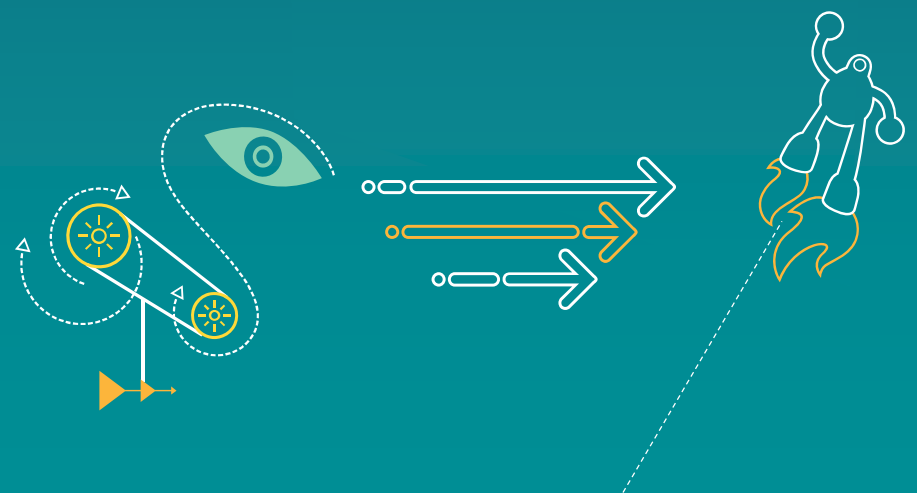
Scope: QCA61x4A, QCA65x4, QCA937x, WCN3680, WCN39xx

MU-MIMO Overview and Test Setup

Qualcomm Technologies, Inc.

80-Y8113-11 Rev. G



Qualcomm Technologies, Inc.
5775 Morehouse Drive
San Diego, CA 92121
U.S.A.

Revision History

Revision	Date	Description
A	October 2014	Initial release
B	April 2015	Updated document title. No change to content
C	August 2015	Updated slides 13,14,18 and 19
D	September 2015	Changed document title and added scope. Added section title for test setup and modified slide set.
E	November 2015	Deleted slide 13, MU-MIMO configuration. Added slide for “MU-MIMO capability on association request (client side)”. On “MU gain in controlled environment” (slide 20), deleted MU-MIMO disabled/enabled columns in table.
F	August 2016	Added WCN39xx in scope
G	February 2017	Modified tables on slides 17 and 18

