

TR-398

Wi-Fi In-Premises Performance Testing

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Corrigendum History

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Executive Summary

TR-398 provides a set of performance test cases with pass/fail requirements for 802.11n/ac implementations according to Institute of Electrical and Electronics Engineers (IEEE) specification 802.11ac [1].

The primary goal of WT-398 Issue 1 is to provide a set of test cases and framework to verify the performance between Access Point (AP) (e.g., a CPE with Wi-Fi) and one or more Station (STA) (e.g., Personal Computer [PC], integrated testing equipment, etc.). The test cases are defined for a Device Under Test (DUT – AP only), tested against a or a set of STA.

Technical contents of TR-398 test plan include test setup information, equipment configuration requirements, test procedures, and pass/fail requirements for each test case.

TR-398i1 Corrigendum 1 makes a correction to Table 15, fixing a copy error created during the publication process. During the final publication process, a pre-release version of the document was made available that contained this error. Due to the proliferation of the errored, pre-release version through the Internet and search engines, the Broadband Forum has provided this corrigendum document to ensure users are made aware of the copy error.

1 Purpose and Scope

1.1 Purpose

TR-398 provides a set of performance test cases with pass/fail requirements for 802.11n/ac implementations according to IEEE specification 802.11ac [1]. The corresponding certification programs of interoperability are “Wi-Fi 4” and “Wi-Fi 5” for 802.11n and 802.11ac in Wi-Fi Alliance, respectively.

The primary goal of WT-398 Issue 1 Corrigendum 1 is to provide a set of test cases and framework to verify the performance between AP (e.g., a CPE with Wi-Fi) and one or more STA (e.g., PC, integrated testing equipment, etc.). The test cases are defined for a Device Under Test (DUT – AP only), tested against a or a set of STA. The DUT SHOULD NOT be a reference design and SHOULD contain the necessary system functionality to execute this test plan (see section 5)

Technical content in this test plan includes test setup information, equipment configuration requirements, test procedures, and pass/fail requirements for each test case. Specific manufacturer information for test and measurement has not been included in this document, except in cases where the selection or use of alternate equipment could negatively impact the results of the testing.

1.2 Scope

This Technical Report intends to provide a performance test plan for “IEEE standard for Information technology-Telecommunications and information exchange between systems Local and metropolitan area networks- Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications specification”. WT-398 Issue 1 Corrigendum 1 is specifically developed for 802.11n/ac compliant access point devices. The performance of Wi-Fi station (STA) is not in the scope of this project.

WT-398 Issue 1 Corrigendum 1 is intended to address a common set of performance test cases according to in-home scenarios that can be applied to different deployment. The performance test cases are intended for the access point, to verify:

- 1) RF capability
- 2) Throughput performance
- 3) Spatial consistency
- 4) Airtime fairness
- 5) Connection capability
- 6) Stability/Robustness

2 References and Terminology

2.1 Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found in RFC 2119 [2].

SHALL	This word, or the term “REQUIRED”, means that the definition is an absolute requirement of the specification.
SHALL NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the term “RECOMMENDED”, means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the term “OPTIONAL”, means that this item is one of an allowed set of alternatives. An implementation that does not include this option SHALL be prepared to inter-operate with another implementation that does include the option.

2.2 References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.

A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document	Title	Source	Year
[1] 802.11ac	<i>IEEE standard for Information technology- Telecommunications and information exchange between systems Local and metropolitan area networks- Specific requirements Part 11: Wireless LAN Medium Access Control (MAC)</i>	IETF	1997

		<i>and Physical Layer (PHY) Specifications specification</i>		
[2]	RFC 2119	<i>Key words for use in RFCs to Indicate Requirement Levels</i>	IEEE	2016
[3]	P.2040-1	<i>Effects of building materials and structures on radiowave propagation above about 100 MHz</i>	ITU-R	2015
[4]	Report	<i>Building Materials and Propagation</i>	Ofcom	2014

2.3 Definitions

The following terminology is used throughout this Technical Report.

CPE	Customer Premises Equipment. In the context of this Technical Report, CPE is used for any device or other equipment placed inside the premises of a Service Provider’s customer.
Wi-Fi	A name created and trademarked by the Wi-Fi Alliance to describe technology based on IEEE 802.11 standards.

