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MT7986 MU-MIMO Application Note

2021/09/24

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Version History

Version	Date	Author (Optional)	Description
1.0	2021-09-24	Wish	External version

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Outline

- Introductions to Wi-Fi MU-MIMO feature
- Basic Concepts of TXBF and MU-MIMO Features
- MT7986 MU-MIMO Environment Preparations
- MT7986 MU-MIMO Connectivity issue Debugging Indicators
- MT7986 MU-MIMO Performance issue Debugging Indicators

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Introductions to Wi-Fi MU-MIMO feature

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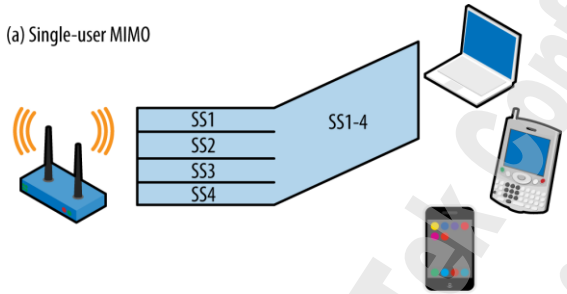
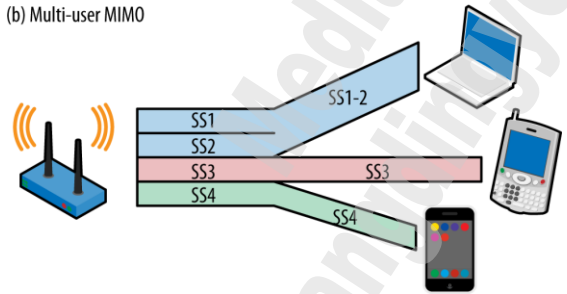
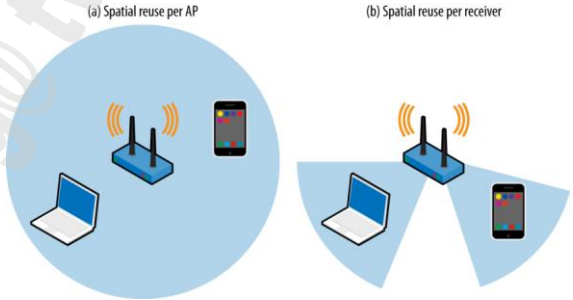
MU-MIMO and SU-MIMO Comparisons

Downlink MU-MIMO is a technology based on Tx Beaforming transmissions







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Basic Concepts of TXBF and MU-User MIMO Feature

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Explicit Tx Beamforming

- A device shapes its transmissions with focusing energy toward a receiver is called Beamformer (BFer). The receiver is called Beamformee (BFee).
- In eTxBF, the quality of sounding handshake process determines the qualify of Beamforming data streaming.
- BFer sends the sounding requests (NDPA packets and NDP) to BFee for channel estimations.
- BFee responses the sounding feedback containing channel estimations as profile based on the transmitted NDP to BFer.
- BFer forms a sounding matrix by received sounding profiles.
- BFer transmits the data packets to BFee by beamforming streaming with calibrated energy based on the sounding matrix.

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Multiple User MIMO (MU-MIMO)

- MU-MIMO is a technology based on explicit eTxBF to achieve multiple independent data streams simutaneously.
- After the Beamforming sounding matrix is formed by the profiles obtained from sounding handshakes for STAs expected to do MU Tx; MU-MIMO AP utilizes the beamforming technology to send multiple data streaming to multiple STAs for MU-MIMO transmissions.
- After the STAs received the data packets, MU-MIMO receivers response the acknowledgements in specific sequences.

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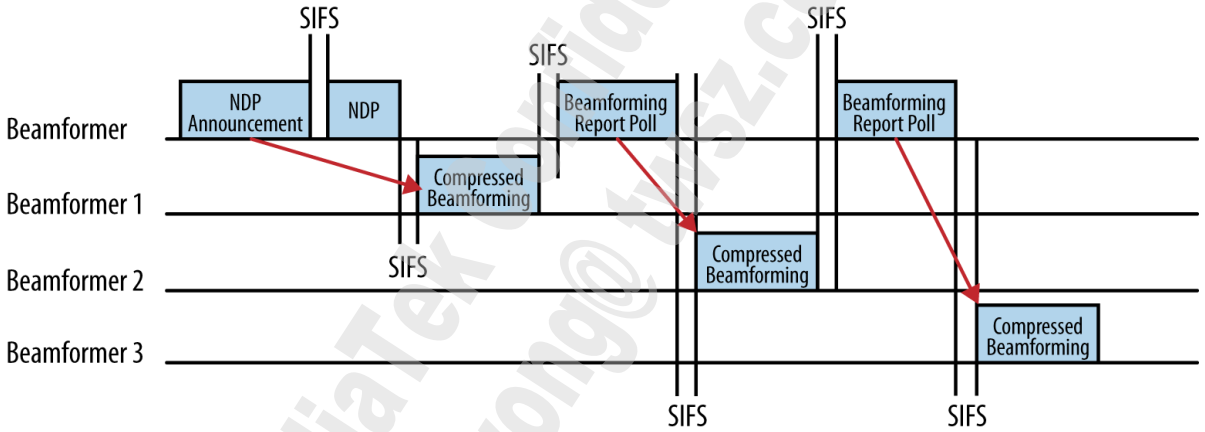
VHT Multiple User Sounding Process