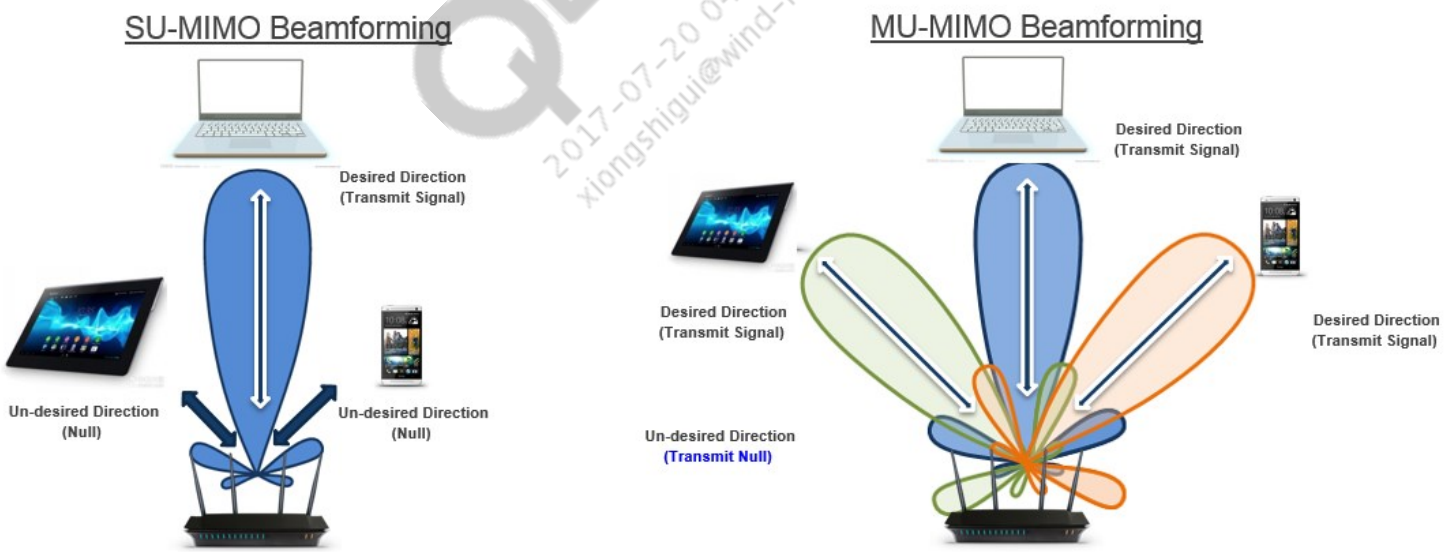
Agenda

MU-MIMO Overview

Section 1

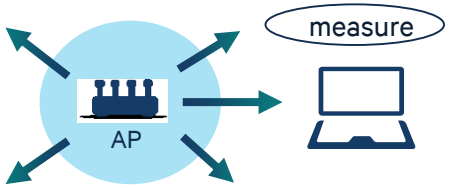
MU-MIMO overview

- **Multiple-input and Multiple-output (MIMO):** A system that uses multiple antennas at both the transmitter and receiver to improve communication performance
- **SU-MIMO:** Process of transmitting one or more streams to one user at-a-time
- **MU-MIMO:** Process of transmitting one or more streams to more than one user at-a-time in the same set of frequency



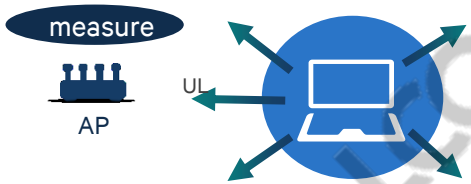
Beamforming overview

Explicit Beamforming



- STA estimates channel and informs AP
- AP performs TxBF

Legacy/Implicit Beamforming



- AP estimates channel
- AP performs TxBF

Multi-User Beamforming (for MU-MIMO)

- All STAs in the group estimate channels and inform AP
- AP performs Resource Allocation (Grouping, Rate Control) and TxBF

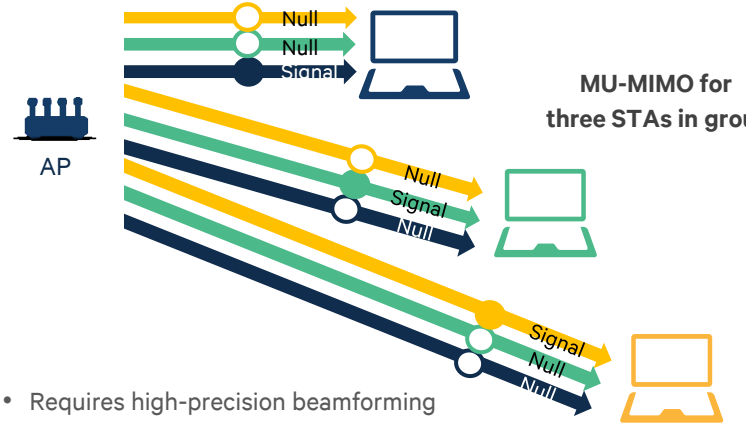
Single-User TxBF

- Requires beamforming in client
- Optimized TxBF to 802.11ac client
- Potential improved mid-range performance for 802.11ac clients

Single-User TxBF

- Does not require 802.11ac beamforming
- Potential improved mid-range performance for legacy and 802.11ac clients

