Multi-User MIMO in WiFi 6

Multi-User MIMO (MU-MIMO) is one of the key features of WiFi 6. While Single-User MIMO (SU-MIMO) results in scaling of per-user throughput as a result of multi-stream transmission, its benefits are somewhat limited by the fact that most clients support either 1 or 2 spatial streams. Hence, even if an AP is capable of supporting 4 or 8 spatial streams, it can send at most 2 spatial streams to match the receiving client. MU-MIMO enables a multi-antenna AP to simultaneously communicate with multiple clients, thereby increasing system throughput.

The IEEE 802.11ac standard includes support for MU-MIMO but is limited to 4 streams. In addition, 802.11ac is limited to downlink transmission only. Further, since 802.11ac is specified for 5GHz operation only, MU-MIMO cannot be used in the 2.4GHz band. IEEE802.11ax supports up to 8-stream MU-MIMO transmissions in both downlink and uplink for 2.4GHz and 5GHz bands. The figure below shows a MU-MIMO scenario where an 8x8 AP is participating in UL/DL transmissions with four 2x2 clients at the same time.

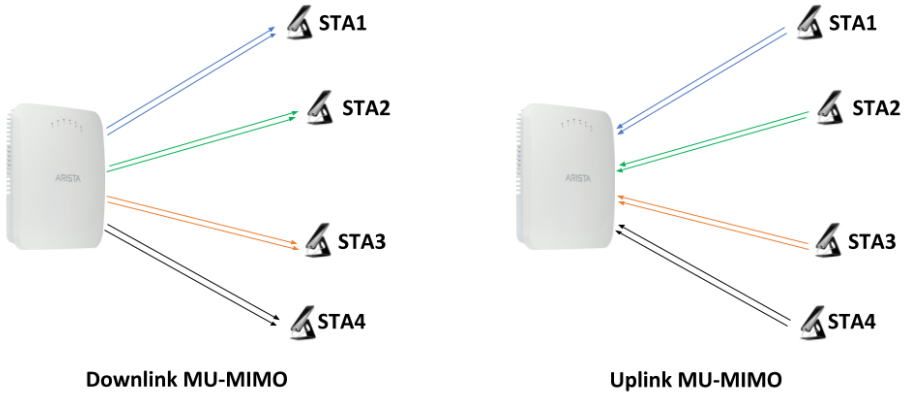

Figure 1: Multi-user MIMO Transmission

APs and STAs (clients) advertise support for DL/UL MU-MIMO in the HE PHY Capabilities Information field of the HE Capabilities element. For WiFi 6 certification, DL MU-MIMO support is mandatory for APs delivering 4 or more spatial streams.

WiFi 6 MU-MIMO Operation

MU-MIMO transmissions are of two types: Full Bandwidth and Partial Bandwidth. Full Bandwidth mode is similar to MU-MIMO operation in 802.11ac, i.e. MU-MIMO streams transmitted to users span the entire channel. For instance, if the channel bandwidth is 20 MHz, MU-MIMO transmission will use a 242-tone RU which effectively occupies the entire channel. Partial Bandwidth mode is used when OFDMA and MU-MIMO need to be used simultaneously, i.e., when users are multiplexed in both frequency and time domains. In this case, the minimum RU size allowed is 106-tones. For example, if the transmission bandwidth is 20 MHz, then a 106-tone RU each can be allocated to two different users for a single MU-MIMO stream.

An AP signals support for MU-MIMO by setting the MU Beamformer subfield of the HE PHY Capabilities Information field in its HE Capabilities element to 1. An MU beamformer is also an SU beamformer and must set the SU Beamformer subfield to 1. If the AP supports 4 or more spatial streams, then both MU Beamformer and SU Beamformer attributes must be set to 1. In the case of clients, the SU Beamformee must be set to 1 by default. A WiFi 6 client must support operation as an MU beamformee.

The table below summarizes the details of MU-MIMO operation for DL and UL.

