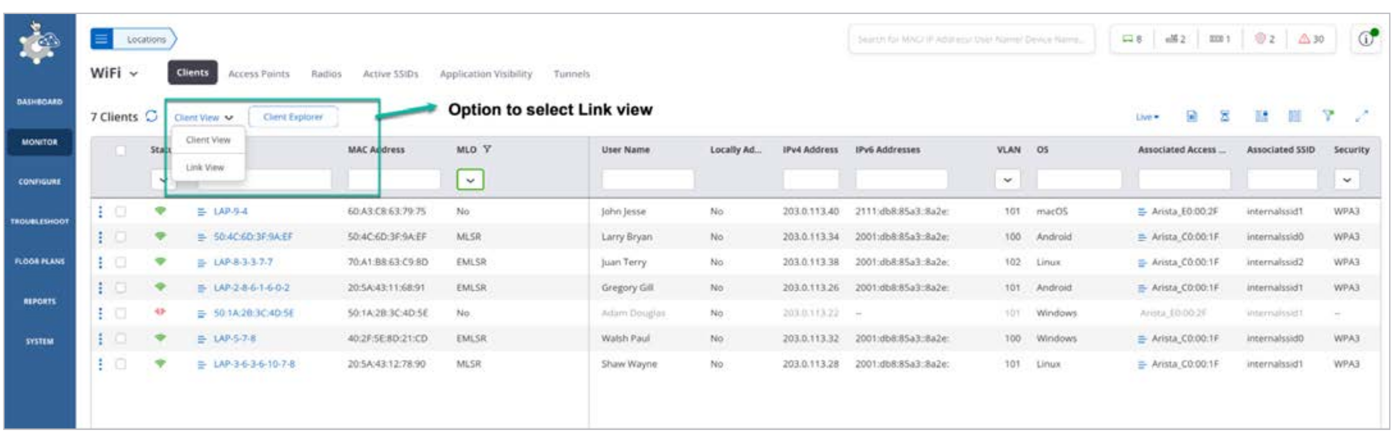
From an access point perspective, it will support STR-MLMR as long as the client also supports it, as shown in the above table. The Qualcomm Fast Connect 7800 Wi-Fi 7 reference adapter is a High Band Simultaneous (HBS) supported card, with proper filtering implemented to avoid in-device interference. Consequently, it can perform STR-MLMR in the 5 GHz and 6 GHz bands, respectively.

The above table is based on specific client driver versions, and changes or behavior correctness may occur over time on the client-vendor side.

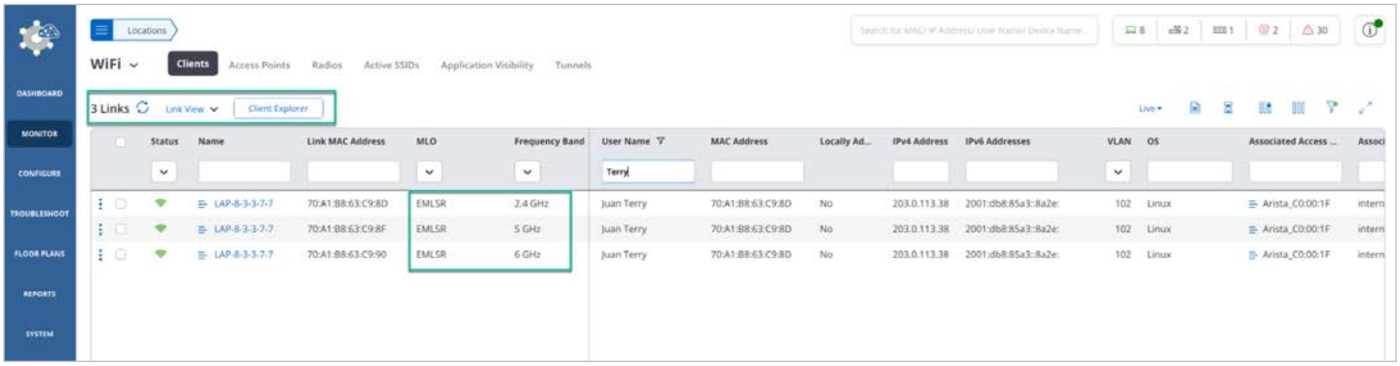
Arista CV-CUE - Ability to show client view and link view for MLO-capable client