DL–Multi-User MIMO

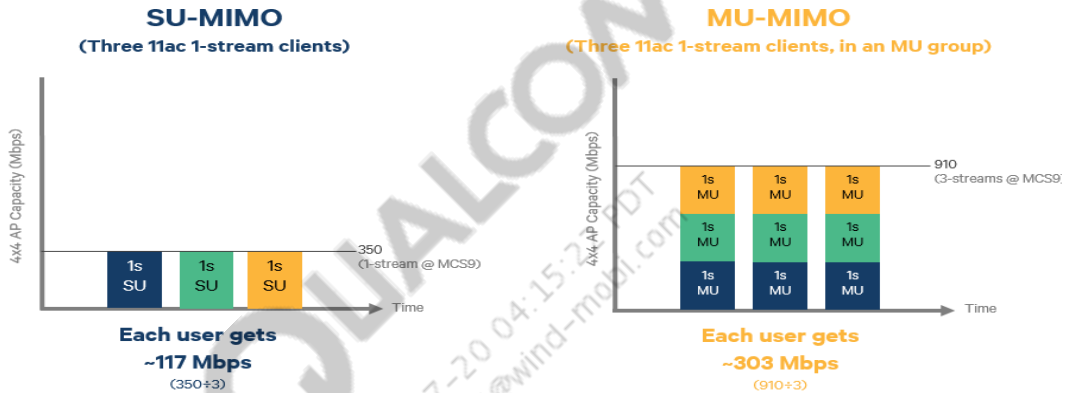


MU-MIMO for three STAs in group

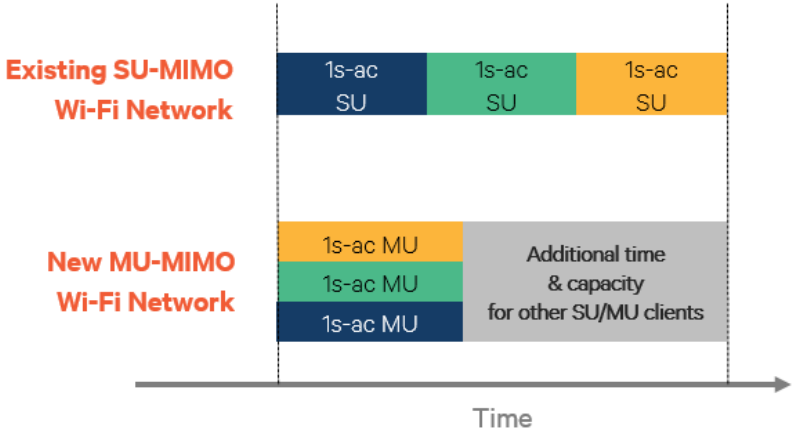
- Requires high-precision beamforming
- Interference between clients limits grouping
- Requires complex resource allocation

Benefits of MU-MIMO (vs. single-user)

- Supports multiple clients at the same time that improves overall DL throughput per client



- With 2 to 3 times greater efficiency for MU clients, the network has more time or capacity to serve other clients. This is required for enterprise network



802.11ac IEEE vs. current vs. Release 2 features

IEEE 802.11ac Features

Mandatory:
80 MHz
1ss client/mobile AP
2ss AP
Optional:
160 MHz, TxBF, MU-MIMO
STBC, LDPC