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HE Multiple User Sounding Process

HE TB MU sounding with MU type sound feedback

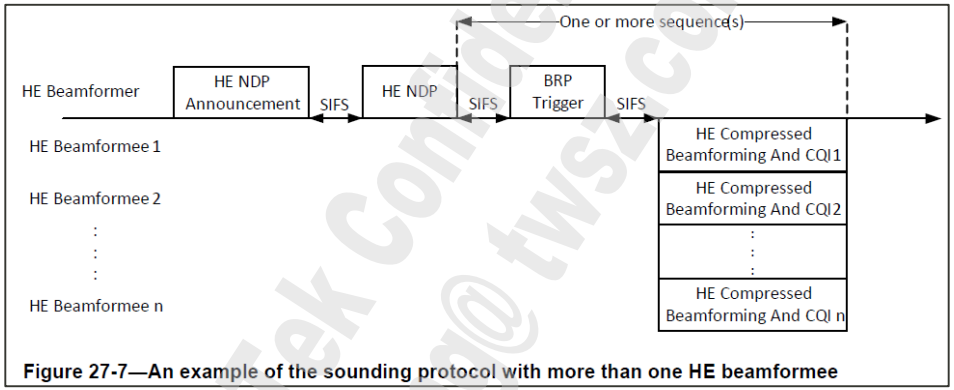

Figure 27-7—An example of the sounding protocol with more than one HE beamformee

HE Non-TB MU sounding with MU type sound feedback

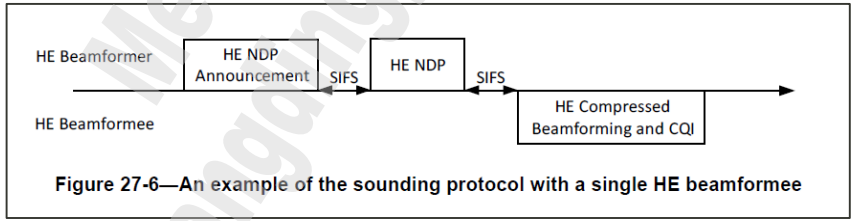

Figure 27-6—An example of the sounding protocol with a single HE beamformee

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MT7986 MU-MIMO Environment Preparations

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MT7986 AP Driver/Kernel Configuration

Linux x86 Driver Compiler Flag

$driver_folder$/os/linux/config.mk

```
HAS_TXBF_SUPPORT=y
HAS_VHT_TXBF_SUPPORT=y
HAS_HE_TXBF_SUPPORT=y
HAS_MU_MIMO_SUPPORT=y
HAS_FALCON_MURU_SUPPORT=y              //for MUMIMO debug command
```

After that, build the driver to enable the eTXBF and the MU-MIMO support

Driver Kernel Configuration

```
CONFIG_TXBF_SUPPORT=y
CONFIG_MUMIMO_SUPPORT=y
CONFIG_DOT11_HE_AX=y                   //for HE DL/UL MUMIMO
CONFIG_CFG_SUPPORT_FALCON_MURU=y       //for MUMIMO debug command
```

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MU-MIMO Profile Mandatory Settings

MUMIMO	TxBF Related	Wi-Fi Parameter Related

• VHT DL MUMIMO
• HE DL MUMIMO
  • MuMimoDlEnable = 1
• HE UL MUMIMO
  • MuMimoUlEnable = 1
	• ETxBfEnCond=1
	• MUTxRxEnable=1
		• HT_TxStream=4
		• HT_RxStream=4
		• HT_AutoBA=1
		• HT_BADecline=0

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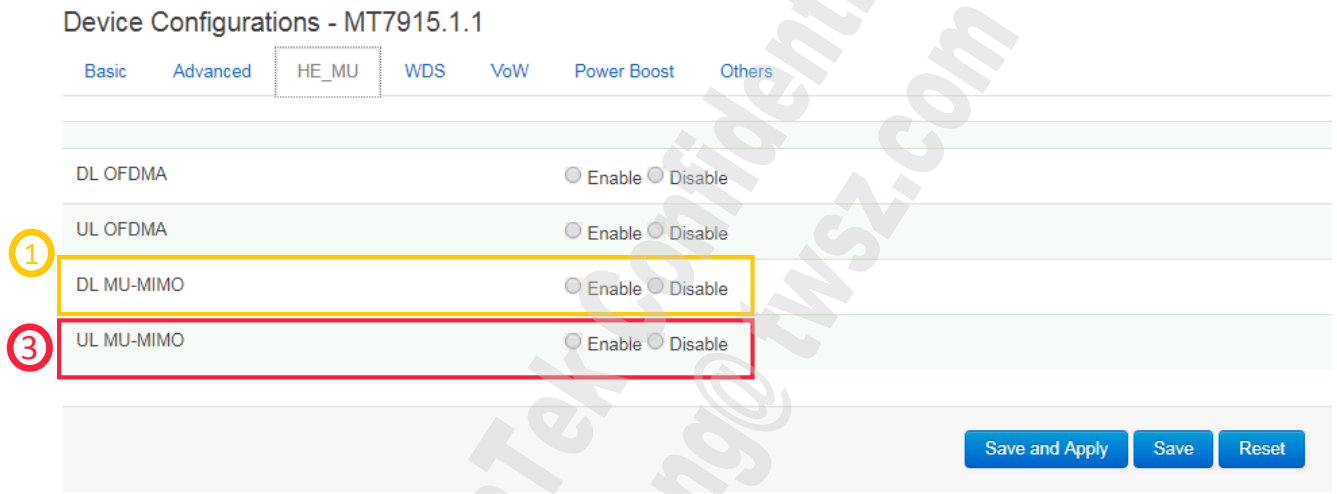
Enable DL/UL MUMIMO by WebUI