2.4 Abbreviations

This Technical Report uses the following abbreviations:

AP	Access Point
DL	Downlink
DTIM	Delivery Traffic Indication Message
DUT	Device Under Test
GE	Gigabit Ethernet
GUI	Graphical User Interface
ICMP	Internet Control Message Protocol
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IPv4	Internet Protocol version 4
LAN	Local Area Network
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MIMO	Multi-input Multi-output
MTU	Maximum Transmission Unit
MU-MIMO	Multi-user MIMO
PC	Personal Computer

PER	Packet Error Rate
PHY	Physical Layer
PSDU	PHY Service Data Unit
QoS	Quality of Service
RF	Radio Frequency
SSID	Service Set Identifier
STA	Station
TCP	Transmission Control Protocol
TR	Technical Report
Tx	Transmission
UL	Uplink
UDP	User Datagram Protocol
VLAN	Virtual Local Area Network
WA	Work Area
WLAN	Wireless Local Area Network
WMM	Wi-Fi Multimedia

3 Technical Report Impact

3.1 Energy Efficiency

TR-398 has no impact on Energy Efficiency.

3.2 Security

TR-398 has no impact on Security.

3.3 Privacy

Any issues regarding privacy are not affected by TR-398.

4 Equipment Features

4.1 Device Under Test (DUT) and Station (STA)

4.1.1 Device Information

Table 1 and Table 2 are intended to provide test engineers and readers of the test report with sufficient information about the DUT and connected STAs in order to assure repeatability of results and to allow for accurate comparisons of reported test results. The information defined in the tables SHALL be provided to the test engineer prior to the start of the testing and SHALL be included as part of the test report. All fields SHALL be populated; if an item is not applicable to the DUT or connected STAs, the item MAY be marked as “Not Applicable” .

Table 1 DUT Information

DUT system vendor	
DUT system firmware version	
DUT chipset vendor	
DUT chipset firmware version	

Table 2 STA Information

STA type (e.g., PC, mobile phone, etc.)	
STA system vendor	
STA system firmware version	
STA chipset vendor	
STA chipset firmware version	
Supported IEEE specification by STA	
Note: Multiple tables of STAs SHALL be created to record the information of STAs with different capability (e.g., legacy STA that supports only 802.11a/b/g).	

4.1.2 Management of the DUT and STA

The DUT SHALL support a DUT Northbound management protocol or local Graphical User Interface (GUI) that allows the ability to configure and retrieve the settings defined in 5.3 in this test plan. The management protocol is DUT vendor discretionary.

The STA SHALL support a STA Southbound management protocol that is required for execution of this test plan except as required to configure the STA to pass Ethernet traffic between the STA and Local Area Network (LAN) interface(s).

4.2 Testing Equipment and Components

This section includes tables to record information of testing equipment and components that are used in the test. The information defined in the tables SHALL be provided to the test engineer prior to the start of the testing and SHALL be included as part of the test report. All fields SHALL be populated; if an item is not applicable to the DUT or connected STAs, the item MAY be marked as “Not Applicable”.

Table 3 Traffic Generator/Analyzer Information

Manufacturer	
Equipment model	
Code version	

Table 4 Attenuator Information

Manufacturer	
Component model	
Supported frequency range	
Attenuation value used in the test	

Table 5 Test Chamber Information

Manufacturer	
Equipment model	

Table 6 Additional Antenna Information

Manufacturer	
Component model	
Where it is used (on test chamber/traffic analyzer/etc.)	

5 Test Environment

The Wi-Fi performance test environment can easily be impacted by external factors and the environment, such as existing office Wi-Fi systems, or nearby appliances (e.g., microwave ovens). The construction of the test environment used by this test plan SHALL be constructed in a fashion to mitigate the impact of these external factors. The test environment SHALL meet the requirements outlined in this section for all tests within this test plan.

5.1 Test Configuration

5.1.1 Ethernet/IP Traffic Setup

The LAN interface(s) used for transmission of test traffic SHALL be a Gigabit Ethernet port(s), supporting speeds of at least 1 Gbps. The Peer Stations (STAs) SHALL send/receive Wi-Fi packets to/from the DUT air interface or coax interface (if it is required). Packet generation, reception, and analysis SHALL be done using testing software or a traffic generator capable of generating stateful Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) traffic with fixed (controlled) packet size.