802.11ac Release 1

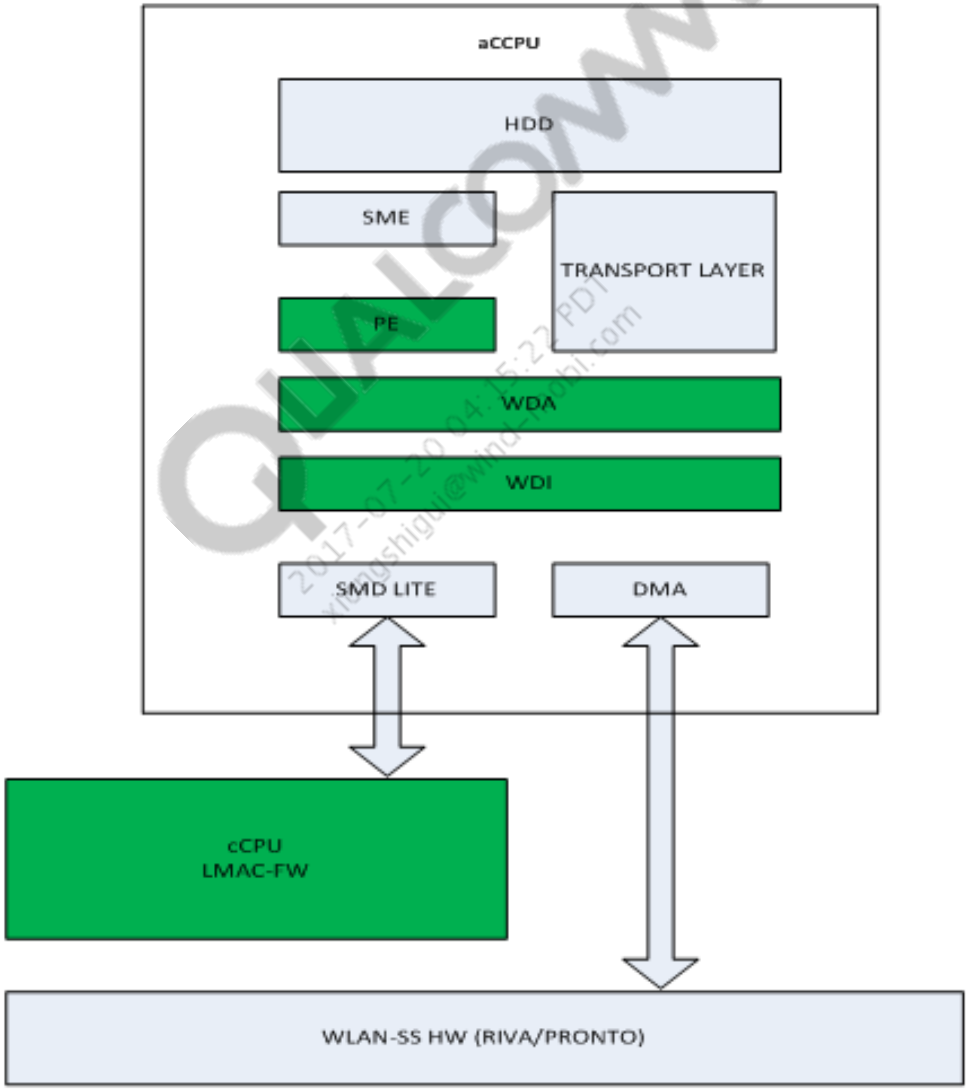
Launch: June 2013

Mandatory:
80 MHz
1ss client/mobile AP
2ss AP
Optional:
3ss
TxBF
STBC, LDPC

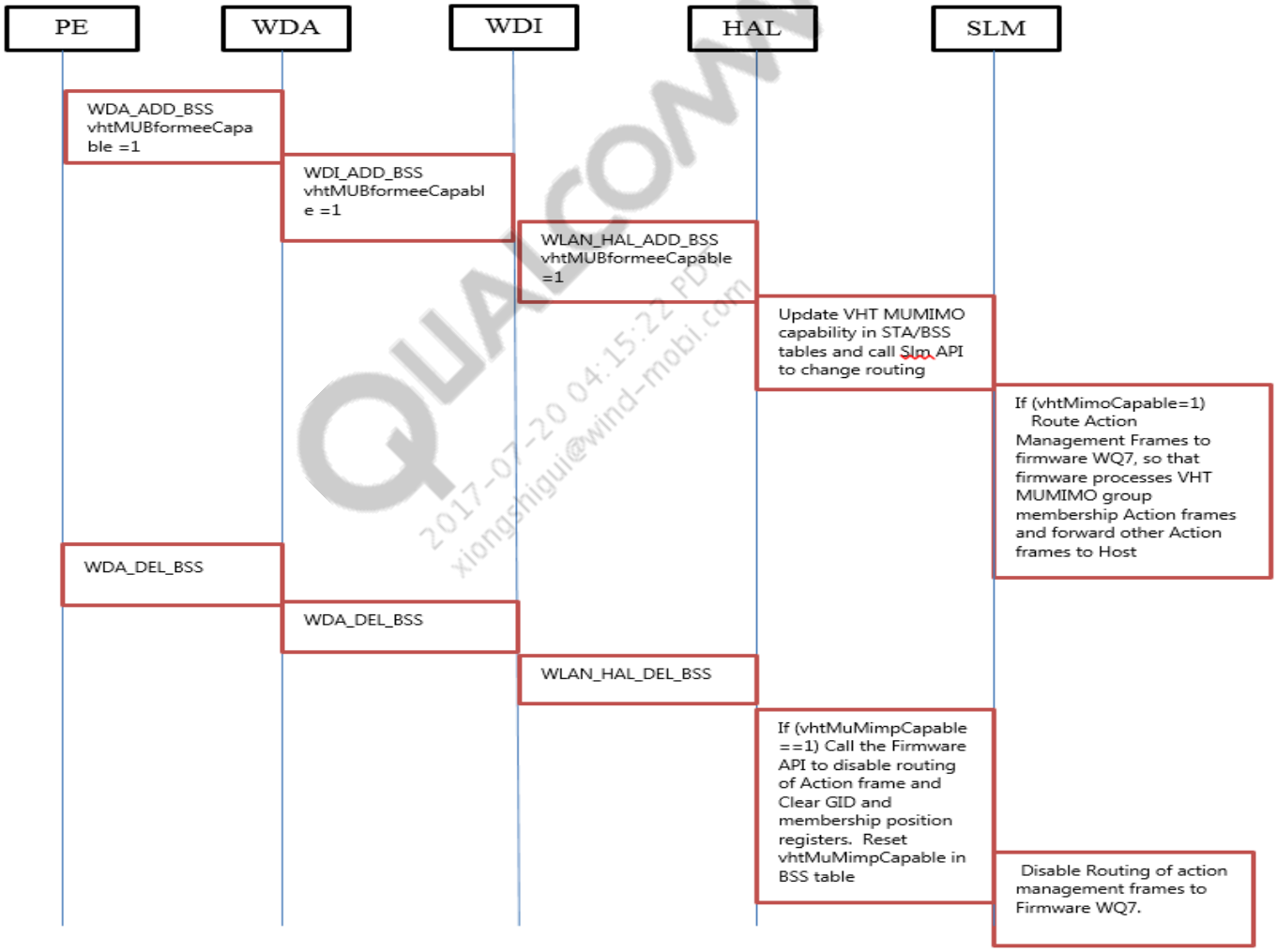
802.11ac Release 2

Mandatory:
Short GI
Optional:
4ss
MU-MIMO
160 MHz

MU-MIMO high-level architecture



MU-MIMO high-level design



The above diagram shows the message exchange between host and LMAC, which is responsible for enabling and disabling MU MIMO feature for a BSS/STA

Feature interaction

S. No.	Feature interacting	Behavior
1	P2P	MU-MIMO is not supported in GO mode. The support exists in CLI mode if GO supports it.
2	Wi-Fi and BT co-existence	Bluetooth (BT) does not know if AP is using DL-MIMO. Therefore, there is no change in the behavior.
3	SAP mode	MU-MIMO is not supported in SAP mode because the device has a single antenna.

- **Note:** From MAC software perspective, there should not be much impact on the existing features. The MU-MIMO feature receives MU streams by decoding GID and user position from the PLCP header, which is performed by PHY/MAC hardware.

Test Setup

Section 2

Test topology

- Use a MU-MIMO AP (for example, Linksys EA8500) with the latest image

  Note: Use the latest image on AP.
- A control PC for the AP supports Gigabit Ethernet, either iperf or licensed IxChariot