VHT DL MU-MIMO: 1+ 2
HE DL MU-MIMO: 1
HE UL MUMIMO: 3

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Enable DL/UL MUMIMO by WebUI

VHT DL MU-MIMO: 1+ 2
HE DL MU-MIMO: 1
HE UL MUMIMO: 3

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MT7986 AP VHT MU-MIMO TX Capability Check

- Check the VHT Capability Section in AP's beacons:
  - The SU Beam-former bit be 1.
  - The MU Beam-former bit shall be 1.
  - The Number of Sounding Dimensions shall be 4.

```
VHT Capabilities Info: 0x33cb79b1
    .... .... .... .... .... .... .... ..01 = Maximum MPDU Length: 7 991 (0x00000001)
    .... .... .... .... .... .... .... 00.. = Supported Channel Width Set: Neither 160MHz nor 80+80 supported (0x00000000)
    .... .... .... .... .... .... ...1 .... = Rx LDPC: Supported
    .... .... .... .... .... .... ..1. .... = Short GI for 80MHz: Supported
    .... .... .... .... .... .... .0.. .... = Short GI for 160MHz and 80+80MHz: Not supported
    .... .... .... .... .... .... 1... .... = Tx STBC: Supported
    .... .... .... .... .... .001 .... .... = Rx STBC: 1 Spatial Stream Supported (0x00000001)
    .... .... .... .... .... 1... .... .... = SU Beam-former Capable: Supported
    .... .... .... .... ...1 .... .... .... = SU Beam-formee Capable: Supported
    .... .... .... .... 011. .... .... .... = Compressed Steering Number of Beamformer Antennas Supported: 4 (0x00000003)
    .... .... .... .011 .... .... .... .... = Number of Sounding Dimensions: 4 (0x00000003)
    .... .... .... 1... .... .... .... .... = MU Beam-former Capable: Supported
    .... .... ...0 .... .... .... .... .... = MU Beam-formee Capable: Not supported
    .... .... ..0. .... .... .... .... .... = VHT TXOP PS: Not supported
    .... .... .1.. .... .... .... .... .... = +HTC-VHT Capable (VHT variant HT Control field): Supported
    .... ..11 1... .... .... .... .... .... = Max A-MPDU Length: 1 048 575 (0x00000007)
    .... 00.. .... .... .... .... .... .... = VHT Link Adaptation: No Feedback (0x00000000)
    ...1 .... .... .... .... .... .... .... = Rx Antenna Pattern Consistency: Supported
    ..1. .... .... .... .... .... .... .... = Tx Antenna Pattern Consistency: Supported
    00.. .... .... .... .... .... .... .... = Reserved: False
```

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VHT MU-MIMO RX Capability Check

- Check the VHT Capability Section in MU Receiver's Probe Request/Association Request:
  - The SU Beam-formee bit be 1.
  - The MU Beam-formee bit shall be 1.
  - The Compressed Steering Number of Beamformer Antennas Supported shall be 4.

```
▲ VHT Capabilities Info: 0x339071b2
    .... .... .... .... .... .... .... ..10 = Maximum MPDU Length: 11 454 (0x00000002)
    .... .... .... .... .... .... .... 00.. = Supported Channel Width Set: Neither 160MHz nor 80+80 supported (0x00000000)
    .... .... .... .... .... .... ...1 .... = Rx LDPC: Supported
    .... .... .... .... .... .... ..1. .... = Short GI for 80MHz: Supported
    .... .... .... .... .... .... .0.. .... = Short GI for 160MHz and 80+80MHz: Not supported
    .... .... .... .... .... .... 1... .... = Tx STBC: Supported
    .... .... .... .... .... .001 .... .... = Rx STBC: 1 Spatial Stream Supported (0x00000001)
    .... .... .... .... .... 0... .... .... = SU Beam-former Capable: Not supported
    .... .... .... .... ...1 .... .... .... = SU Beam-formee Capable: Supported
    .... .... .... .... 011. .... .... .... = Compressed Steering Number of Beamformer Antennas Supported: 4 (0x00000003)
    .... .... .... .000 .... .... .... .... = Number of Sounding Dimensions: 1 (0x00000000)
    .... .... .... 0... .... .... .... .... = MU Beam-former Capable: Not supported
    .... .... ...1 .... .... .... .... .... = MU Beam-formee Capable: Supported
    .... .... ..0. .... .... .... .... .... = VHT TXOP PS: Not supported
    .... .... .0.. .... .... .... .... .... = +HTC-VHT Capable (VHT variant HT Control field): Not supported
    .... ..11 1... .... .... .... .... .... = Max A-MPDU Length: 1 048 575 (0x00000007)
    .... 00.. .... .... .... .... .... .... = VHT Link Adaptation: No Feedback (0x00000000)
    ...1 .... .... .... .... .... .... .... = Rx Antenna Pattern Consistency: Supported
    ..1. .... .... .... .... .... .... .... = Tx Antenna Pattern Consistency: Supported
    00.. .... .... .... .... .... .... .... = Reserved: False
```