Table 1: MU-MIMO Modes

Mode	Direction	Description	Capability Signaling
Full Bandwidth	DL	• AP schedules MU-MIMO transmissions such that the RU allocation for each user spans the entire PPDU bandwidth. • For an N-stream transmission, the full bandwidth of a stream is allocated to a single user.	Full bandwidth mode is supported by default if number of AP spatial streams is 4 or more.
Partial Bandwidth	DL	• AP schedules MU-MIMO transmission such that the RU allocation for a user is greater than or equal to 106 tones and does not span the entire PPDU bandwidth.	If this mode is supported, client sets the *Partial Bandwidth DL MU-MIMO* subfield of the HE PHY Capabilities Information field in the HE Capabilities element to 1.
Full Bandwidth	UL	• STA sends MU-MIMO transmissions such that the RU allocation spans the entire PPDU bandwidth.	If this mode is supported, client/ AP sets the *Full Bandwidth UL MU-MIMO* subfield of the HE PHY Capabilities Information field in the HE Capabilities element to 1.
Partial Bandwidth	UL	• STA sends MU-MIMO transmission such that the RU allocation is greater than or equal to 106 tones and does not span the entire PPDU bandwidth.	If this mode is supported, Client/ AP sets the Partial Bandwidth UL MU-MIMO subfield of the HE PHY Capabilities Information field in the HE Capabilities element to 1.

The combination of SU transmissions and MU-MIMO transmissions on different RUs in one PPDU is also supported. For instance, in case of a 20MHz channel, the 106-tone RUs may be used for MU-MIMO while the central 26-tone RU is used for SU-MIMO. The figure below shows a sample allocation for 20MHz bandwidth.

Table 2: Partial Bandwidth MU-MIMO Resource Allocation Example			
Space-Time Stream (STS) Index	**Upper 126-tone RU**	**Centre 26-tone RU**	**Lower 126-tone RU**
STS#1	STA1, 2SS	STA4, 4SS	STA5, 1SS
STS#2			STA6, 3SS
STS#3	STA2, 1SS		
STS#4	STA3, 1SS		

Spatial Streams

The number of MU-MIMO space-time streams (STS) supported by the AP in the Downlink and Uplink depends on the number of Tx and Rx antennas, respectively. In general, an AP with N antennas should be able to support up to N STS in both downlink and uplink. In case of clients, the maximum number of STS per user cannot exceed 4, even if the number of.antennas is greater than 4. In fact, the maximum number of streams is further restricted by the number of streams supported by the client for SU-MIMO.

Table 3: Maximum MU-MIMO Streams per User Example			
	Antenna Configuration	**Number of DL SU-MIMO Streams Supported**	**Max. DL MU-MIMO Streams**
STA1	8x8	8	4
STA2	4x4	2	2
STA3	4x4	4	4

The table above shows the relationship between the numbers of antennas and the maximum numbers of SU-MIMO/MU-MIMO streams for 3 clients. While STA1 and STA3 are straightforward cases, the STA2 case is different since the number of streams for SU-MIMO is less than the number of antennas. This may happen, for example, if the client has different MIMO capabilities for different transmission bandwidths.

In addition to the number. of STS per user constraints mentioned above, a client's ability to receive MU-MIMO streams is also dependent on its sounding capability. If STA3 in the table above is capable of providing sounding feedback for 8 streams, then it can take part in an UL/DL MU-MIMO transmission which has upto 8 total streams across all the users scheduled to transmit/receive. However, if the STA supports sounding for only 4 streams, then it can only be a part of UL/DL MU-MIMO transmissions where the total number. of streams is 4.

The Beamformee STS ≤ 80 MHz and Beamformee STS > 80 MHz attributes in the HE Capabilities Information Element are used to indicate the following:

- Maximum number of STS that the client can receive in an HE sounding Null Data Packet (see the Channel Sounding section for details)
- Maximum value for the total number of STS over all the users that can be sent in a DL MU-MIMO transmission that includes the client

An important conclusion based on these considerations is that clients may have different MU-MIMO capabilities for 20/40/80 MHz and 80+80/160 MHz transmissions.

Table 4: Total Number of STS for MU-MIMO Example			
	Antenna Configuration	Beamformee STS ≤ 80 MHz subfield	Total number of STS (across all users) for BW ≤ 80MHz
STA1	2x2	4	4
STA2	4x4	4	4
STA3	1x1	2	2
STA4	2x2	8	8

The figure below shows how the sounding capability restricts total number of spatial streams (based on the table above).