Per client Link view for MLO capable client



Link View

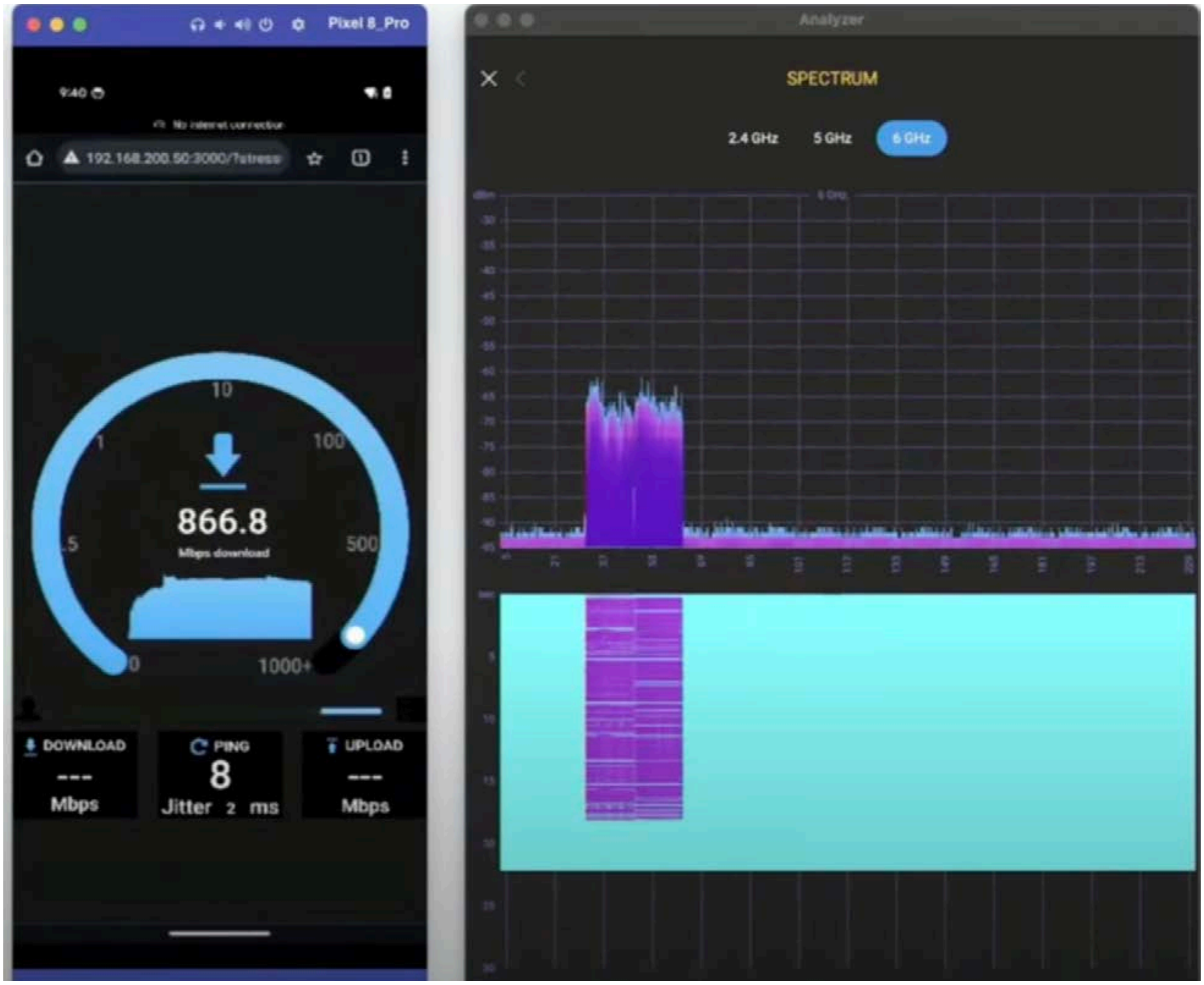


Link View

Spectrum View of STR-MLMR:

STR-MLMR: Concurrent transmit and receive in 6GHz and 2.4GHz band.