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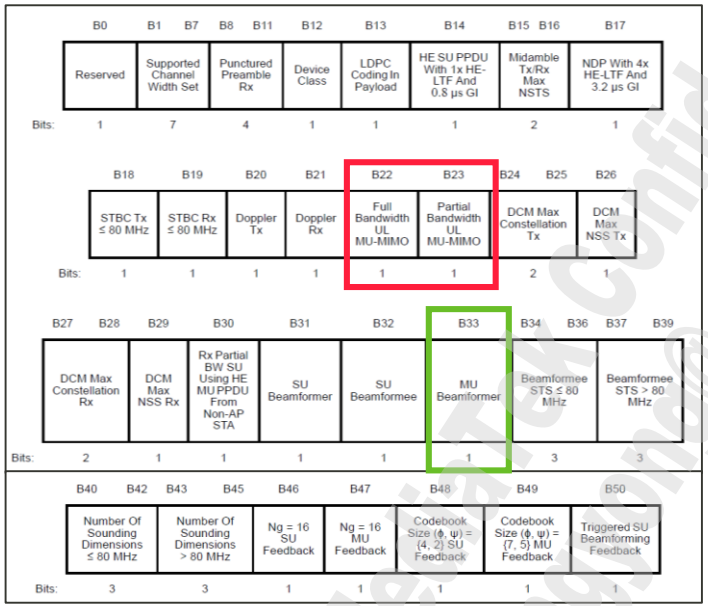
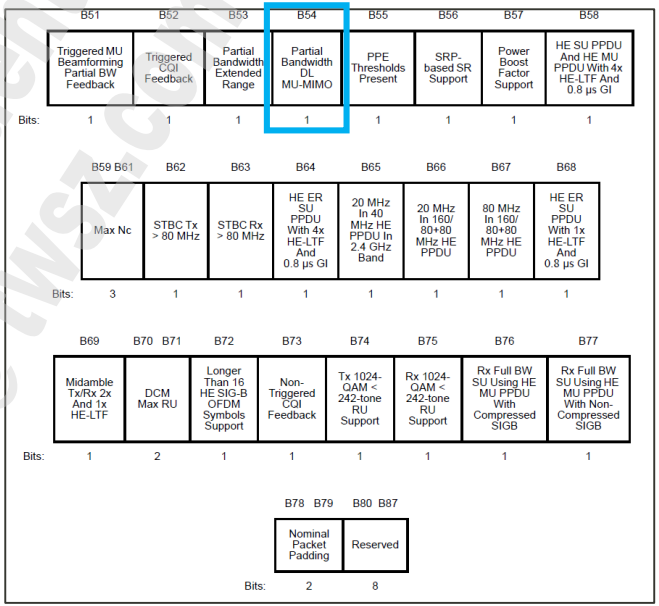
HE PHY Capability for MU-MIMO TX/RX





O : UL MU-MIMO

: DL MU-MIMO

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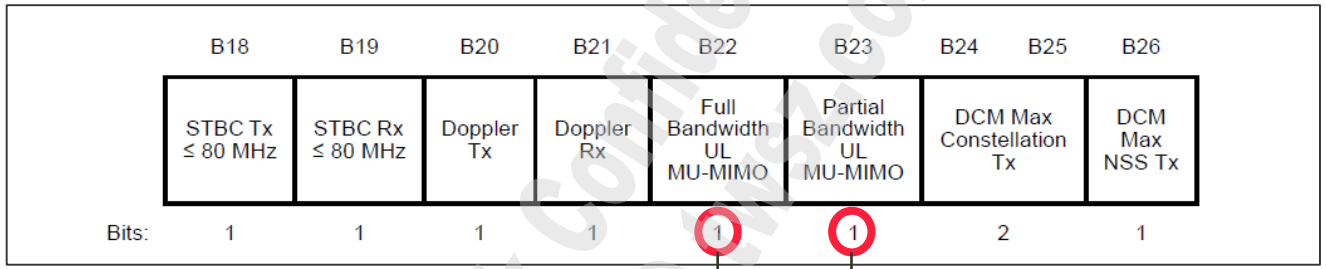
HE PHY Capability for MU-MIMO TX/RX



AP	Non-AP STA
support for MU-MIMO RX of an HE TB PPDU on an RU that spans the entire PPDU BW.	support for the TX of an HE TB PPDU on an RU that spans the entire PPDU BW.

AP	Non-AP STA
support for RX an RU in an HE TB PPDU where MU-MIMO is employed.	support for TX an RU in an HE TB PPDU where MU-MIMO is employed.

: UL MU-MIMO

: DL MU-MIMO

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HE PHY Capability for MU-MIMO TX/RX

B27	B28	B29	B30	B31	B32	B33	B34	B36	B37	B39
DCM Max Constellation Rx		DCM Max NSS Rx	Rx Partial BW SU Using HE MU PPDU From Non-AP STA	SU Beamformer	SU Beamformee	MU Beamformer	Beamformee STS ≤ 80 MHz		Beamformee STS > 80 MHz	
Bits: 2		1	1	1	1	1	3		3	

AP?

support for the RX of payload in a 20 MHz HE MU PPDU with a single 106-tone RU in the primary 20 MHz channel.

