Network Testing & Emulation Solutions

TR-398

Wi-Fi In-Premises Performance Testing

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TR-398 Test Plan Summary

6.1.1 Receiver Sensitivity Test
Test the Quality/Ability of the AP's receiver in being able to handle different coding schemes at different power levels .

6.2.1 Maximum Connection Test
The Maximum Connection test intends to verify that the Wi-Fi AP can support 32 STAs simultaneously connected with minimal packet loss and no disassociations taking place

6.2.2 Maximum Throughput Test
Test intends to measure the maximum throughput performance of the DUT.

6.2.3 Airtime Fairness Test
Verify the capability of Wi-Fi device to guarantee the fairness of airtime usage when handle a mix of clients using new and legacy 802.11 standards.

6.3.1 Range Versus Rate Test
Test measures the Throughput of the DUT with the station being at different distances from the AP.

6.3.2 Spatial Consistency Test
Test measures the performance of the AP at various antenna orientations with respect to the stations.

6.4.1 Multiple STAs Perf Test
Measure performance of the AP with multiple stations at different distances, to emulate the real world behavior.

6.4.2 Multiple Assoc/Disassoc Stability
In a multi client scenario, test if the AP throughput performance degrades with other clients connecting and disconnecting simultaneously

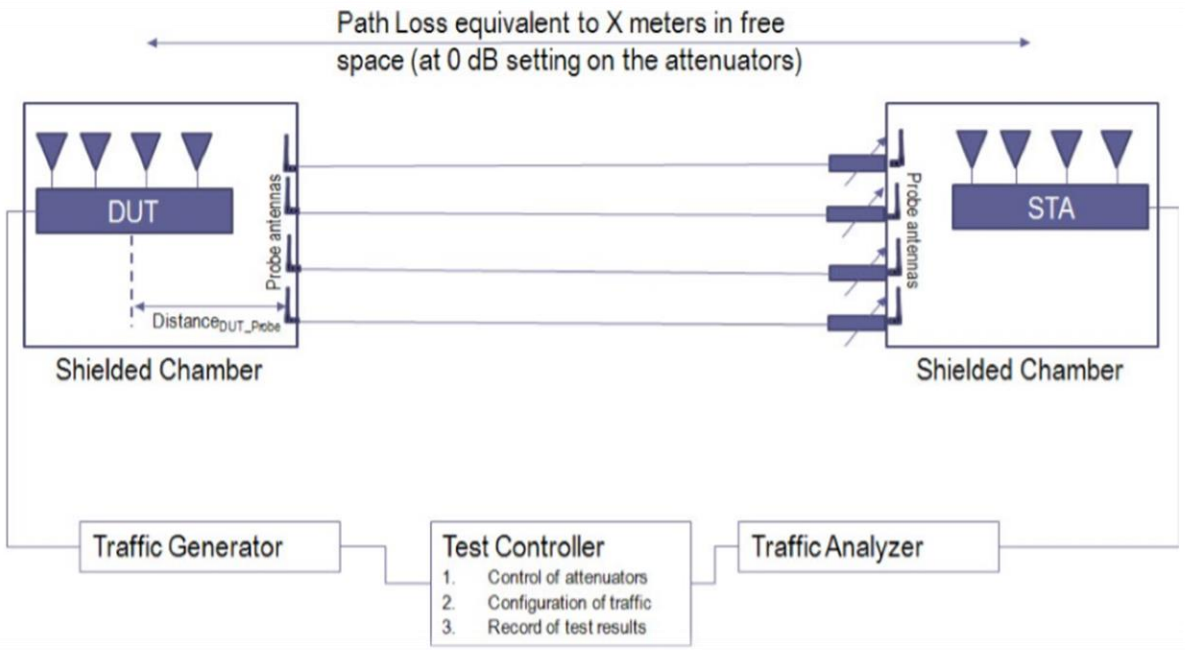
6.4.3 Downlink MU-MIMO Perf
Test to ensure the downlink throughput increases substantially with multiple clients and MU-MIMO enabled.

6.5.1 Long Term Stability
Test to make sure the AP can consistently achieve high throughput over a very long test duration.

6.5.2 AP Coexistence
Test to make sure the AP can achieve good performance in the presence of other neighboring APs and clients

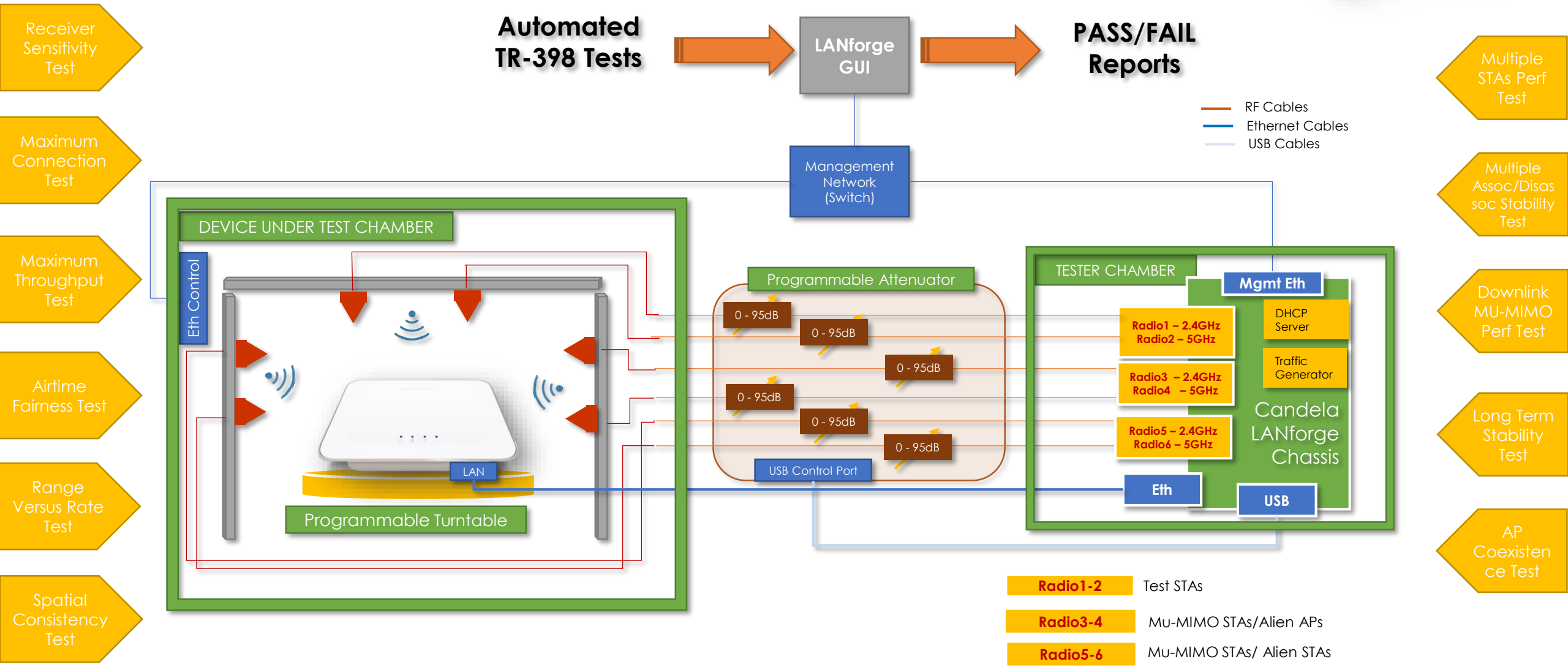
TR-398 Testbed Building Blocks

- ✓ Multi-station Emulator
- ✓ Traffic Generator
- ✓ Path Loss Emulator (Programmable Attenuator)
- ✓ Shielded Chambers / RF enclosures
- ✓ Programmable Turntable for Spatial Consistency Testing
- ✓ Mu-MIMO Station emulator for Mu-MIMO testing
- ✓ AP Emulator (to create Alien AP and Alien STAs for co-existence testing)
- ✓ Test Controller and Automation Test Software