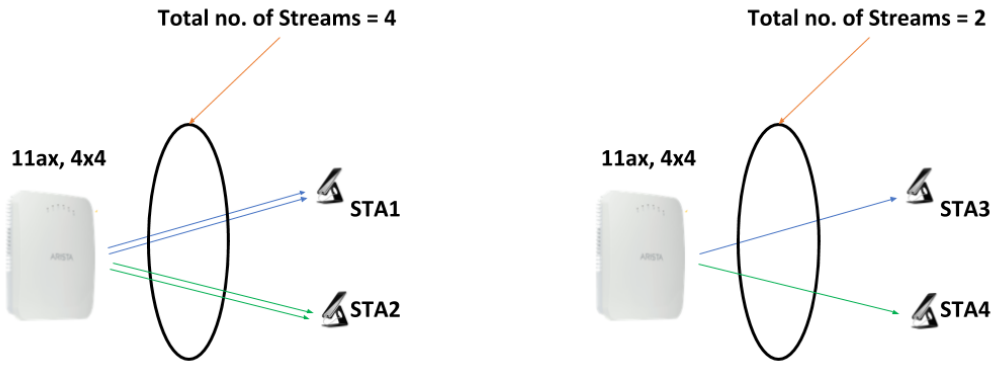

Figure 2: MU-MIMO Transmission Examples

As seen from the figure, in the second case, since STA3 supports sounding for 2 streams, it can only take part in the MU-MIMO transmission if the total number of streams is 2. As a result, STA4 which has better sounding capability is also restricted to using only one spatial stream when grouped with STA3 for an MU-MIMO transmission. This also motivates the need for smart grouping of users based on their MIMO capabilities to maximise the benefits of MU-MIMO.

In the case of UL MU-MIMO, the constraints are more or less the same as in DL MU-MIMO. The maximum number of STS that can be transmitted by a client taking part in UL MU-MIMO transmission cannot exceed 4 and must be less than or equal to the maximum number of STS supported by the client for UL SU-MIMO. In addition, the total number of STS (summed over all users) is less than or equal to 8. For the UL, the trigger frame contains the information about the streams relevant to a client.

Resource Allocation Examples

MU-MIMO and OFDMA can be used together. This enables multiple ways to schedule users based on AP/STA MIMO capabilities. In the following, we provide some examples of resource allocation.

Case 1: Full Bandwidth Allocation

The table below shows a sample RU allocation for an MU-MIMO transmission where the total number of streams is 4.

Table 5: Full Bandwidth MU-MIMO Resource Allocation Example	
Space-Time Stream (STS) Index	Antenna Configuration
STS#1	User 1
STS#2	User 1
STS#3	User 2
STS#4	User 2

In this case, AP has scheduled DL MU-MIMO transmission for 2 users. User 1 is assigned 242-subcarrier RUs mapped to streams 1 and 2; and User 2 is also assigned the same 242-subcarrier RUs, mapped to streams 3 and 4. The figure below illustrates the RU and streams allocation.

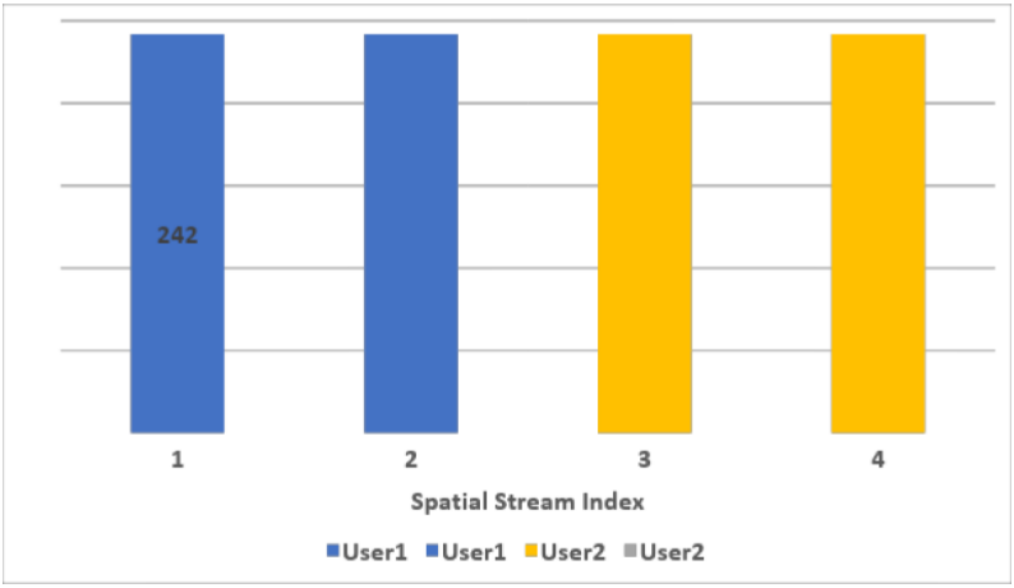

Figure 3: RU Allocation for Full Bandwidth MU-MIMO

Case 2: Partial Bandwidth Allocation

Partial BW MU-MIMO combines the advantages of OFDMA and MU-MIMO. The table shows a sample allocation for Partial BW MU-MIMO for 20MHz scenario, with a total of 4 streams.