A non-AP HE STA shall not transmit a 20 MHz HE MU PPDU with a single 106-tone RU to a peer STA unless it has received from the peer STA an HE Capabilities element with the Rx Partial BW SU Using HE MU PPDU From Non-AP STA subfield in the HE PHY Capabilities Information field equal to 1.

O : UL MU-MIMO

O : DL MU-MIMO

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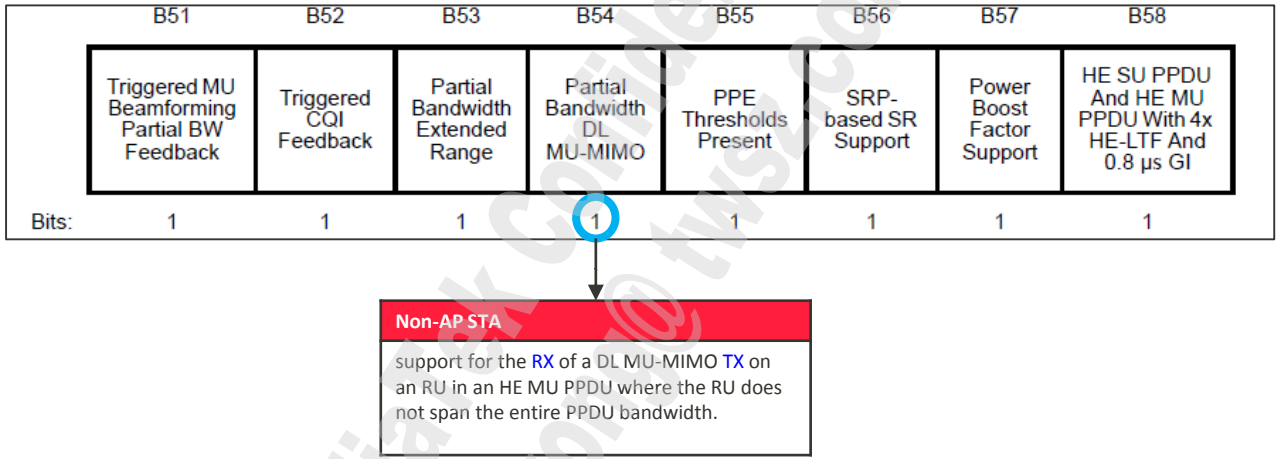
HE PHY Capability for MU-MIMO TX/RX



: UL MU-MIMO

: DL MU-MIMO

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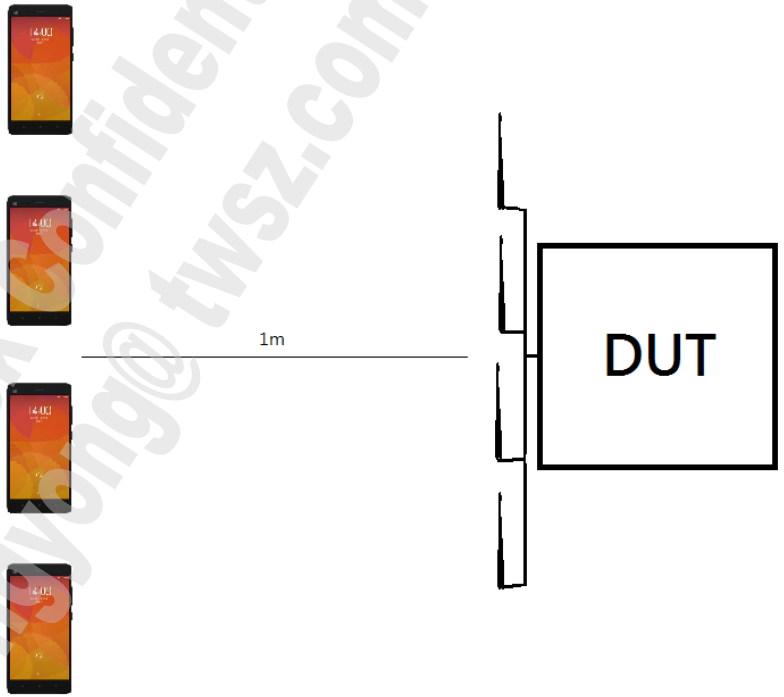
Basic OTA MU Test Topology

- **MU client**
  - MU Rx Capable STAs
- **Downlink Traffic:**
  - DUT -> Clients
  - UDP / TCP



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Environment for Connectivity Check

- A clean channel is required to avoid signal interferences.
- The relative position between MU clients and DUT antennas should be Line-of-Sight (LOS) propagations.
  - The distance between each MU client should be longer than 20cm
  - Please erect antennas of DUT and MU clients
- STA/AP Signal Strength (RSSI) should be better than -46 dBm
  - Suggested: -34 dBm ~ -55 dBm

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MT7986 MU-MIMO Connectivity Issue Debugging Indicators

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MU-MIMO Connectivity Flow

- Enable MU-MIMO feature in MT7986 like AP.
- Let MU Rx capable STAs connect to AP.
- Check the MU-MIMO group tables in 2MU, 3MU and 4MU scenarios.
  - ➢ The initial rates in each MU-MIMO group tables means the sounding matrix for such transmission combination are basically available.
- If above are not observed, check below conditions:
  - Environment settings are correct.
  - BFer/BFee capabilities are enabled exactly.
  - The signal strengths between AP and STAs are good enough.