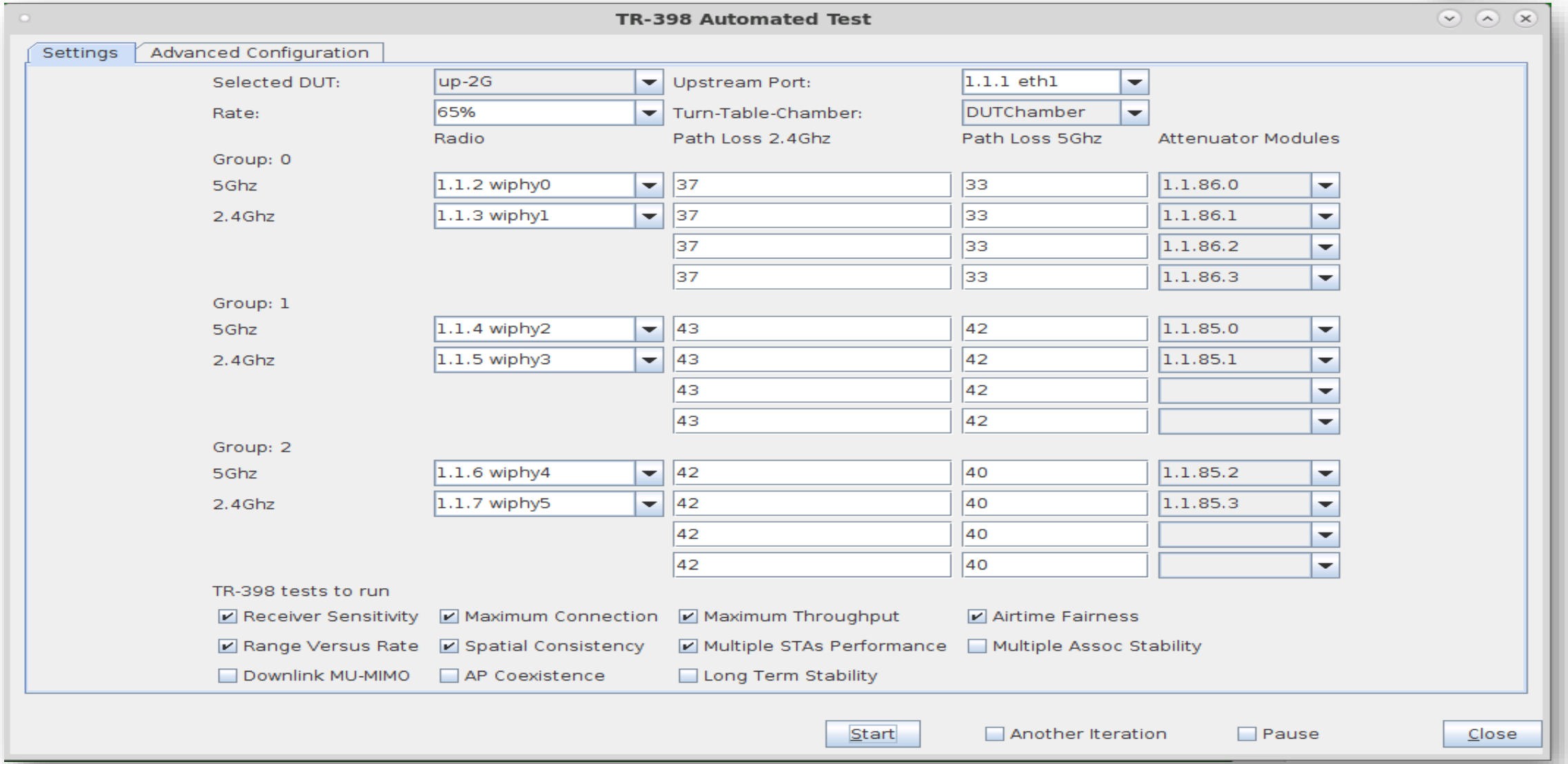
Candela Technologies offers a fully automated TR-398 Test suite with PASS/FAIL test results and all the testbed building blocks.

TR-398 Testbed Setup



TR-398 Testbed Pictures

TR-398 Automated Test GUI



Sample Test Results

Summary Results

Test	Result
6.1.1 Receiver Sensitivity Test	FAIL
6.2.1 Maximum Connection Test (32-stations)	FAIL
6.2.2 Maximum TCP Throughput Test	FAIL
6.2.3 Airtime Fairness Test	FAIL
6.3.1 Range Versus Rate Test	FAIL
6.3.2 Spatial Consistency Test	FAIL
6.4.1 Multiple STAs Performance Test	FAIL
6.4.2 Multiple Association/Disassociation Stability Test	Skipped
6.4.3 Downlink MU-MIMO Performance Test	Skipped
6.5.2 AP Coexistence Test	Skipped
6.5.1 Long Term Stability Test	Skipped

6.1.1 Receiver Sensitivity Test

Type	Result	Notes
	FAIL	radio: 0 mcs: 0 rot: 0 last-atten-pass: 18 passing value: 46
	FAIL	radio: 0 mcs: 9 rot: 0 last-atten-pass: 0 passing value: 21

6.1.1 Receiver Sensitivity Test Log

6.2.2 Maximum TCP Throughput Test

Type	Result	Notes
Total 2.4Ghz download throughput	PASS	Sum-total download: 100.14 Mbps
Total 2.4Ghz upload throughput	FAIL	Total upload: 95.94 Mbps must be at least 100Mbps on 2.4Ghz.
Total 5Ghz download throughput	FAIL	Total download: 388.64 Mbps must be at least 650Mbps on 5Ghz.
Total 5Ghz upload throughput	FAIL	Total upload: 346.58 Mbps must be at least 650Mbps on 5Ghz.

6.2.2 Maximum TCP Throughput Test Log

6.2.3 Airtime Fairness Test

Type	Result	Notes
STA1-throughput-1 2.4Ghz	PASS	Avg: 24.68 Mbps MIN: 23.45 MAX: 25.92 STA1-Throughput: 25.23 STA2-Throughput: 24.14
STA2-throughput-1 2.4Ghz	PASS	Avg: 24.68 Mbps MIN: 23.45 MAX: 25.92 STA1-Throughput: 25.23 STA2-Throughput: 24.14
STA1-throughput-2 2.4Ghz	FAIL	2.4Ghz: STA1_throughput-2 must be +-15% of average of STA2 + STA1 for subtest 1, Avg: 24.68 Mbps Min: 20.98 Max: 28.39 STA1-Throughput-2: 33.17 STA1-Throughput-3: 19.86
STA2-throughput-3 2.4Ghz	FAIL	2.4Ghz: STA2_throughput-3 must be +-15% of average of STA2 + STA1 for subtest 1, Avg: 24.68 Mbps Min: 20.98 Max: 28.39 STA1-Throughput-2: 33.17 STA1-Throughput-3: 19.86
STA1/2 Throughput-1 Total	FAIL	STA1-Throughput-1: 25.23 Mbps STA2-Throughput-1: 24.14 Mbps SUM: 49.37 Mbps: Must be at least: 80.00 Mbps
STA1/2 Throughput-2 Total	FAIL	STA1-Throughput-2: 33.17 STA2-Throughput-2: 18.61 SUM: 51.78: Must be at least: 54.00 Mbps
STA1/3 Throughput-3 Total	FAIL	STA1-Throughput-3: 19.86 STA3-Throughput-3: 10.72 SUM: 30.58: Must be at least: 50.00 Mbps
STA1-throughput-1 5Ghz	PASS	Avg: 138.85 Mbps MIN: 131.91 MAX: 145.79 STA1-Throughput: 143.10 STA2-Throughput: 134.61
STA2-throughput-1 5Ghz	PASS	Avg: 138.85 Mbps MIN: 131.91 MAX: 145.79 STA1-Throughput: 143.10 STA2-Throughput: 134.61
STA1-throughput-2 5Ghz	PASS	Avg: 138.85 Mbps Min: 104.14 Max: 173.57 STA1-Throughput-2: 162.09 STA1-Throughput-3: 228.31
STA2-throughput-3 5Ghz	FAIL	5Ghz: STA2_throughput-3 must be +-25% of average of STA2 + STA1 for subtest 1, Avg: 138.85 Mbps Min: 104.14 Max: 173.57 STA1-Throughput-2: 162.09 STA1-Throughput-3: 228.31
STA1/2 Throughput-1 Total	FAIL	STA1-Throughput- be at least: 475.00
STA1/2 Throughput-2 Total 5Ghz	PASS	STA1-Throughput- 280.00 Mbps
STA1/3 Throughput-3 Total 5Ghz	PASS	STA1-Throughput- Mbps