Table 6: Partial Bandwidth MU-MIMO Resource Allocation Example

Space-Time Stream (STS) Index	Lower 106-tone RU Allocation	Middle 26-tone RU Allocation	Upper 106-tone RU Allocation
STS#1	User 1	User 7	User 2
STS#2	User 3	User 7	User 4
STS#3	User 3	User 7	User 5
STS#4	User 3	User 7	User 6

In this case, 7 users are scheduled. For the sake of simplicity, pilot or null subcarriers are not shown in the figure.The RU allocation is as follows:

- 5 users (User1, User2, User4, User5, and User6) are assigned 106-subcarrier RUs each.
- User3 is allocated one 106-subcarrier RU in 3 different spatial streams.
- User7 is allocated a single 26-subcarrier RU on each of the 4 spatial streams.

Thus, MIMO enables transmission across four spatial streams and each spatial stream uses OFDMA to distribute RUs among users. The figure below illustrates the RU and spatial stream allocation.

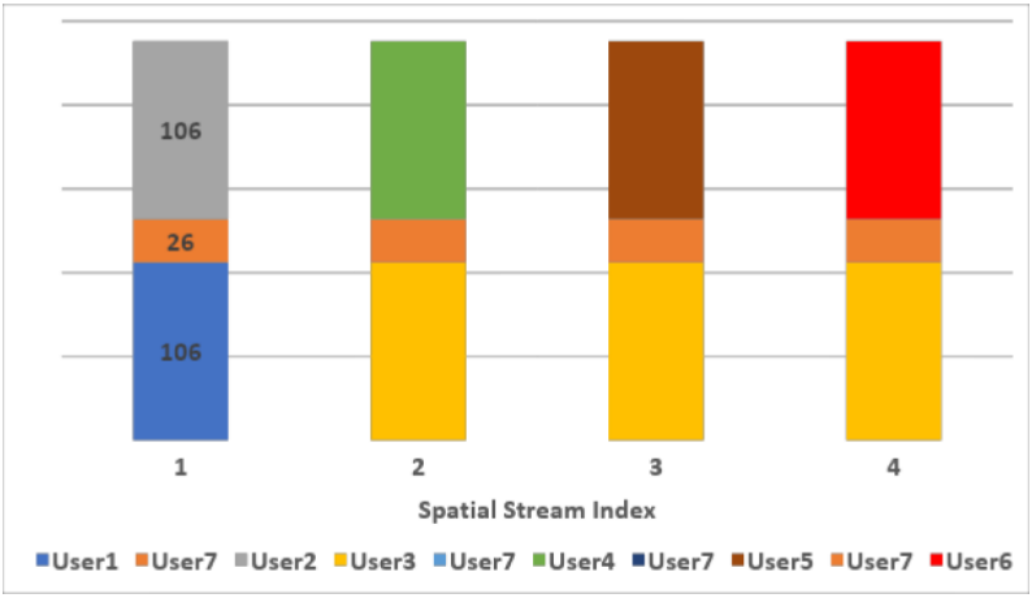

Figure 4: RU Allocation for Partial Bandwidth MU-MIMO

Channel Sounding

The IEEE 802.11ax standard defines an HE sounding protocol for clients to determine the channel state and report it to the AP. Channel state information is required to compute a steering matrix that is applied to the transmit signal to beamform it towards one or more receivers. Both trigger-based and non-trigger based explicit feedback mechanisms are supported. The sounding process is illustrated below.

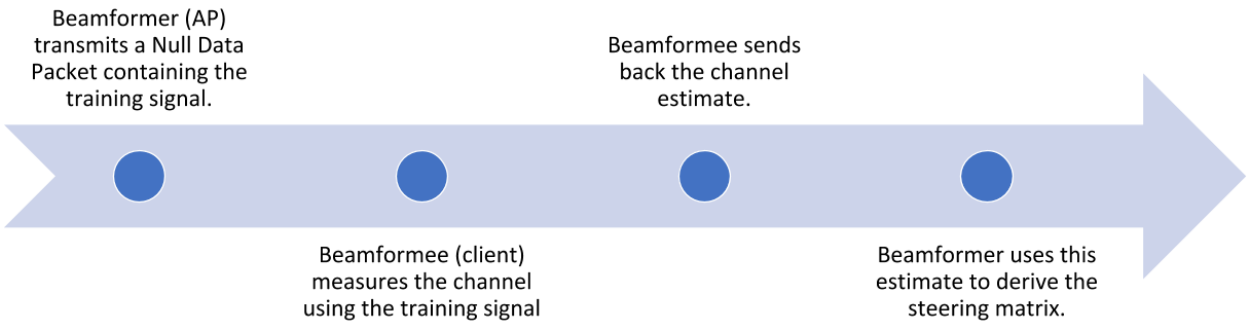

Figure 5: Sounding Process

The figure below shows an example of sounding exchange between an AP and a group of clients.