In this test, we have the SSID configured in the 2.4 GHz, 5 GHz, and 6 GHz bands. A Google Pixel 8 joins the SSID with STR-MLMR performing concurrent transmit and receive in both bands respectively as shown in the figure below.



Key Takeaway:

Here are a few takeaways from early experiments on Wi-Fi 7 client behavior:

1. **Client Behavior with 5 GHz and 6 GHz Bands:** Popular clients may not fully utilize the aggregation benefits with 5 GHz and 6 GHz bands using concurrent transmission, primarily due to in-device coexistence issues (IDC) refers to the technology that enables multiple wireless components within a single device to operate simultaneously without interfering with each other)

2. **Driver Enhancements Over Time:** Over time, client drivers are expected to be enhanced to support E-MLSR mode, enabling better latency benefits.

3. **Getting the Most Out of Your Investment:** Upgrading to Wi-Fi 7 APs will future-proof your network. To maximize your investment, please ensure that wireless devices have been updated to use the latest wireless drivers.

   By taking these factors into account, we can ensure that Wi-Fi 7 deployments are optimized for current and future client capabilities, providing enhanced performance and reliability.

Preamble Puncturing:

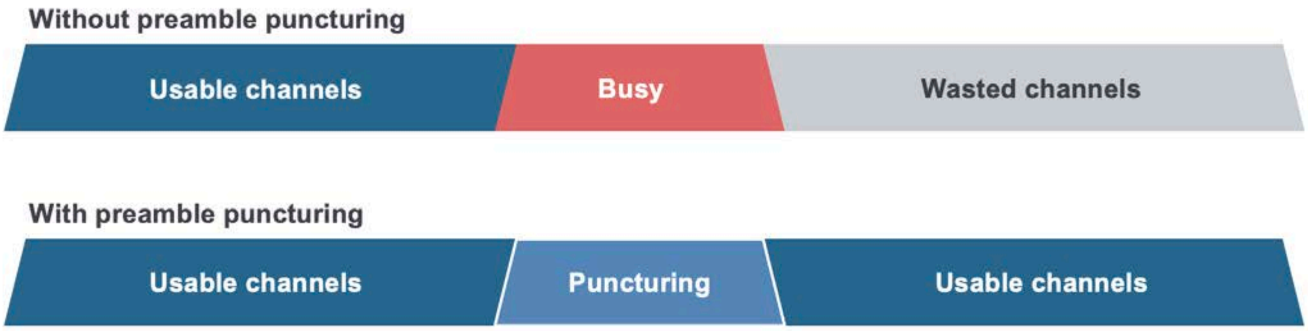
Preamble puncturing is a significant enhancement in Wi-Fi 7 that allows for more efficient utilization of available bandwidth. This technique addresses the challenge of interference within the channel width, enabling better performance in crowded and complex wireless environments.

Traditional Channel Usage

Without preamble puncturing, the presence of interference in any part of the secondary channel can render the entire secondary channel unusable. This is illustrated by the following:

- **Usable Channels:** Portions of the spectrum that are free from interference and can be used for data transmission.
- **Busy Channels:** Segments of the spectrum experiencing interference, making them unusable.
- **Wasted Channels:** Remaining parts of the spectrum that, despite being free from interference, cannot be used because the interference within the channel width affects the entire channel.

In this scenario, even a small interference section can cause substantial portions of the channel to go to waste, significantly reducing overall network efficiency and throughput.



Bandwidth after the interference in the whole of channel width can now be utilized

Enhanced Channel Usage

With the introduction of preamble puncturing in Wi-Fi 7, it becomes possible to utilize bandwidth more effectively:

- **Usable Channels:** As in the traditional setup, these are the interference-free portions of the spectrum.
- **Puncturing:** The technique allows certain spectrum segments to be "punctured" or excluded, effectively ignoring the interfered parts of the channel.
- **Usable Channels After Puncturing:** This innovation ensures that the remaining usable parts of the channel can still be leveraged for data transmission, even if some segments are interfered with.

In this scenario, even a small interference section can cause substantial portions of the channel to go to waste, significantly reducing overall network efficiency and throughput.