- All STAs (support either 1x1 or 2x2) have iperf or IxChariot endpoint environment

  Note: Download the iPerf or IxChariot application from Playstore
- Maintain 1 or 3 m away from AP to all STAs, and 1 m away between STAs
- AP and STAs are placed in isolated chambers or an open environment

Test procedure

1. Enable AP with 5 GHz, 80 MHz, and WPA2 (open) security.
2. Make sure MU-MIMO is enabled on AP and STAs by default.
3. Associate STAs with AP.
4. Run UDP DL and TCP DL peak TPUT between AP to STAs, simultaneously, on all STAs.
5. Capture the throughputs on the STAs (Rx).
6. Aggregate the throughput observed on all the STAs.
7. Compare the results with MU-MIMO disabled.
   - Disable MU-MIMO mode from AP (or STA).
   - MU-MIMO gain = (MU-MIMO-enabled throughput)/(MU-MIMO disabled throughput).

MU-MIMO capability on beacon (AP side)

OmniPeek

File Edit View Capture Send Monitor Tools Window Help

Filters | Start Page | MU_beamform_enable.pkt

Enter a filter expression here (use F1 for help)

Dashboards: Network, Voice & Video, Apdex, Compass
Capture: Packets, Log
Expert: Clients/Servers, Flows, Applications
Web: Servers, Clients, Pages, Requests
Voice & Video: Calls, Media
Visuals: Peer Map, Graphs
Statistics: Summary, Nodes, Protocols
Wireless: WLAN, Channels, Signal
Roaming: Log, by Node, by AP