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MT7986 MU-MIMO Feature Supports

- MU-MIMO TX chooses best scores in MU-MIMO TX groups to start MU-MIMO transmissions. The transmissions are dynamically decided by MU Rate Group Algorithm (RGA).
- Maximal STAs for simultaneous MU-MIMO Transmissions: 4
- Maximal STAs in the MU-MIMO candidate pool: 8
- Maximal spatial stream supports in each MU Rx STA: (3x3)
- Possible MU-MIMO transmission group combinations in spatial streams:
  - 2-User (2MU): (1ss, 1ss) / (1ss, 2ss) / (1ss, 3ss) / (2ss, 2ss)
  - 3-User (3MU): (1ss, 1ss, 1ss) / (1ss, 1ss, 2ss)
  - 4-User (4MU): (1ss, 1ss, 1ss, 1ss)

The connection ordering in above is exchangeable.

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MT7986 MU-MIMO Group Table Query

Command to query MU-MIMO Group Table

Step1: iwpriv ra0 show get_muru_glo_addr //Only needed once

Step2: iwpriv ra0 show get_mu_grouptbl=$Group_ID //0~511

```
root@OpenWrt:/# iwpriv ra0 show get_mu_grouptbl=8 ; dmesg -c
[  449.143125] MURU MUM GROUP TABLE ENTRY: GROUP IDX = 8
[  449.143140] |-DW0 (Addr: 0x0223AA54)(Value: 0x40004119)
[  449.143141] | |-u1NumUser     = 1
[  449.143142] | |-u1DlGi        = 2
[  449.143144] | |-u1UlGi        = 1
[  449.143145] | |-u1Ax          = 1
[  449.143146] | |-u1PFIDUser0   = 0
[  449.143147] | |-u1PFIDUser1   = 1
[  449.143148] | |-u1PFIDUser2   = 0
[  449.143149] | |-u1PFIDUser3   = 0
[  449.143150] | |-u1DlVld       = 1
[  449.143152] | |-u1UlVld       = 0
[  449.143157] |-DW1 (Addr: 0x0223AA58)(Value: 0x00000586)
[  449.143158] | |-u1RuAlloc     = 134
[  449.143160] | |-u1NssUser0    = 1
[  449.143161] | |-u1NssUser1    = 1
[  449.143162] | |-u1NssUser2    = 0
[  449.143163] | |-u1NssUser3    = 0
[  449.143168] |-DW2 (Addr: 0x0223AA5C)(Value: 0x000000BB)
[  449.143170] | |-u1DlMcsUser0 = 11
[  449.143171] | |-u1DlMcsUser1 = 11
[  449.143172] | |-u1DlMcsUser2 = 0
[  449.143173] | |-u1DlMcsUser3 = 0
[  449.143174] | |-u1DlWfUser0   = 0
[  449.143175] | |-u1DlWfUser1   = 0
[  449.143177] | |-u1DlWfUser2   = 0
[  449.143178] | |-u1DlWfUser3   = 0
[  449.143183] |-DW3 (Addr: 0x0223AA60)(Value: 0x00000000)
[  449.143184] | |-u1UlMcsUser0 = 0
[  449.143185] | |-u1UlMcsUser1 = 0
[  449.143187] | |-u1UlMcsUser2 = 0
[  449.143188] | |-u1UlMcsUser3 = 0
[  449.143189] | |-u1UlWfUser0   = 0
[  449.143190] | |-u1UlWfUser1   = 0
[  449.143191] | |-u1UlWfUser2   = 0
[  449.143192] | |-u1UlWfUser3   = 0
```

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Commands to Check PFMU_ID for STAs

Command to query AID of STAs

iwpriv ra0 show stainfo

- This command can be used to find out the AID of each STAs connected to this AP.
- We only need to check the MAC address of the targeted STA and find its Wlan index in system for advanced queries in MU sounding profiles.
- In below example, the Wlan index for STA (0A:0C:43:26:60:50) is 2

```
# iwpriv rax0 show stainfo ; dmesg -c
 Show_MacTable_Proc(): arg=
 Dump MacTable entries info, EntType=0x20001

 MAC                MODE  AID  WCID  BSS PSM WMM MIMOPS RSSI0/1/2/3          PhMd(T/R)    BW(T/R)  MCS(T/R)     S
 MWDSCap HT Operating Mode : 0
 0A:0C:43:26:60:40  STA   2    1     1   0   1   3      -33/-33/-32/-32      HE_SU/HE_SU 80M/80M  2S-M11/2S-M11
 NO                                                                  MaxCap:HE          80M       2S-M11
 HT Operating Mode : 0
 0A:0C:43:26:60:50  STA   3    2     1   0   1   3      -33/-33/-32/-32      HE_SU/HE_SU 80M/80M  2S-M11/2S-M11
 NO                                                                  MaxCap:HE          80M       2S-M11
```