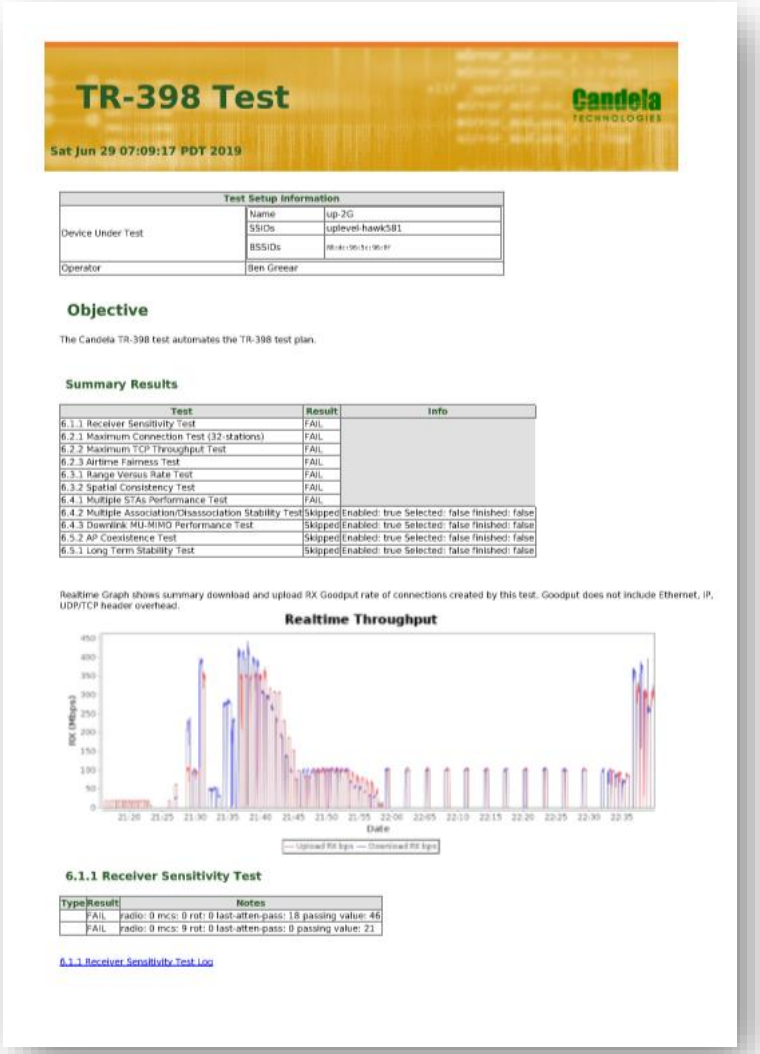
6.4.1 Multiple STAs Performance Test

Type	Result	Notes
2.4Ghz DL step: 0	PASS	Req: 70 Rpt: 99.35
2.4Ghz UL step: 0	PASS	Req: 70 Rpt: 98.30
2.4Ghz DL step: 1	PASS	Req: 60 Rpt: 86.76
2.4Ghz UL step: 1	PASS	Req: 60 Rpt: 92.06
2.4Ghz DL step: 2	PASS	Req: 50 Rpt: 70.85
2.4Ghz UL step: 2	PASS	Req: 50 Rpt: 85.29
5Ghz DL step: 0	FAIL	Req: 500 Rpt: 358.85
5Ghz UL step: 0	FAIL	Req: 500 Rpt: 316.01
5Ghz DL step: 1	FAIL	Req: 400 Rpt: 370.85
5Ghz UL step: 1	FAIL	Req: 400 Rpt: 302.66
5Ghz DL step: 2	FAIL	Req: 300 Rpt: 259.92
5Ghz UL step: 2	PASS	Req: 300 Rpt: 303.20

6.3.1 Range Versus Rate Test

Type	Result	Notes
	FAIL	2.4Ghz DL [0] req: 100.0 reported: 98.9 rssi: -38
	PASS	2.4Ghz DL [10] req: 100.0 reported: 100.1 rssi: -39
	FAIL	2.4Ghz DL [21] req: 100.0 reported: 98.0 rssi: -45
	FAIL	2.4Ghz DL [24] req: 100.0 reported: 97.7 rssi: -47
	PASS	2.4Ghz DL [27] req: 100.0 reported: 100.8 rssi: -50
	PASS	2.4Ghz DL [30] req: 100.0 reported: 101.0 rssi: -52
	PASS	2.4Ghz DL [33] req: 100.0 reported: 101.6 rssi: -55
	PASS	2.4Ghz DL [36] req: 95.0 reported: 101.1 rssi: -58
	PASS	2.4Ghz DL [39] req: 80.0 reported: 100.6 rssi: -61
	PASS	2.4Ghz DL [42] req: 75.0 reported: 99.0 rssi: -65
	PASS	2.4Ghz DL [45] req: 50.0 reported: 68.4 rssi: -68
	PASS	2.4Ghz DL [48] req: 45.0 reported: 55.9 rssi: -70
	PASS	2.4Ghz DL [51] req: 35.0 reported: 52.8 rssi: -73
	PASS	2.4Ghz DL [54] req: 25.0 reported: 42.6 rssi: -76
	PASS	2.4Ghz DL [57] req: 14.0 reported: 32.8 rssi: -79
	PASS	2.4Ghz DL [60] req: 9.0 reported: 29.5 rssi: -82
	FAIL	2.4Ghz DL [63] req: 8.0 reported: 6.8 rssi: -84
	FAIL	2.4Ghz UL [0] req: 100.0 reported: 82.4
	FAIL	2.4Ghz UL [10] req: 100.0 reported: 82.2
	FAIL	2.4Ghz UL [21] req: 100.0 reported: 97.6
	FAIL	2.4Ghz UL [24] req: 100.0 reported: 97.7
	PASS	2.4Ghz UL [27] req: 100.0 reported: 100.1

Comprehensive PDF Test Reports



TR-398 Test

Sat Jun 29 07:09:17 PDT 2019

Test Setup Information		
Device Under Test	Name	up-2G
	SSIDs	uplevel-hawk581
	BSSIDs	
Operator	Ben Greear	

Objective

The Candela TR-398 test automates the TR-398 test plan.