Packet	Source	Destination	BSSID	Flags	Chan...	Signal	Signal ...	Data ...	Size	.	Relative Time	Protocol	Summary
2	8C:FD:F0:01:62:5D	Ethernet B...	8C:FD:F0:01:62:5D	*P	149	100%	-43	6.0	304	.	0.102357	802.11 Beacon	FC=.....,SN= 890,FN=
3	8C:FD:F0:01:62:5D	Ethernet B...	8C:FD:F0:01:62:5D	*P	149	100%	-43	6.0	304	.	0.204789	802.11 Beacon	FC=.....,SN= 891,FN=
4	8C:FD:F0:01:62:5D	Ethernet B...	8C:FD:F0:01:62:5D	*P	149	100%	-43	6.0	304	.	0.307154	802.11 Beacon	FC=.....,SN= 892,FN=
5	8C:FD:F0:01:62:5D	Ethernet B...	8C:FD:F0:01:62:5D	*P	149	100%	-43	6.0	304	.	0.409500	802.11 Beacon	FC=.....,SN= 893,FN=
6	8C:FD:F0:01:62:5D	Ethernet B...	8C:FD:F0:01:62:5D	*P	149	100%	-43	6.0	304	.	0.512025	802.11 Beacon	FC=.....,SN= 894,FN=

```
Reserved:                0x40 [213]
VHT Capabilities element
  Element ID:            191  VHT Capabilities element [214]
  Length:                12 [215]
  VHT Capabilities Info:%101100100111100110001011001100110011 [216-219]
    Reserved:            %10 [216 Mask 0xC0]
    Tx Antenna Pattern Consistency:%1  Tx antenna pattern does not change during the lifetime of the current association [216 Mask 0x20]
    Rx Antenna Pattern Consistency:%1  Rx antenna pattern does not change during the lifetime of the current association [216 Mask 0x10]
    VHT Link Adaptation Capable:%00 [216 Mask 0x0C]
    Maximum A-MPDU Length Exponent:%100 [216-217 Mask 0x0380]
    +HTC-VHT Capable:    %1  supported [217 Mask 0x40]
    VHT TXOP PS:         %1 [217 Mask 0x20]
    MU Beam-formee Capable:%1 [217 Mask 0x10]
    MU Beam-former Capable:%1 [217 Mask 0x08]
    Number Of Sounding Dimensions:%001 [217 Mask 0x07]
    Compressed Steering Number of Beamformer Antennas Supported:%100 [218 Mask 0xE0]
    SU Beam-formee Capable:%0  not supported [218 Mask 0x10]
    SU Beam-former Capable:%1  supported [218 Mask 0x08]
    Rx STBC:             %011  support of one, two and three spatial streams [218 Mask 0x07]
    Tx STBC              %0  not supported [219 Mask 0x80]
    Short GI for 160 and 80+80 MHz:%0  not supported [219 Mask 0x40]
    Short GI for 80 MHz: %1  supported [219 Mask 0x20]
    Rx LDPC:             %1  supported [219 Mask 0x10]
```

MU-MIMO capability on association request (client side)

OmniPeek

File Edit View Capture Send Monitor Tools Window Help

Filters | Start Page | Capture 1 | mu_enabled.pkt | sniffer_gEnableMuBformee1.pcap

Enter a filter expression here (use F1 for help)

Dashboards: Network, Voice & Video, Apdex, Compass
Capture: Packets, Log
Expert: Clients/Servers, Flows, Applications
Web: Servers, Clients, Pages, Requests
Voice & Video: Calls, Media
Visuals: Peer Map, Graphs
Statistics: Summary, Nodes, Protocols
Wireless: WLAN, Channels, Signal
Roaming: Log, by Node, by AP

Packet	Source	Destination	BSSID	Flags	Chan...	Signal	Signal ...	Data ...	Size	Relative...	Delta Time	Protocol
4910	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98	8C:FD:F0:01:62:98	*	36		-32	6.0	34	11.9...	0.00...	802.11 Auth
4911	8C:FD:F0:01:62:98	F8:CF:C5:3C:03:10		#	36		-36	6.0	14	11.9...	0.00...	802.11 Ack
4912	8C:FD:F0:01:62:98	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98	*	36		-40	6.0	34	11.9...	0.00...	802.11 Auth
4913	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98		#	36		-32	6.0	14	11.9...	0.00...	802.11 Ack
4914	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98	8C:FD:F0:01:62:98	*	36		-32	6.0	193	11.9...	0.00...	802.11 Assoc Req
4915	8C:FD:F0:01:62:98	F8:CF:C5:3C:03:10		#	36		-37	6.0	14	11.9...	0.00...	802.11 Ack
4916	8C:FD:F0:01:62:98	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98	*	36		-41	6.0	153	12.0...	0.00...	802.11 Assoc Rsp
4917	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98		#	36		-32	6.0	14	12.0...	0.00...	802.11 Ack
4948	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98	8C:FD:F0:01:62:98	*	36		-35	6.0	37	12.0...	0.09...	802.11 Action
4949	8C:FD:F0:01:62:98	F8:CF:C5:3C:03:10		#	36		-37	6.0	14	12.0...	0.00...	802.11 Ack
4950	8C:FD:F0:01:62:98	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98	*	36		-41	6.0	37	12.0...	0.00...	802.11 Action
4951	F8:CF:C5:3C:03:10	8C:FD:F0:01:62:98		#	36		-36	6.0	14	12.0...	0.00...	802.11 Ack
4959		F8:CF:C5:3C:03:10		#	36		-43	6.0	14	12.1...	0.00...	802.11 CTS
4962		F8:CF:C5:3C:03:10		#	36		-43	6.0	14	12.1...	0.00...	802.11 CTS