If the test case requires test traffic larger than 1 Gbps at the LAN interface, multiple Gigabit Ethernet ports SHALL be employed to fulfill the test traffic demand in the test. In this case, identical traffic streams with same Quality of Service (QoS) setting SHALL be injected to Gigabit Ethernet ports, respectively.

If the DUT supports Ethernet port with higher rate than 1Gbps (e.g., 2.5G, 5G, or 10G Ethernet, etc.), no additional port is used in the testing.

Figure 1 shows the basic setup for passing Ethernet/IP traffic through the DUT and single STA. Appendix I shows the instantiations of the test setups. The Packet Generator/Analyzer MAY be a discrete device from the STA, or the Packet Generator/Analyzer may be embedded directly on the STA device. The Packet Generator/Analyzer SHALL NOT be combined with the DUT and SHALL be a discrete device running the testing software to generate/receive the packets for DUT.

Note: The Physical Layer Test Setup shown in Figure 1 contains any specific test setup(s) or equipment that may be required within the Wi-Fi link, such as a channel simulator, attenuators, etc.

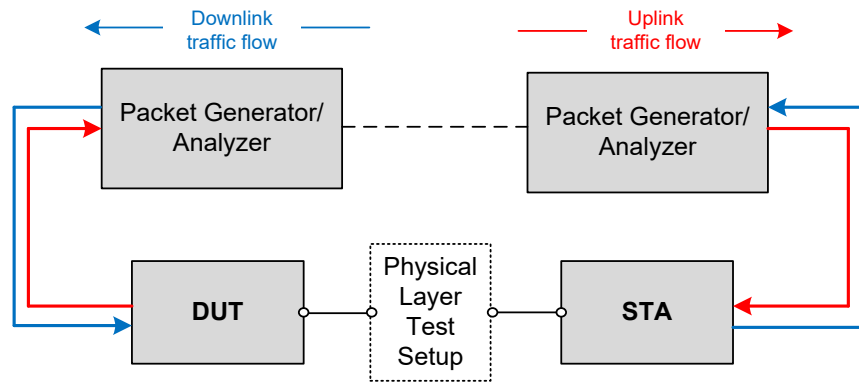


Figure 1 Test setup for performance testing for single STA

The DUT and STA SHOULD support the following requirements to enable these tests.

The DUT SHOULD support:

1. Forwarding of Ethernet/IP traffic between the Wi-Fi interface(s) and the northbound Ethernet interface, based on MAC learning or Virtual Local Area Network (VLAN) markings.
2. Allocating local IP address for STA through physical interface (air or coax cable) and for traffic generator.

The STA SHOULD support at least one of the following configurations:

1. In case the Packet Generator/Analyzer is used for STA, the interfaces between STA and Packet Generator/Analyzer SHALL fulfill the traffic flow requirement and not impact the performance test.

5.1.2 Ethernet Traffic Flow Generation

This section provides requirements for TCP and UDP setting in order to create consistent flow pattern while different testing software, operating system or independent equipment are utilized in the test.

Where the Packet Generator/Analyzer is used to implement the traffic throughout measurements within this test plan, the following settings SHALL be used to configure the traffic generator. All throughput measurements SHALL be the layer 4 (payload rate) for the TCP or UDP traffic streams.

- Common setting for both TCP and UDP:
 - a) Establish TCP/UDP link through IP pairing before generation of traffic flow, i.e., setting up the IP address of DUT and STA to make sure that all of the devices are in the same LAN.
 - b) The flow generation SHALL base on IPv4.
 - c) Create 5 and 1 measurement streams between DUT and each STA for TCP and UDP,

respectively. The throughput between the DUT and STA is the summation of all the measurement streams.

- d) No delay SHALL be reserved after starting the measurement.
 - e) No rate limitation SHALL be set for the TCP/UDP flow.
 - f) The data sent over the TCP SHALL not be compressed.
- Setting for TCP:
 - a) TCP window size SHALL be set as 64KB.
 - b) A code file (file size of 100000 bytes for 2.4GHz testing and 10000000 bytes for 5 GHz testing) transaction SHALL be simulated in the TCP connection. This transaction SHALL be continuously conducted during the measurement time.
 - c) Each fragment of the file is send continuously to operating system that the test software runs over. The TCP payload size SHOULD be determined by the operating system.
 - Setting for UDP:
 - a) A code file (file size of 730000) transaction SHALL be simulated in the UDP connection. This transaction SHALL be continuously conducted during the measurement time.
 - b) The UDP payload size SHALL be set as 1460 bytes.
 - Note:** This leads to 1472 bytes Ethernet frame size. The size of the transmitted data is 1460 bytes with 20-bytes IP header and 8-byte UDP header.