Command to query PFMU ID of particular STA

iwpriv ra0 show wtbl=$Wlan_Index

- This command shows the wireless table for particular STA by Wlan index. The PFMU_ID is also included.
- We can use get the PFMU_ID of this particular STA to check the SU/MU sounding profile for this STA.
- Menwhile, we also can see the BF type of this STA recognized by AP.
- In this example right side, the PFMU_IDX for STA Wlan index 2 is 1; the TxBF type of this STA is eBF.

```
# iwpriv rax0 show wtbl=2 ; dmesg -c
 WTBL Basic Info:
 show_wtbl_proc(): arg=2
 Dump WTBL entries info, start=2, end=2, idx=2
 Dump WTBL info of WLAN_IDX:2
 LMAC WTBL Addr: group:0x820d4200=0x0 addr: 0x820d8200
 DW00: 34 00 50 60
 DW01: 26 43 0c 0a
```

```
LWTBL DW 3
 WMM_Q:1/ RXD_DUP_MODE:2
 VLAN2ETH:0/ BEAM_CHG:0/ DIS_BA256:0
 PFMU_IDX:0/ ULPF_IDX:0/ RIBF:0/ ULPF:0
 IGN_FBK:0/ TBF:1/ TBF_VHT:1/ TBF_HE:1
```

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Command to Check mibinfo

Command to check mibinfo for SU/MU Tx packet counts

iwpriv ra0 show mibinfo

- This command can be used to check the SU/MU Tx packet proportions.
- As below screenshot, we can see the AMPDU Tx aggregation size allocations in total Tx packets.
- Meanwhile, we also can see the total Tx packet counts in MU and SU transmissions.
- The indicators also display the MU_Tx_Ok and MU_Tx_Total packets. But MU TX MPDU Count includes both MUOFDMA TX and MUMIMO TX.
- Usually we need to check the section for band 0 in mibinfo results.
- Please note this is a read-and-clear command. We have to wait for certain time to catch the new Tx transmission results.

```
===Tx Related Counters(Generic)===
 BeaconTxCnt=0x11a0
 Tx 20MHz Cnt=0x16a0
 Tx 40MHz Cnt=0x6
 Tx 80MHz Cnt=0xffff
 Tx 160MHz Cnt=0x0
 AMPDU Cnt=0xb98d
 AMPDU MPDU Cnt=0x4cf82f
 AMPDU MPDU Ack Cnt=0x4ca6c0
 AMPDU MPDU PER=0.4%
===MU Related Counters===
 MUBF_TX_COUNT=0x43af
 MU_TX_MPDU_COUNT(Ok+Fail)=0x3eb39f
 MU_TX_OK_MPDU_COUNT=0x3e72d0
 MU_TO_SU_PPDU_COUNT=0x3
 SU_TX_OK_MPDU_COUNT=0xe5856
```

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Useful Debugging Methods

- **Basic MU-MIMO Connectivity Issue:**
  - Check the BF/MU capabilities in AP and STAs.
  - Get the sniffer captures in associations.
  - Check the counters in MU-MIMO status monitor.
  - Get the AP SU Tx rates in test environment
  - Get the RSSIs from STAs by stainfo command
  - Collect necessary log/dump files mentioned in later slide pages for advanced analysis.
- **Sounding Handshake Issue:**
  - Get the sniffer captures in MU sounding handshakes.
  - Get the Sounding Profiles from STAs.

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MT7986 MU-MIMO Performance Issue Debugging Indicators

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MT7986 MU-MIMO Performance Tests

- **MU-MIMO Performance Gain Calculations:**

  MU-Gain = MU T-Put / SU T-Put

  Ex: HE BW80, two STA 2x2

  2MU T-Put = 1871Mbps , 2SU T-Put = 1055Mbps, the MU Gain = 1871 / 1055 = 1.77

- **Preconditions to obtain best MU-MIMO throughputs:**
  - A clean channel with good signal strength is required.
  - LOS test topology is suggested for best performance results.
  - Good MU Rx capability in STAs. Please make sure the SW version of the MU Rx STAs are identical to avoid unbalanced Wi-Fi capability issue.
  - Good SU downlink throughput between AP and each MU STAs are required.
  - Good/Reasonable multiple user SU downlink throughput between AP and all STAs accompanying tests are required.
  - The reasonable/fair SU downlink throughputs between each AP + STA combinations are required.
  - The Tx rates from STAs are qualified, its better to have MCS8/MCS9 with low PER.
  - 3-MU is much recommended setup than 4-MU since 4-MU requires extremely good environmental condition
  - MU gain is much larger when traffic is heavily and evenly distributed to each Muser.

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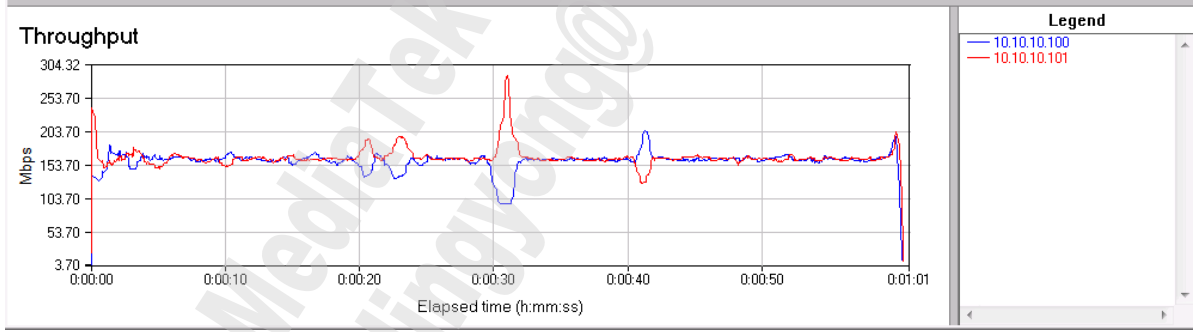
Example of Good & Fair SU Throughput