Summary Results

Test	Result	Info
6.1.1 Receiver Sensitivity Test	FAIL	
6.2.1 Maximum Connection Test (32-stations)	FAIL	
6.2.2 Maximum TCP Throughput Test	FAIL	
6.2.3 Airtime Fairness Test	FAIL	
6.3.1 Range Versus Rate Test	FAIL	
6.3.2 Spatial Consistency Test	FAIL	
6.4.1 Multiple STAs Performance Test	FAIL	
6.4.2 Multiple Association/Disassociation Stability Test	Skipped	Enabled: true Selected: false Finished: false
6.4.3 Downlink MU-MIMO Performance Test	Skipped	Enabled: true Selected: false Finished: false
6.5.2 AP Coexistence Test	Skipped	Enabled: true Selected: false Finished: false
6.5.1 Long Term Stability Test	Skipped	Enabled: true Selected: false Finished: false

Realtime Graph shows summary download and upload RX Goodput rate of connections created by this test. Goodput does not include Ethernet, IP, UDP/TCP header overhead.

Realtime Throughput

6.1.1 Receiver Sensitivity Test

Type	Result	Notes
	FAIL	radio: 0 mcs: 0 rot: 0 last-atten-pass: 18 passing value: 46
	FAIL	radio: 0 mcs: 9 rot: 0 last-atten-pass: 0 passing value: 21

6.1.1 Receiver Sensitivity Test Log

Testbed Options and Pricing

Test Case	LANforge Radio1-2	Attenuator Unit 1	Tester Chamber	DUT Chamber	LANforge Radio 3-4	Attenuator Unit 2	LANforge Radio 5-6	Turntable in DUT Chamber
6.2.1 Maximum Connection Test	✓	✓	✓	✓				
6.2.2 Maximum Throughput Test	✓	✓	✓	✓				
6.3.1 Range Versus Rate Test	✓	✓	✓	✓				
6.4.2 Multiple Assoc/Disassoc Stability	✓	✓	✓	✓				
6.5.1 Long Term Stability	✓	✓	✓	✓				
6.2.3 Airtime Fairness Test	✓	✓	✓	✓	✓	✓		
6.4.3 Downlink MU-MIMO Performance	✓	✓	✓	✓	✓	✓	✓	
6.5.2 AP Coexistence	✓	✓	✓	✓	✓	✓	✓	
6.1.1 Receiver Sensitivity Test	✓	✓	✓	✓				✓
6.3.2 Spatial consistency test	✓	✓	✓	✓	✓	✓	✓	✓
6.4.1 Multiple STAs Performance Test	✓	✓	✓	✓	✓	✓	✓	✓

- **Covers only 5 tests**
- Needs single LANforge system with 2 radios, 1 4-port attenuator and 2 medium RF chambers
- **System Price: $60K**

- **Covers 8 tests**
- Add 4 more LANforge radios and second attenuator
- **System Price: $80K**

- **Covers all 11 tests**
- Change DUT chamber to a large chamber with Turntable
- **System Price: $100K**

All System prices are approximate and include H/W , S/W, all accessories including RF cables, splitters etc… and 1 year customer support

Full Testbed Bill of Materials (BOM)

- ✓ **Hardware**
  - ✓ **01x** LANforge Units – minimum 6 wave-2 radios (3x 2.4GHz, 3x 5GHz NICs), 2-eth ports (optional 10gE Ports)
  - ✓ **01x** CT820a-Medium RF Chambers
  - ✓ **01x** CT840a-Large RF Chamber with Programmable Turntable
  - ✓ **02x** CT704b- 4 Port Programmable Attenuators
  - ✓ **16x** 2:1 Splitters
  - ✓ **08x** Directional Antennas (optional)
  - ✓ **48x** RF Cables
  - ✓ **08x** Ethernet Cables
  - ✓ **01x** 8-port Ethernet Switches
  - ✓ **01x** USB Hubs
  - ✓ **01x** USB to USB Cables
- ✓ **Software**
  - ✓ **01x** 128 Virtual Stations License
  - ✓ **01x** 1000 Concurrent Connections License
  - ✓ **01x** 10GE Port License (optional)
  - ✓ **02x** 1GE Port Licenses
  - ✓ **01x** TR-398 Automation Software License
- ✓ **Support/Warranty**
  - ✓ **01x** 1-year hardware and software support

All Hardware and Software can be supplied by Candela on a single purchase order and the entire tested fully integrated, fully automated and tested before shipping to customer.

Test Equipment and Components

CT523c
LANforge Station Emulator/Traffic Generator

- ✓ 3x 5GHz and 3x 2.4GHz NICs (4x4 Wave2)
- ✓ 2x 10GE Copper Port
- ✓ 64 STAs per Radio
- ✓ Background (Alien) APs and STA
- ✓ L2-7 traffic generation and monitoring

CT820a
Candela Medium RF Chamber

- ✓ Isolation: 75+ dB
- ✓ Frequency(GHz): 0.8 to 6GHZ
- ✓ Standard Interfaces: 16x SMAs, 2x USB 3.0, 2x 10G Ethernet, USB-C, 4K HDMI, RF Coax, Fiber, fan, DC power, universal A/C power strip. Other options available.
- ✓ In Dim(mm): 480(W) 490(D) 480(H)
- ✓ Out Dim(mm): 550(W) 650(D) 535(H)
- ✓ Weight: 30kg

CT840a
Candela Large RF chamber with 2D turntable

- ✓ Isolation: > 80 dB
- ✓ Frequency(GHz): 0.8 to 6GHZ
- ✓ Standard Interfaces: 16x SMAs, 2x USB 3.0, 2x 10GE, USB-C, 4K HDMI, RF Coax, Fiber, fan, DC power, universal A/C power strip.
- ✓ Programmable Turn Table
- ✓ In Dim(mm): 890 x 450 x495
- ✓ Out Dim(mm): 1060 x 770 x 880
- ✓ Weight: 90kg

Software
Candela TR-398 Automation Test Suite

- ✓ LANforge TR-398 Automation Test Suite.
- ✓ PASS/FAIL Test Report

CT704b
Candela 4-port Programmable Attenuator

- ✓ Frequency Range:0.3 GHz – 6.0 GHz
- ✓ Attenuation Range:0 – 95.5 dB
- ✓ Attenuation Steps:0.5 dB increments
- ✓ Insertion Loss:8 dB nominal, 10 dB max
- ✓ Attenuation Accuracy:1-15 dB: ±1dB, 16+ dB: ±1.5dB or 4%

SMA Cable Bundle

- ✓ Semi-rigid cable package included
- ✓ Splitter/Combiners
- ✓ Fixed Attenuators

TR-398 Tests

As specified by the Broadband Forum Document
(https://www.broadband-forum.org/download/TR-398.pdf)

DUT SETTINGS

Table 8 SSID setting configuration

Configuration Parameters	Default value
SSID name	BBF_Wi-Fi_Perf_Test_XG (NOTE1)
Enable SSID	True
Number of associated devices	32
Broadcast SSID	True
Enable WMM	True
Authentication Mode	WPA2-Personal
Encryption Mode	AES
WPA PreShareKey	(NOTE2)
WPA Group Key Regeneration Interval	3600 seconds
Note 1: "X" represent "2.4" when DUT is configured to work in 2.4 GHz band while "X" represent "5" when DUT is configured to work in 5 GHz band.	
Note 2: Defined by test agent.	

Table 9 Work setting configuration for 2.4 GHz band

Configuration Parameters	Default value
Tx Power	100 % (NOTE1)
Regulatory Domain	(NOTE2)
Channel	Channel 6
Chanel Width	20 MHz
Standard mode	802.11b/g/n
DTIM period	1
Beacon Period	100 ms
Note 1: 100% is corresponding to 20 dBm, this value indicates the aggregated power of all the chains used for communication by air-interface.	
Note 2: Defined by test agent or automatically selected by the DUT.	

Table 10 Work setting configuration for 5 GHz band

Configuration Parameters	Default value
Tx Power	100 % (NOTE1)
Regulatory Domain	(NOTE2)
Channel	Channel 36
Chanel Width	20/40/80 MHz
Standard mode	802.11a/ac
DTIM period	1
Beacon Interval	100 ms
Note 1:100% is corresponding to 23 dBm, this value indicates the aggregated power for all the chains used for communication by air-interface.	
Note 2: defined by test agent or automatically selected by the DUT.	