VHT Capabilities element
- Element ID: 191 *VHT Capabilities element* [164]
- Length: 12 [165]
- VHT Capabilities Info:%101100100111000110010000000110011 [166-169]
  - Reserved: %10 [166 Mask 0xC0]
  - Tx Antenna Pattern Consistency:%1 *Tx antenna pattern does not change during the lifetime of the current association* [166 Mask 0x20]
  - Rx Antenna Pattern Consistency:%1 *Rx antenna pattern does not change during the lifetime of the current association* [166 Mask 0x10]
  - VHT Link Adaptation Capable:%00 [166 Mask 0x0C]
  - Maximum A-MPDU Length Exponent:%100 [166-167 Mask 0x0380]
  - +HTC-VHT Capable: %1 *supported* [167 Mask 0x40]
  - MU Beam-formee Capable:%1 [167 Mask 0x10]
  - MU Beam-former Capable:%0 [167 Mask 0x08]
  - Number Of Sounding Dimensions:%001 [167 Mask 0x07]
  - Compressed Steering Number of Beamformer Antennas Supported:%100 [168 Mask 0xE0]
  - SU Beam-formee Capable:%1 *supported* [168 Mask 0x10]
  - SU Beam-former Capable:%0 *not supported* [168 Mask 0x08]
  - Rx STBC: %000 *no support* [168 Mask 0x07]
  - Tx STBC %0 *not supported* [169 Mask 0x80]

iPerf commands used for WCN3680 throughput tests

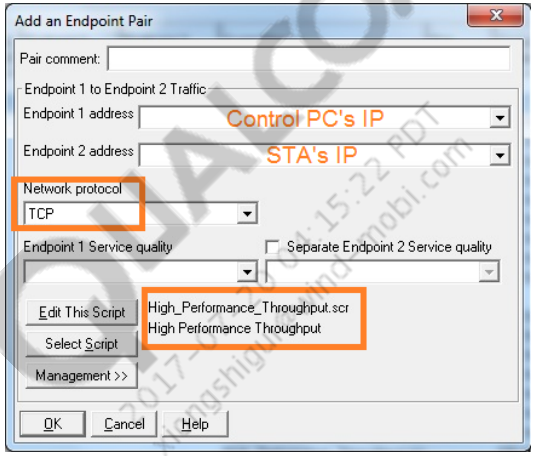
Mode	Clients Spatial stream	Protocol	iPerf commands (server) for AP	iPerf commands (client) for STA
VHT80	1SS + 1SS	UDP	iperf –c <IP> -u –i 1 –f m –w 2M –t 300 –b 350M	iperf –s -u –i 1 –f m –w 2M
		TCP	iperf –c <IP> –i 1 –f m –w 2M –t 300 –P 5	iperf –s –i 1 –f m –w 2M
	1SS + 1SS + 1SS	UDP	iperf –c <IP> -u –i 1 –f m –w 2M –t 300 –b 320M	iperf –s -u –i 1 –f m –w 2M
		TCP	iperf –c <IP> –i 1 –f m –w 2M –t 300 –P 5	iperf –s –i 1 –f m –w 2M
VHT40	1SS + 1SS	UDP	iperf –c <IP> -u –i 1 –f m –w 512k –t 300 –b 200M	iperf –s -u –i 1 –f m –w 2M
		TCP	iperf –c <IP> –i 1 –f m –w 512k –t 300 –P 5	iperf –s –i 1 –f m –w 2M
	1SS + 1SS + 1SS	UDP	iperf –c <IP> -u –i 1 –f m –w 512k –t 300 –b 200M	iperf –s -u –i 1 –f m –w 2M
		TCP	iperf –c <IP> –i 1 –f m –w 512k –t 300 –P 5	iperf –s –i 1 –f m –w 2M
VHT20	1SS + 1SS	UDP	iperf –c <IP> -u –i 1 –f m –w 512k –t 300 –b 70M	iperf –s -u –i 1 –f m –w 2M
		TCP	iperf –c <IP> –i 1 –f m –w 512k –t 300 –P 5	iperf –s –i 1 –f m –w 2M
	1SS + 1SS + 1SS	UDP	iperf –c <IP> -u –i 1 –f m –w 512k –t 300 –b 70M	iperf –s -u –i 1 –f m –w 2M
		TCP	iperf –c <IP> –i 1 –f m –w 512k –t 300 –P 5	iperf –s –i 1 –f m –w 2M