- The total 2SU (1ss, 1ss) throughput is qualified: 323 Mbps

Test Setup | Throughput | Transaction Rate | Response Time | Raw Data Totals | Endpoint Configuration

Group	Pair Group Name	Run Status	Timing Records Completed	95% Confidence Interval	Average (Mbps)	Minimum (Mbps)	Maximum (Mbps)	Measured Time (sec)	Relative Precision
10.10.10.100			1,204		159.165	1.600	17.738		
10.10.10.101			1,248		164.981	1.927	26.059		



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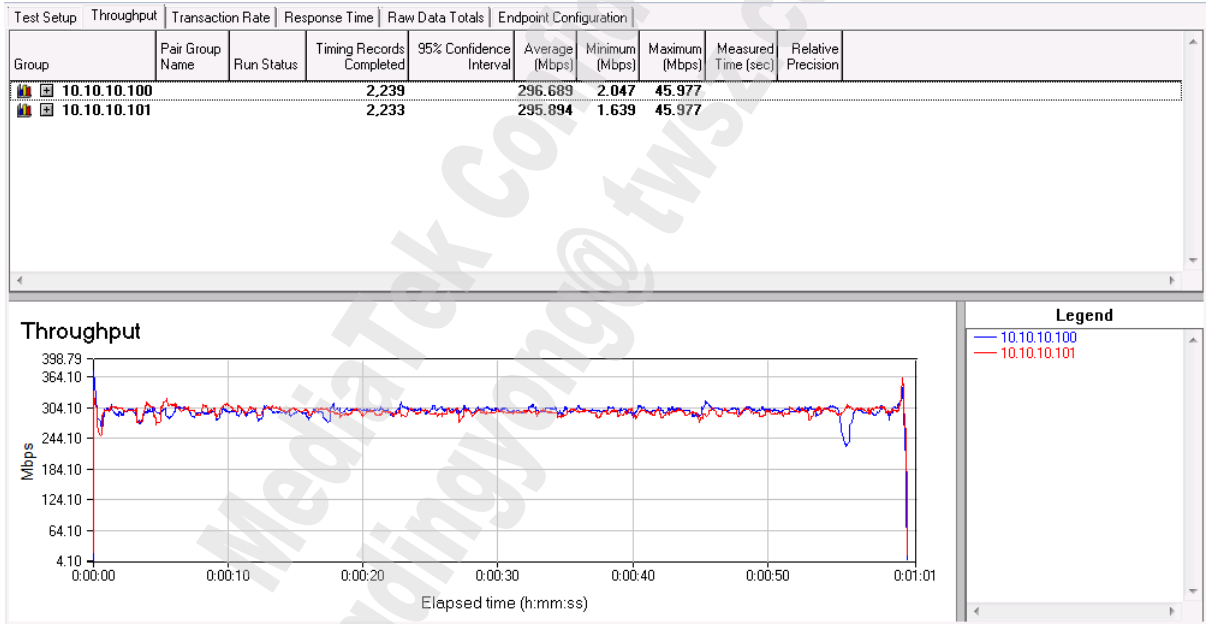
Example of Good & Fair MU Throughput

- The total 2MU (1ss, 1ss) throughput is qualified: 592 Mbps
- The MU Gain : 592 / 323 = 1.83



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MU-MIMO Performance Test Tool

- Ixia Chariot or iPerf tool are suggested.
- The Chariot Endpoint shall be upgraded to recent versions.
- The iPerf tool version in both STA and AP backbone PC shall be the identical.
- Suggest amount of traffic pairs to obtain best performance:
  - TCP Downlink: 10 Pairs for each STA.
  - UDP Downlink: 15 ~ 20 Pairs for each STA.
- iPerf is alternative for throughput tests, especially in UDP related throughput tests.
- The Chariot script for TCP tests is High_Performance.scr with 1MB file size.
- The Chariot script for UDP tests is Throughput.scr with 1MB file size and 65390 Sending/Receiving Buffer Size.
- The TCP Window Size for iPerf test could be 256 KB to 2MB.

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Common T-Put Debugging Methods in MU

- Check the MU-MIMO connectivity in MU-MIMO monitor and group table query.
- Check if the sounding handshake behaviors meet expectations; especially in the sounding request type of NDPA packets and the Nc/Nr settings in sounding feedbacks.
- Check the group table to see if there are high delta MCS rates in STAs frequently in group table updates.
- Check the SU/MU data packet proportions by mibinfo commands.
- Check the 2MU throughputs with two MU Rx STAs with the same model name.
- Check the SU performance capabilities of STAs in multiple SU downlink throughput tests.
- Check UDP throughout to divide the possible STA Tx capability issue in throughput tests.
- Check data packet transmission behaviors by sniffer capture logs.
- Fixing the MU Tx rates and SU Tx rates is another method to narrow down the root cause.

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