6.1 RF capability

6.1.1 Receiver Sensitivity Test

Receiver Sensitivity is a receiver's ability to receive and correctly demodulate weak signals. This test provides a simplified measurement of the receiver's sensitivity, relative to the total attenuation inserted between the DUT and the STA. As that attenuation is increased, the STA is limited to a single coding scheme, eventually causing the connection to degrade. The point at which the connection degrades represents the receiver's approximate sensitivity. This is an approximate measurement only, where a detailed receiver sensitivity measurement would typically be performed in a conducted test environment with calibrated transmitter power levels. The test is repeated with multiple coding schemes, ensuring the DUT should smoothly transition between coding schedules as the attenuation increases in normal operation

Setup

1. The test setup SHALL utilize a shielded chamber
2. A Traffic Generator/Analyzer is connected to the station and DUT, capable of sending and receiving Ethernet frames in order to measure packet error rate. A UDP link SHALL be established between DUT and STA and traffic rate SHALL be set to 65% of the theoretical maximum throughput rate for each Modulation and Coding Scheme (MCS). The direction of data packet is from STA to DUT.
3. A controllable attenuator is added to each RF path between the STA and DUT. The attenuator SHALL support the attenuation values between 0 dB and 60 dB, in 1 dB steps.
4. The PHY Service Data Unit (PSDU) of the transmission packet by Wi-Fi link SHALL be set to
5. The STA SHALL use omnidirectional antenna for packet transmission.
6. A rotation platform is used to rotate the DUT for angle-based data collection

Procedure

1. Set the rotation angle to 0 degree.
2. Configure the STA to use the MCS rate for the first test index from Table 12 or Table 13 applicable to the test configuration from Table 11.
3. Configure the Traffic Generator to use the test data rate from Table 12 or Table 13 for the configured MCS rate.
4. Allow STA to associate with the DUT.
5. Configure the attenuator(s) to 0dB.
6. Enable packet generation from the STA to the DUT for 20 seconds.
7. Record packet error rate (PER).
8. Increase the attenuator by 1 dB and repeat steps 6-8 until the PER is greater than 10%. Record the final attenuation value as the approximate receiver sensitivity.
9. Increase the rotation angle by 45 degrees. Repeat Step 5 through 8 until the DUT has been rotated by 360 degrees. Calculate the average receiver sensitivity.
10. Repeat steps 1 through 9 for each test index applicable to the test configuration from Table 11.
11. Repeat steps 1 through 10 for each test configuration in Table 11 supported by the DUT.

Metrics (Pass/Fail Criteria)

The measured average (between all rotation points) receiver sensitivity (inserted attenuation) in the test SHALL be greater than or equal to the required receiver sensitivity, as shown in Table 14 and Table 15

Table 11 Wi-Fi Test Configurations for Receiver Sensitivity

Test Configuration	Wi-Fi configuration
1	802.11n/2.4 GHz/20 MHz
2	802.11ac/80 MHz
NOTE: Both configurations SHALL use a station supporting one spatial stream (Nss =1) only.	

Table 12 MCS Rate and Traffic Test Configuration for 802.11n

Test Index	MCS Index	Modulation	Data Rates (Mbps) GI = 800 ns 20 MHz channel, Nss = 1	
			Theoretical	Test
1	0	BPSK	6.5	4.23
2	7	64-QAM	65	42.25

Table 13 MCS and Traffic Test Configuration for 802.11ac

Test Index	MCS Index	Modulation	Data Rates (Mbps) GI = 800 ns 80 MHz channel, Nss = 1	
			Theoretical	Test
3	0	BPSK	29.3	19.05
4	9	256-QAM	390	253.5

Table 14 Required Receiver Sensitivity for 802.11n

Test Index	MCS Index	Modulation	Approximately Receiver Sensitivity (dB)
			Required (Nss=1)
1	0	BPSK	56
2	7	64-QAM	38

Table 15 Required Receiver Sensitivity for 802.11ac

Test Index	MCS Index	Modulation	Approximately Receiver Sensitivity (dB)
			Required (Nss=1)
3	0	BPSK	46
4	9	256-QAM	21

6.2 Baseline performance

6.2.1 Maximum Connection Test

The Maximum Connection test intends to verify that the Wi-Fi AP can support 32 STAs simultaneously connected with minimal packet loss and no disassociations taking place.

Setup

1. A Traffic Generator/Analyzer, sending the Ethernet packets, connects to the LAN interface (e.g., GE port) of the DUT. The peer STAs is put at a distance of 2 meters to the DUT (For 2.4 GHz band, 2 meters free space of wireless channel leads to 46 dB attenuation).
2. 32 STAs are prepared and associated to DUT during the test.
3. UDP connection SHALL be used for Ethernet packet transmission in the test.

Procedure

1. Configure the working mode of DUT to 802.11n with default configuration.
2. Establish the LAN connection and allow STA to associate with the DUT.
3. Simultaneously measure the downlink UDP packet loss, using a test time of 120 seconds and a traffic rate of 2 Mbps for 802.11n or 8 Mbps for 802.11ac, through each STA. Record the number of packets transmitted and received to calculate the packet error rate.
4. Simultaneously measure the uplink UDP packet loss, using a test time of 120 seconds and a traffic rate of 2 Mbps for 802.11n or 8 Mbps for 802.11ac, through each STA. Record the number of packets transmitted and received to calculate the packet error rate.
5. Change the working mode of DUT to 802.11ac with default configuration.
6. Establish the LAN connection and allow STA to associate with the DUT.
7. Simultaneously measure the downlink UDP packet loss, using a test time of 120 seconds and a traffic rate of 2 Mbps for 802.11n or 8 Mbps for 802.11ac, through each STA. Record the number of packets transmitted and received to calculate the packet error rate.
8. Simultaneously measure the uplink UDP packet loss, using a test time of 120 seconds and a traffic rate of 2 Mbps for 802.11n or 8 Mbps for 802.11ac, through each STA. Record the number of packets transmitted and received to calculate the packet error rate.

Metrics (Pass/Fail Criteria)

1. For each of the test configuration, Packet Error Rate (PER) for each STA SHALL achieve less than 1 %.
2. For each of the test configuration, the overall throughput of all connected STA SHALL achieve:
    A. For 32 connected STA (802.11n), both downlink and uplink summed throughput SHALL be not less than 64 Mbps * 99%.
    B. For 32 connected STA (802.11ac), both downlink and uplink summed throughput SHALL be not less than 256 Mbps * 99%.

6.2 Baseline performance

6.2.2 Maximum Throughput Test

Maximum throughput test intends to measure the maximum throughput performance of the DUT. The test is conducted with connection by air interface in short distance (by considering the actual utilization of Wi-Fi).

Setup

1. The test setup SHALL be located in the anechoic shielded chamber.
2. A Traffic Generator/Analyzer, sending the Ethernet packets, connects to the LAN interface (e.g., GE port) of the DUT. The peer STA is put at a distance of 2 meters to the DUT (For 2.4 GHz band, 2 meter free space of wireless channel leads to 46 dB attenuation).
3. TCP connection SHALL be used for Ethernet packet transmission in the test.

Procedure

1. Configure the working mode of DUT to 802.11n with default configuration.
2. Establish the LAN connection and allow STA to associate with the DUT.
3. Measure the downlink TCP throughput to the STA, using a test time of 120 seconds.
4. Measure the uplink TCP throughput to the STA, using a test time of 120 seconds.
5. Set the working mode of DUT to 802.11ac, and repeat steps 3-4 for bandwidth 80MHz.