iPerf commands used only for QCA61x4A/QCA65x4/QCA937x throughput tests

Mode	Clients	Protocol	iPerf commands (server) for AP	iPerf commands (client) for STA
	Spatial stream			
VHT80	2SS + 2SS	UDP	iperf –c <IP> -u –i 1 –f m –w 2M –t 300 –b 350M	iperf –s -u –i 1 –f m –w 3M
		TCP	iperf –c <IP> –i 1 –f m –w 2M –t 300 –P 5	iperf –s –i 1 –f m –w 3M
	2SS + 2SS + 2SS	UDP	iperf –c <IP> -u –i 1 –f m –w 2M –t 300 –b 320M	iperf –s -u –i 1 –f m –w 3M
		TCP	iperf –c <IP> –i 1 –f m –w 2M –t 300 –P 5	iperf –s –i 1 –f m –w 3M
VHT40	2SS + 2SS	UDP	iperf –c <IP> -u –i 1 –f m –w 512k –t 300 –b 200M	iperf –s -u –i 1 –f m –w 3M
		TCP	iperf –c <IP> –i 1 –f m –w 512k –t 300 –P 5	iperf –s –i 1 –f m –w 3M
	2SS + 2SS + 2SS	UDP	iperf –c <IP> -u –i 1 –f m –w 512k –t 300 –b 200M	iperf –s -u –i 1 –f m –w 3M
		TCP	iperf –c <IP> –i 1 –f m –w 512k –t 300 –P 5	iperf –s –i 1 –f m –w 3M
VHT20	2SS + 2SS	UDP	iperf –c <IP> -u –i 1 –f m –w 512k –t 300 –b 70M	iperf –s -u –i 1 –f m –w 3M
		TCP	iperf –c <IP> –i 1 –f m –w 512k –t 300 –P 5	iperf –s –i 1 –f m –w 3M
	2SS + 2SS + 2SS	UDP	iperf –c <IP> -u –i 1 –f m –w 512k –t 300 –b 70M	iperf –s -u –i 1 –f m –w 3M
		TCP	iperf –c <IP> –i 1 –f m –w 512k –t 300 –P 5	iperf –s –i 1 –f m –w 3M

IxChariot setup

1. Install the latest licensed IxChariot and UDP Rx only due to Chariot scripts issue on TCP.
2. Make 10 pairs per STA, approximately.



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

Group	Pair Group Name	Run Status	Endpoint 1	Endpoint 2	Network Protocol	Endpoint 1 Service Quality	Endpoint 2 Service Quality	Script/Stream Filename	Pair Comment	Console knows Endpoint 1	Console Protocol	Console Serv. Qual.	Endpoint 1 knows Endpoint 2	UDP Compliant with RFC768
STA_1														
Pair 1	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 2	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 3	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 4	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 5	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 6	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 7	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 8	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 9	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
Pair 10	STA_1	Finished	192.168.1.112	192.168.1.101	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.101	n/a
STA_2														
Pair 11	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 12	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 13	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 14	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 15	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 16	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 17	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 18	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 19	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
Pair 20	STA_2	Finished	192.168.1.112	192.168.1.141	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.141	n/a
STA_3														
Pair 21	STA_3	Finished	192.168.1.112	192.168.1.137	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.137	n/a
Pair 22	STA_3	Finished	192.168.1.112	192.168.1.137	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.137	n/a
Pair 23	STA_3	Finished	192.168.1.112	192.168.1.137	TCP			High_Performance_Throughput.scr		192.168.1.112	TCP	n/a	192.168.1.137	n/a

MU gain in controlled environment

- 70 to 80% of lower performance is expected in an open environment while using different AP

Mode	Scenarios	Protocol	MU-MIMO gain
VHT80	1SS + 1SS	UDP	1.74
		TCP	1.72
	1SS + 1SS + 1SS	UDP	2.43
		TCP	2.32
	2SS + 1SS	UDP	1.71
		TCP	1.70
	2SS + 2SS	UDP	1.29
		TCP	1.23
	2SS + 2SS + 2SS	UDP	1.21
		TCP	1.14

Thank You