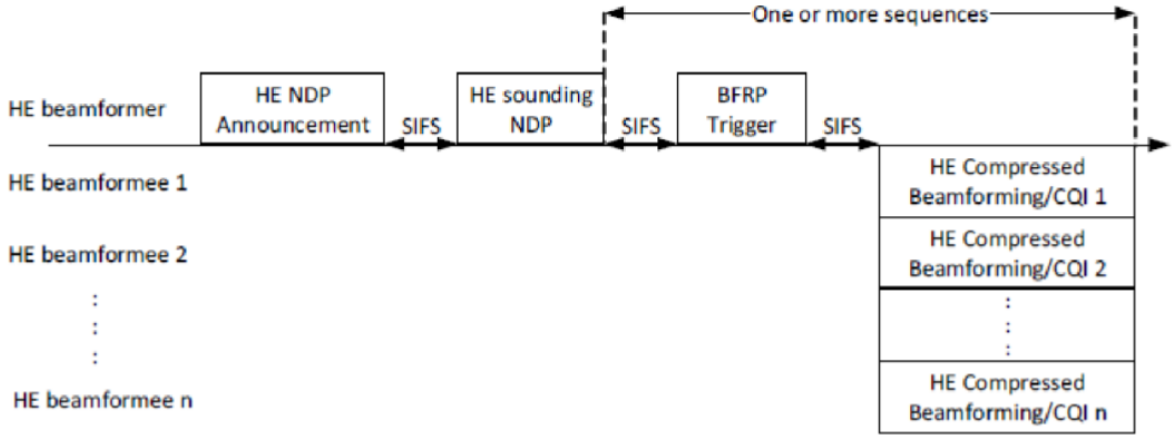

Figure 6: Sounding Protocol

The channel state is reported by a client using an HE compressed beamforming/CQI report, which may correspond to one of the following:

- SU feedback: The report consists of an HE Compressed Beamforming Report field
- MU feedback: The report consists of an HE Compressed Beamforming Report field and HE MU Exclusive Beamforming Report field
- CQI feedback: The report consists of an HE CQI Report field

Depending on the number of STS and the channel bandwidth, the report size can vary. Hence, it may be carried in one or more HE Compressed Beamforming/CQI frames.

Compared to IEEE 802.11ac—where sounding reports were sent sequentially, one client at a time—the use of multi-user uplink transmission for gathering feedback is more efficient and faster.

Conclusion

MU-MIMO is one of the most promising features of WiFi 6, especially for high-density, high-throughput scenarios. MU-MIMO improves the overall system performance by leveraging multiple spatial streams to serve multiple users simultaneously. Combining MU-MIMO and OFDMA further boosts performance by multiplexing users in both frequency and spatial domains. Benefits of MU-MIMO, however, depend on client capabilities as well as efficient channel sounding. The AP scheduler needs to consider multiple factors while grouping users for MU-MIMO transmission, thus adding to overall system complexity. Arista's WiFi 6 Access Points support all the key features of IEEE802.11ax, including MU-MIMO.

Santa Clara—Corporate Headquarters
5453 Great America Parkway,
Santa Clara, CA 95054

Phone: +1-408-547-5500
Fax: +1-408-538-8920
Email: info@arista.com

Ireland—International Headquarters
3130 Atlantic Avenue
Westpark Business Campus
Shannon, Co. Clare
Ireland

Vancouver—R&D Office
9200 Glenlyon Pkwy, Unit 300
Burnaby, British Columbia
Canada V5J 5J8

San Francisco—R&D and Sales Office 1390
Market Street, Suite 800
San Francisco, CA 94102

India—R&D Office
Global Tech Park, Tower A & B, 11th Floor
Marathahalli Outer Ring Road
Devarabeesanahalli Village, Varthur Hobli
Bangalore, India 560103

Singapore—APAC Administrative Office
9 Temasek Boulevard
#29-01, Suntec Tower Two
Singapore 038989

Nashua—R&D Office
10 Tara Boulevard
Nashua, NH 03062

Copyright © 2016 Arista Networks, Inc. All rights reserved. CloudVision, and EOS are registered trademarks and Arista Networks is a trademark of Arista Networks, Inc. All other company names are trademarks of their respective holders. Information in this document is subject to change without notice. Certain features may not yet be available. Arista Networks, Inc. assumes no responsibility for any errors that may appear in this document. 04/20 02-0088-01