Metrics (Pass/Fail Criteria)

The measured average throughput SHALL meet the performance requirement of Table 16 according to the GI used in the test

Table 16 The Throughput Requirement

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)	Downlink throughput requirement Mbps GI-400ns	Uplink throughput requirement Mbps GI-400ns	Downlink throughput requirement Mbps GI-800ns	Uplink throughput requirement Mbps GI-800ns
802.11n (Nss-2)	802.11n (Nss-2)	20	100	100	90	90
802.11ac (Nss-2)	802.11ac (Nss-2)	80	560	560	504	504

6.2 Baseline performance

6.2.3 Airtime Fairness Test

Airtime Fairness Test intends to verify the capability of Wi-Fi device to guarantee the fairness of airtime usage

Setup

1. Three peer STAs are used in the test. STA1 and STA2 are 802.11n/ac devices with the same number of spatial streams supported by the DUT in both 2.4 and 5GHz bands. STA3 is a legacy 802.11a/b/g device. All STAs are located in the distance of 2 meter to the DUT (For 2.4 GHz band, 2 meter free space of wireless channel leads to 46 dB attenuation).
2. DUT is set to 2.4 GHz operating frequency band with default configuration in the beginning of the test.
3. A Traffic Generator/Analyzer, sending the Ethernet packet to each peer STA, connects to the LAN interface (e.g., GE port) of the DUT.

Procedure

1. Establish the setup using default configuration.
2. Associate STA1 and STA2 with DUT. Establish the LAN connection and wait for 10 seconds.
3. Measure the downlink TCP throughput to each STA1 and STA2, using a test time of 120 seconds. Record this as STA1 _throughput_1 and STA2 _throughput_1.
4. Move STA2 to a medium distance to the DUT (equivalent to 38 dB@2.4GHz and 32 dB @5GHz attenuation between DUT and STA2). Wait for 10 seconds.
5. Measure the downlink TCP throughput to STA 1 and STA2, using a test time of 120 seconds. Record this as STA1 _throughput_2 and STA2 _throughput_2.
6. Disassociate STA2 with the DUT. Replace STA 2 by STA 3 and remove the attenuation. STA3 is configured to support only a 2.4 GHz connection. Establish the Wi-Fi connection between STA3 and DUT and wait for 10 seconds.
7. Measure the downlink TCP throughput to STA 1 and STA3, using a test time of 120 seconds. Record this as STA1 _throughput_3 and STA3 _throughput_3.
8. Replace STA 3 with a STA that uses only 802.11a. Set the DUT to operating frequency band of 5 GHz. Repeat Step 2 to 7.

Metrics (Pass/Fail Criteria)

For the test in 2.4 GHz frequency band: 1. STA1_throughput_1 SHALL be within (1±5%)*Mean(STA2_throughput_1, STA1_throughput_1) . 2. STA2_throughput_1 SHALL be within (1±5%)*Mean(STA2_throughput_1, STA1_throughput_1) . 3. STA1_throughput_2 SHALL be within (1±15%)*Mean(STA2_throughput_1, STA1_throughput_1) . 4. STA1_throughput_3 SHALL be within (1±15%)*Mean(STA2_throughput_1, STA1_throughput_1).
For the test in 5 GHz frequency band: 1. STA1_throughput_1 SHALL be within (1±5%)*Mean(STA2_throughput_1, STA1_throughput_1). 2. STA2_throughput_1 SHALL be within (1±5%)*Mean(STA2_throughput_1, STA1_throughput_1). 3. STA1_throughput_2 SHALL be within (1±25%)*Mean(STA2_throughput_1, STA1_throughput_1). 4. STA1_throughput_3 SHALL be within (1±25%)*Mean(STA2_throughput_1, STA1_throughput_1).
For the test in 2.4 GHz frequency band with Nss = 2: 1. The summation of STA1_throughput_1 and STA2_throughput_1 SHALL be larger than 80 Mbps. 2. The summation of STA1_throughput_2 and STA2_throughput_2 SHALL be larger than 54 Mbps. 3. The summation of STA1_throughput_3 and STA3_throughput_3 SHALL be larger than 50 Mbps.
For the test in 5 GHz frequency band with Nss = 2: 1. The summation of STA1_throughput_1 and STA2_throughput_1 SHALL be larger than 475 Mbps. 2. The summation of STA1_throughput_2 and STA2_throughput_2 SHALL be larger than 280 Mbps. 3. The summation of STA1_throughput_3 and STA3_throughput_3 SHALL be larger than 230 Mbps.

6.3 Coverage

6.3.1 Range Versus Rate Test

Range versus rate test intends to measure the baseband and RF chain performance of Wi-Fi device. The attenuation of signals due to range increase is achieved by using attenuator in the STA sides

Setup

1. A Traffic Generator/Analyzer, sending the Ethernet packets, connects to the LAN interface (e.g., GE port) of the DUT. The peer STA is located in 2 meter to the DUT (46dB attenuation for 2.4 GHz, 53 dB attenuation for 5.2 GHz).
2. Additional attenuation is added in each RF chain of STA to simulate the incremental distance. The host SHALL send the Ethernet packet at the maximum rate which the DUT can achieve theoretically. 5. TCP connection SHALL be used for Ethernet packet transmission in the test.

Procedure

1. Configure the attenuator with 0 dB attenuation. Configure the working mode of DUT to 802.11n and operating frequency band to 2.4 GHz with default configuration.
2. Establish the LAN connection and allow STA to associate with the DUT.
3. Measure the downlink TCP throughput to the STA, using a test time of 120 seconds.
4. Measure the uplink TCP throughput to the DUT, using a test time of 120 seconds.
5. Change the attenuation for STA RF chain until the attenuation reaches to 63 dB. Repeat step 2-4.
6. Configure the attenuator with 0 dB attenuation. Set the working mode of DUT to 802.11ac with 80MHz bandwidth. Repeat step 2-4 for all attenuation values

Metrics (Pass/Fail Criteria)

In order to pass the test case, the recorded results SHALL meet the Pass/Fail Criteria, described as following: The measured average throughput SHALL meet the performance requirement of Table 19. For each configuration, the test allows no more than 2 testing points fall below the throughput requirement.

Table 19 The throughput requirement

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)	Attenuation (dB)	Throughput requirement (Mbps)		Attenuation (dB)	Throughput requirement (Mbps)	
				DL	UL		DL	UL
802.11n (Nss=2)	802.11n (Nss=2)	20	0	100	100	42	75	75
			10	100	100	45	50	50
			21	100	100	48	45	31
			24	100	100	51	35	24
			27	100	100	54	25	17
			30	100	100	57	14	12
			33	100	100	60	9	7
			36	95	95	63	8	4
802.11ac (Nss=2)	802.11ac (Nss=2)	80	39	80	80			
			0	560	560	42	100	100
			10	530	530	45	45	45
			21	420	420	48	25	25
			24	400	400	51	5	5
			27	360	360	54	1	1
			30	300	300			
			33	220	220			
				150	150			
			39	125	125			

6.3 Coverage

6.3.2 Spatial consistency test

Spatial consistency test intends to verify the Wi-Fi signal consistency in spatial domain

Setup

1. DUT and peer STA is in a distance of 2 meters. DUT is fixed in a two-dimensional rotation platform.
2. A Traffic Generator/Analyzer, sending the Ethernet packet, connects to the LAN interface (e.g., GE port) of the DUT. The Peer STA receives the Wi-Fi packet from the DUT through air interface.
3. Additional attenuation is added in each RF chain of STA to simulate the incremental distance.
4. TCP connection SHALL be used for Ethernet packet transmission in the test.