Topology:

We will be comparing both scenarios, with and without puncturing, and observing the spectrum view during puncturing. In this test, we have the SSID configured in the 2.4 GHz and 6 GHz bands. A Google Pixel 8 joins the SSID with STR-MLMR. When it is associated with both bands, we inject interference into the secondary channel of the 6 GHz band. The AP detects the interference and punctures the interference area.

Spectrum View of 6GHz Band Before Puncturing

Test showing full 6GHz band is utilized before preamble puncturing, station under test is Google Pixel 8

Spectrum View of 6GHz Band After Puncturing

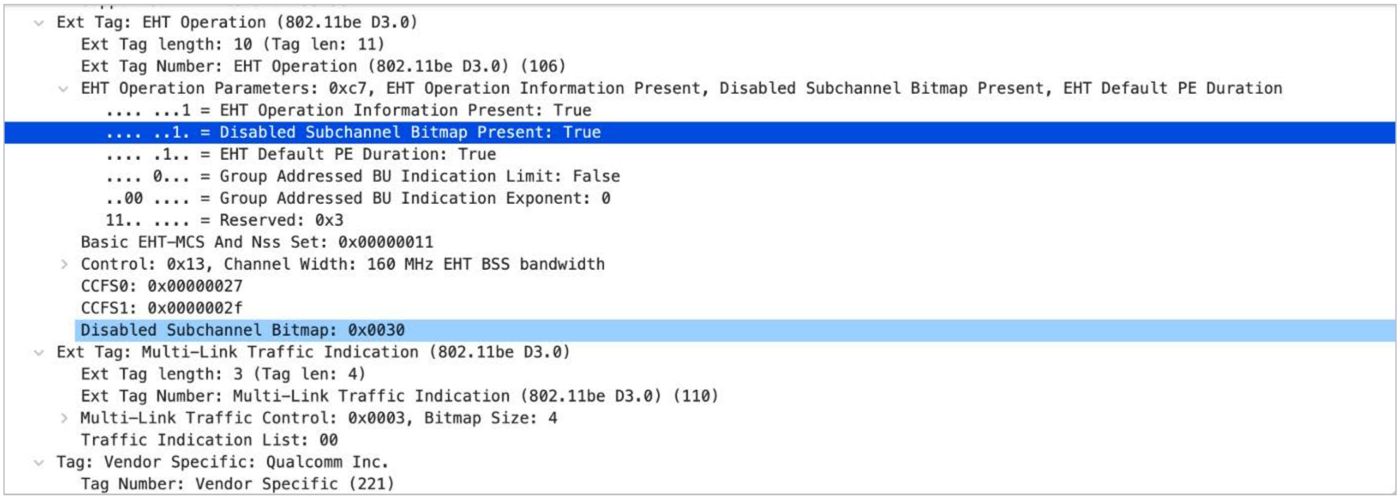
Preamble Puncturing test performed using Google Pixel 8

By enabling selective usage of the channel, preamble puncturing ensures that interference in part of the channel does not affect the entire channel's usability. This leads to:

1. **Improved Spectrum Efficiency:** More efficient use of the available spectrum by avoiding the wastage of large portions of the channel due to minor interference.
2. **Increased Throughput:** Enhanced data transmission rates as more of the channel can be utilized effectively, even in the presence of interference.
3. **Greater Reliability:** Improved network performance and stability, particularly in dense environments with many overlapping networks and potential sources of interference.

Preamble Puncturing Beacon:

Once puncturing is successful over the air, we see the "Disabled Subchannel Bitmap Present" flag set to True. The "Disabled Subchannel Bitmap" will contain the details of the punctured channels, informing the Wi-Fi client supporting preamble puncturing about the subchannels that are punctured. Consequently, the client will not expect the preamble on those punctured areas.