Procedure

1. Configure the working mode of DUT to 802.11n, operating frequency band to 2.4 GHz with default configuration.
2. Establish the LAN connection and allow STA to associate with to the DUT.
3. Measure the downlink TCP throughput to the STA, using a test time of 60 seconds. Wait for 10 seconds. Measure the uplink TCP throughput to the STA, using a test time of 60 seconds.
4. Rotate the DUT platform by 30° and repeat Step 3 until the platform has been rotated by 360°.
5. Increase the attenuation for each RF chain and reset the position of DUT platform to 0°, until all the attenuation values have been tested. Repeat Step 2-5.
6. Set the working mode of DUT to 802.11ac with a bandwidth of 80 MHz and operating frequency to 5 GHz, reset the position of DUT platform to 0°. Repeat Step 2-5.

Metrics (Pass/Fail Criteria)

A. The average throughput measured at each angle SHALL satisfy the requirements in Table 21
B. The maximum variation during rotation SHALL satisfy the requirements in Table 22:

Table 21 Pass/Fail criteria for spatial consistency test by performance

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)	Throughput under different attenuation (Mbps)					
			Strong signals		Medium signals		Weak signals	
			DL	UL	DL	UL	DL	UL
802.11n (Nss=2)	802.11n (Nss=2)	20	90	90	70	70	35	35
802.11ac (Nss=2)	802.11ac (Nss=2)	80	500	500	200	200	100	100

Table 22 Pass/Fail criteria for spatial consistency test by variation

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)	Variation under different attenuation (%)					
			Strong signals		Medium signals		Weak signals	
			DL	UL	DL	UL	DL	UL
802.11n (Nss=2)	802.11n (Nss=2)	20	30%	30%	30%	30%	30%	30%
802.11ac (Nss=2)	802.11ac (Nss=2)	80	40%	40%	40%	40%	40%	40%

6.4 Multiple STAs Performance

6.4.1 Multiple STAs Performance Test

Multiple STAs performance test intends to measure the performance of Wi-Fi device connected with multiple STAs simultaneously. To simulate a circumstance of real environment, various levels of signals reflecting various distance between Wi-Fi device and STA are considered in the test.

Setup

1. Total 9 STAs are engaged in the test. Three STAs are located in a short distance to the DUT. Three STAs are located in a medium distance to the DUT. The rest STAs are located in a long distance to the DUT. The short/medium/long distance are emulated by adding additional attenuation for the signals as follows:
   A. STA in short distance: 10 dB @2.4GHz band, 10 dB @5GHz band;
   B. STA in medium distance: 38 dB @2.4GHz band, 32 dB @5GHz band;
   C. STA in long distance: 48 dB @2.4 GHz band, 42 dB @5GHz band.
2. A Traffic Generator/Analyzer, sending the corresponding Ethernet packets to each STA, connects to the LAN interface (e.g., GE port) of the DUT.
3. TCP connection SHALL be used for Ethernet packet transmission in the test.

Procedure

1. Configure DUT working mode as 802.11n, operating frequency band as 2.4GHz with default configuration.
2. Enable the radios on the STAs with the short distance. Allow STA to associate with the DUT.
3. Measure the downlink TCP throughput to each STA, using a test time of 120 seconds. Calculate the summation of downlink TCP throughput of the three STA in short distance. Record the result as "Throughput_S_DL". Wait for 10 seconds. Measure the uplink TCP throughput to each STA, using a test time of 120 seconds. Calculate the summation uplink TCP throughput of the three STA in short distance. Record the result as "Throughput_S_UL".
4. Enable the radios on the STAs with the medium distance. Allow STA to associate with the DUT. Measure the downlink TCP throughput to each STA, using a test time of 120 seconds. Calculate the summation of downlink TCP throughput of all STA (three STA in short distance and the three STA in medium distance). Record the result as "Throughput_SM_DL". Wait for 10 seconds. Measure the uplink TCP throughput to each STA, using a test time of 120 seconds. Calculate the summation of uplink TCP throughput of all STA (the three STA in short distance and the three STA in medium distance). Record the result as "Throughput_SM_UL".

5. Enable the radios on the STAs with the long distance. Allow STA to associate with the DUT. Measure the downlink TCP throughput to each STA, using a test time of 120 seconds. Calculate the summation of all STA (downlink TCP throughput of the three STA in short distance, the three STA in medium distance and the three STA in long distance). Record the result as "Throughput_SML_DL". Wait for 10 seconds. Measure the uplink TCP throughput to each STA, using a test time of 120 seconds. Calculate the summation of uplink TCP throughput of all STA (the three STA in short distance, the three STA in medium distance and the three STA in long distance). Record the result as "Throughput_SML_UL".
6. Set the working mode of DUT to 802.11ac according to Table 23, and bandwidth to 80 MHz if applicable, and repeat Step 2- 5

Table 23 Throughput requirement of Multiple STAs Performance Test

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)	Throughput_S (Mbps)		Throughput_SM (Mbps)		Throughput_SML (Mbps)	
			DL	UL	DL	UL	DL	UL
11n (Nss=2)	11n (Nss=2)	20	70	70	60	60	50	50
11ac (Nss=2)	11ac (Nss=2)	80	500	500	400	400	300	300

Metrics (Pass/Fail Criteria)

A. Throughput of the Peer STAs SHALL satisfy the requirement in Table 23

6.4 Multiple STAs Performance

6.4.2 Multiple Association/Disassociation Stability

Multiple association/disassociation stability test intends to measure stability of Wi-Fi device under a dynamic environment with frequent change of connection status

Setup

1. 16 peer STAs SHALL be connected to the dedicated operating frequency band (2.4 GHz or 5 GHz) and in a short distance of 2 meter to the DUT (For 2.4 GHz band, 2 meter free space of wireless channel leads to 46 dB attenuation). The test is only conducted for one operating frequency band in each test circle.
2. UDP connection SHALL be used for Ethernet packet transmission in the test

Procedure

1. Configure the working mode of DUT as 802.11n, operating frequency as 2.4GHz with the default configuration.
2. 8 STAs are picked for sending/receiving packet while the other 8 STAs are picked to do association/ re-association process during the test. Establish the LAN connection and allow STA to associate with the DUT. Enable downlink UDP flow (4 Mbps @2.4GHz and 8 Mbps @5GHz) from DUT to each STA.
3. Continue monitoring the traffic flow of each STA by recording the UDP flow rate every second.
4. Disassociate the rest peer STAs. Wait for 30 seconds. Re-associate the STAs simultaneously.
5. Configure the working mode of DUT as 802.11ac, operating frequency band as 5 GHz and the channel bandwidth to 80 MHz, respectively. Wait for 10 seconds, repeat Steps 2-4.

Metrics (Pass/Fail Criteria)

A. The disassociation/association does not affect the performance of other peer STAs: (1) Error-free UDP traffic rate is at leat 99% of the configured rate for each STA.

6.4 Multiple STAs Performance

6.4.3 Downlink MU-MIMO Performance

Downlink MU-MIMO Performance Test intends to verify the performance of Wi-Fi device when Downlink MU-MIMO is applied. This best represents a typical deployment, where stations may only support 1x1 or 2x2 .RF chain configurations. The test is only applicable to the Wi-Fi device supporting the 802.11ac. Downlink MU-MIMO capability, also referred to as 802.11ac Wave 2. The DUT SHALL support 802.11ac MU-MIMO and at least 4 spatial streams

Setup

1. The DUT and engaged peer STAs SHALL support 802.11ac and MU-MIMO. One STA (STA 1) supports maximum two spatial streams while two STAs (STA 2 and STA 3) support only one spatial stream. All STAs are located in the distance of 2 meter to the DUT (For 5.2 GHz band, 2-meter free space of wireless channel leads to 52.8 dB attenuation) and are placed at different angles relative to the DUT, ideally more than 45 degrees apart.
2. A Traffic Generator/Analyzer, sending the Ethernet packet to each peer STA, connects to the LAN interface of the DUT.
3. TCP connection SHALL be used for Ethernet packet transmission in the test.

Procedure

1. Establish the setup by using the default configuration as detailed above.
2. Associate STA 1 with DUT. Establish the LAN connection and wait for 10 seconds.
3. Measure the downlink TCP throughput to STA1, using a test time of 120 seconds. Record this value as STA1_throughput_1.
4. Disassociate STA1. Wait for 10 seconds. Associate STA 2 with DUT. Wait for 10 seconds. Measure the downlink TCP throughput to STA2, using a test time of 120 seconds. Record this value as STA2_ throughput_1.
5. Disassociate STA 2. Wait for 10 seconds. Associate STA 3 with DUT. Wait for 10 seconds. Measure the downlink TCP throughput to STA 3, using a test time of 120 seconds. Record this value as STA3_throughput_1.
6. Associate STA 1 and STA 2 with DUT (STA 3 remains associated). Simultaneously measure the downlink TCP throughput to all STA, using a test time of 120 seconds. Record these value as STA1_throughput_2, STA2_throughput_2 and STA3_throughput_2.
7. Disable DL MU-MIMO and wait for 10 seconds. Measure the downlink TCP throughput to each STA, using a test time of 120 seconds. Record these values as STA1_throughput_3, STA2_throughput_3 and STA3_throughput_3. If the DUT does not support this operation, this step and the associated test metric SHALL NOT apply.

Metrics (Pass/Fail Criteria)

In order to pass the test case, the recorded results SHALL meet the Pass/Fail Criteria, described as following:

A. The sum of STA1_throughput_2, STA2_throughput_2, and STA3_throughput_2 SHALL be at least 45% of the sum of STA1_throughput_1, STA2_throughput_1, and STA3_throughput_1.
B. The sum of STA1_throughput_2, STA2_throughput_2, and STA3_throughput_2 SHALL be greater than the sum of STA1_throughput_3, STA2_throughput_3, and STA3_throughput_3. This test metrics SHALL only apply to the DUT that supports the configuration to disable DL MU-MIMO.

6.5 Stability/Robustness

6.5.1 Long Term Stability

Long term stability test intends to measure the stability performance of Wi-Fi device under stress. Throughput and connection availability are continuously monitored in a long period of time (24 hours).

Setup

1. Total 3 STAs are engaged in the test. In each test cycle, one operating frequency band (2.4 GHz or 5 GHz) is used. Two STAs are picked for packet reception and ping test and one STA periodically association/disassociation. All of the STAs are put in a distance of 2 meters to the DUT.
2. A Traffic Generator/Analyzer, establishing the Ethernet packets transmission to the STA (allocated to receive packets), connects to the LAN interface (e.g., GE port) of the DUT. DUT SHALL select 20 MHz bandwidth for 2.4 GHz band and 80MHz bandwidth for 5 GHz band if applicable.
3. TCP connection SHALL be used for Ethernet packet transmission in the test.

Procedure

1. Configure the STAs and DUT to the 802.11n configuration.
2. Establish the LAN connection and let STA register to the DUT. Wait for 10 seconds.
3. Configure the STA not being used for the throughput and ping tests to join (associate) and leave (disassociate) the network once every 6 minutes (for example, the station should be active for 5 minutes, followed by 1 minute inactive, followed by 5 minutes active, etc.). This process continues throughout the remainder of the test procedure.
4. Start an Internet Control Message Protocol (ICMP) Ping Test between each STA and AP, transmitting one 64-byte ping per second.
5. Perform a downlink TCP throughput test for each STA, using a test time of 120 seconds. Record the throughput rates as STA1_throughput_interval_X and STA2_throughput_interval_X, where X indicates the throughput test (1 through 288).
6. Wait for 3 minutes.
7. Repeat steps 5 through 6, for a total of 288 measurements (24 hour total test time).
8. Stop the ping test and record ping success rate as STA1_ping_success and STA2_ping_success.
9. Configure the STAs and DUT to the 802.11ac configuration, repeat steps 2 through 7.

Metrics (Pass/Fail Criteria)

In order to pass the test case, the recorded results SHALL meet the Pass/Fail Criteria, described as following:

A. Downlink throughput of the Peer STAs keeps stable in each frequency band with less than 20% deviation of the minimum sampling points by referring to the average throughput during the measurement of 24 hours;
B. For every hour, PER of the Ping test SHALL be less than 0.1 %.

6.5 Stability/Robustness

6.5.2 AP Coexistence

AP coexistence test intends to verify Wi-Fi device performance with existence of alien AP. The alien AP in the test SHALL support the same Wi-Fi standard (802.11n/802.11ac).

Setup

1. A host sends/receives the Ethernet packets/IP packets to DUT. The Peer STA receives/sends the Wi-Fi packets from/to the DUT through air interface.
2. The host SHALL send the Ethernet packets/IP packets at the maximum rate which the DUT can achieve theoretically.
3. A set of Wi-Fi interfaces/radios, supporting the same Wi-Fi standard (802.11n/802.11ac), are used to generate the alien network interference. The QoS settings on the alien network SHALL match those on the DUT.
4. TCP connection SHALL be used for Ethernet packet transmission in the test.

Procedure

1. Configure the working mode of DUT to 802.11n, operating frequency band to 2.4 GHz with default configuration. Allow peer STA registers the DUT.
2. The channel of alien network SHALL be set to the same channel as DUT.
3. Keep the alien network radios shutdown (not transmitting any signals).
4. Wait for 10 seconds. Measure the downlink TCP throughput to peer STA, using a test time of 120 seconds. Record this measurement as THROUGHPUT_SHORT_DUT.
5. Enable the alien network radios. The alien network will transmit beacon frames according to the default configuration settings.
6. Wait for 10 seconds. Measure the downlink TCP throughput to peer STA, using a test time of 120 seconds. Record this measurement as THROUGHPUT_SHORT_DUT_1.
7. Configure the alien network to utilize 50% of the available "air time". This can be achieved by packet transmission using the alien network of 1500-byte packets at one of the following rates, depending on the configuration used for the alien network and the wireless MSC rate selected by the transmitter: 32 Mbps for 802.11n 20MHz channels with 1 spatial stream, 90 Mbps for 802.11ac 40MHz with 1 spatial stream, 195 Mbps for 802.11ac 80MHz with 1 spatial stream, 65 Mbps for 802.11n 20MHz channels with 2 spatial streams, 180 Mbps for 802.11ac 40MHz with 2 spatial streams, or 390 Mbps for 802.11ac 80MHz with 2 spatial streams.
8. Wait for 10 seconds. Measure the downlink TCP throughput to peer STA, using a test time of 120 seconds. Record this measurement as THROUGHPUT_SHORT_DUT_2.
9. Change the channel configuration of alien AP according to Table 26 until all the configuration has been tested. Repeat Step 8. Stop the packet transmission for alien network.
10. Shut down the radios on the alien network.
11. Configure the working mode of DUT to 802.11ac, operating frequency band to 5 GHz, and channel bandwidth to 80 MHz. Allow peer STA registers the DUT.
12. Repeat Steps 2-11. Record the corresponding average throughput for new working frequency.

Metrics (Pass/Fail Criteria)

In order to pass the test case, the recorded results SHALL meet the Pass/Fail Criteria, described as following:

A. The average throughput measured SHALL satisfy the requirements in Table 27:

Table 27 Pass/Fail criteria for AP coexistence test

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)	Throughput requirement referred to the No-Alien-device-turn-on				
			No alien device turn on	Alien AP turn on	Alien network working (same channel)	Alien network working (over-lapping channel)	Alien network working (adjoining channel)
802.11n (Nss=2)	802.11n (Nss=2)	20	-	<5%	<60 %	<60%	<5%
802.11ac (Nss=2)	802.11ac (Nss=2)	80	-	<5 %	<60 %	<60 %	<5 %
Note: Percentage indicates the performance deduction referred to the case with no alien device turned on.							

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