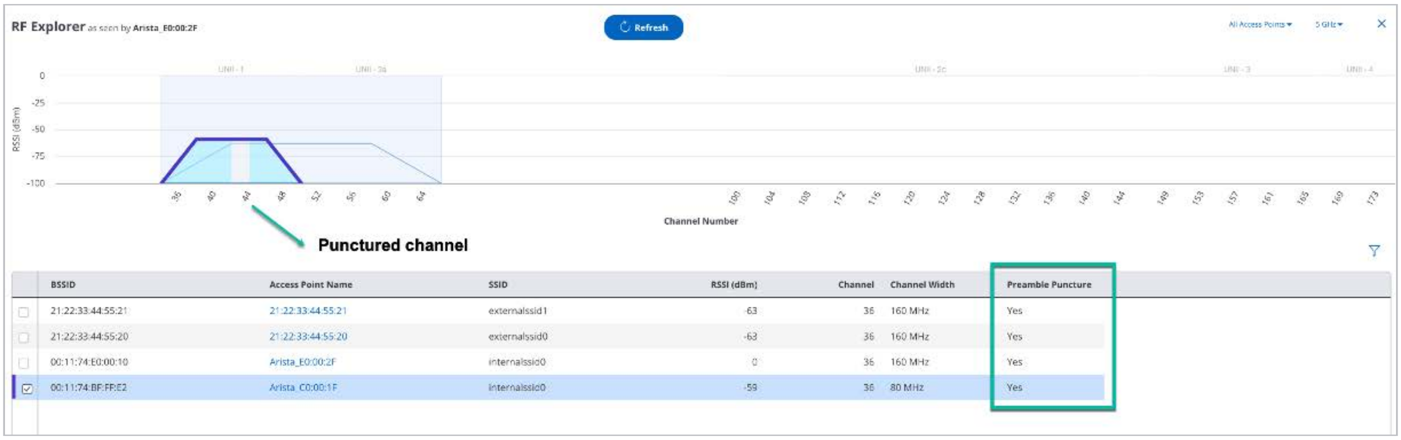
```
⌄ Ext Tag: EHT Operation (802.11be D3.0)
    Ext Tag length: 10 (Tag len: 11)
    Ext Tag Number: EHT Operation (802.11be D3.0) (106)
  ⌄ EHT Operation Parameters: 0xc7, EHT Operation Information Present, Disabled Subchannel Bitmap Present, EHT Default PE Duration
      .... ...1 = EHT Operation Information Present: True
      .... ..1. = Disabled Subchannel Bitmap Present: True
      .... .1.. = EHT Default PE Duration: True
      .... 0... = Group Addressed BU Indication Limit: False
      ..00 .... = Group Addressed BU Indication Exponent: 0
      11.. .... = Reserved: 0x3
    Basic EHT-MCS And Nss Set: 0x00000011
  › Control: 0x13, Channel Width: 160 MHz EHT BSS bandwidth
    CCFS0: 0x00000027
    CCFS1: 0x0000002f
    Disabled Subchannel Bitmap: 0x0030
⌄ Ext Tag: Multi-Link Traffic Indication (802.11be D3.0)
    Ext Tag length: 3 (Tag len: 4)
    Ext Tag Number: Multi-Link Traffic Indication (802.11be D3.0) (110)
  › Multi-Link Traffic Control: 0x0003, Bitmap Size: 4
    Traffic Indication List: 00
⌄ Tag: Vendor Specific: Qualcomm Inc.
    Tag Number: Vendor Specific (221)
```

Preamble puncturing allows Wi-Fi networks to utilize bandwidth more efficiently by ignoring segments of a channel that experience interference. The provided screenshot shows critical information related to this feature:

- The presence of the "Disabled Subchannel Bitmap Present" flag indicates that preamble puncturing is in effect.
- The "Disabled Subchannel Bitmap" provides a hexadecimal value (0x0030) that corresponds to the specific subchannels that have been punctured.

Wi-Fi clients use this information to adjust their channel usage, ensuring that they do not expect preamble transmissions in the punctured areas, thereby optimizing performance even in the presence of interference.

CV-CUE: RF Explorer - Preamble Puncturing Status



Users will find the option for the punctured channel in Arista CV-CUE in the RF Explorer, along with the preamble puncturing status for the respective access points deployed on the floor.

Summary

In conclusion, Arista's early experiments and field trials have successfully demonstrated the potential of Wi-Fi 7 technologies to enhance network performance and reliability. By understanding client behavior and leveraging advanced features like MLO and Preamble Puncturing, enterprises can optimize their network design and future-proof their investments. The ongoing testing and data collection efforts will further refine our understanding and capabilities, ensuring Wi-Fi 7 meets the evolving needs of modern enterprises effectively.

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