5.1.3 Example: Ethernet traffic generation by iPerf3

Where the open source program iPerf3 is used to implement the traffic throughout measurements within this test plan, a predetermined set of command line flags SHALL be used to start and run the iPerf3 program as documented below, unless a specific test case provides alternate commands, to ensure consistency within testing.

The iPerf3 program runs as either a client or server process, where the server acts as a traffic reflector/recipient, while the client is responsible for the definition of specific tests/measurements to perform between the client and server processes. For the purposes of definitions below, the commands assume the iPerf3 server process is running on the AP side and the client process is running on the STA side of the Wi-Fi link. The processes MAY be run on either side of the link during testing, provided the uplink/downlink definitions are consistently maintained.

The iPerf3 server SHALL be started with the command *iPerf3 --server*.

Specific client commands for each test scenario are located below. An explanation of the commands follows, for information only.

SERVER_IP address is the IP address of the system where the server is running.

TEST_TIME is the length of time the measurement will run for. This is set within each test case below.

The *bitrate* parameter is set to zero, to instruct iPerf3 to attempt to determine (measure) the maximum throughput between the client and server.

The *parallel* parameter instructs iPerf3 to run five measurement streams in parallel between the client and server. This improves the overall accuracy of the measurement. The individual bandwidth used by each stream can vary, and the summation/average is used to calculate the overall measurement.

The *reverse* parameter instructs iPerf3 to measure the bandwidth from the server to the client. The default behaviour performs the measurement from the client to the server.

The *udp* parameter instructs iPerf3 to use the UDP transport instead of the default TCP transport.

The *omit 2* parameter instructs iPerf3 to “discard” the first 2 seconds of the measurement, to avoid inclusion of TCP slow start, etc.

Additional commands MAY be used to alter/direct logging or format of results, such as the *--logfile* or *--json* options. However, any additional command SHALL NOT alter the operation or measurement traffic used by the program.

The iPerf3 programs SHALL be run on a Linux based system, using a kernel version of 4.14 or newer. The system SHALL include at least one processor, with two cores, of at least 2 GHz.

5.1.3.1 Commands for Downlink Testing

5.1.3.1.1 TCP Traffic Throughput

```
iPerf3 --client <SERVER_IP> --time <TEST_TIME> --bitrate 0 --parallel 5 --reverse --omit 2
```

5.1.3.1.2 UDP Traffic Throughput

```
iPerf3 --client <SERVER_IP> --time <TEST_TIME> --bitrate <BITRATE> --reverse --udp --omit 2
```

5.1.3.2 Commands for Uplink Testing

5.1.3.2.1 TCP Traffic Throughput

```
iPerf3 --client <SERVER_IP> --time <TEST_TIME> --bitrate 0 --parallel 5 --omit 2
```

5.1.3.2.2 UDP Traffic Throughput

```
iPerf3 --client <SERVER_IP> --time <TEST_TIME> --bitrate <BITRATE> --udp --omit 2
```

5.2 Test Setup Characteristics

Test results obtained as a result of testing performed in accordance with WT-398 Issue 1 SHALL contain the information described in sections 5.2.1.

5.2.1 Shielded Test Chamber

Several tests specify an anechoic shielded chamber environment. Within this test environment, the ambient noise + signal power SHALL be less than -100 dBm total in an 80 MHz bandwidth at the working channel frequency, as measured by a spectrum analyzer with receive sensitivity of at least -103 dBm in the same bandwidth. This condition guarantees no false back off or contention take place and facilitates the correct performance measurement in extreme cases (e.g., performance testing with large attenuation).

5.2.1.1 Temperature and Humidity

The ranges of temperature and humidity of the test facility, over the entire time tests are conducted, SHALL be recorded as the high and low values observed during testing (see Table 7) and SHALL be included as part of the test report. The temperature SHOULD be within 21 ± 5 °C. The humidity SHOULD be between 20% and 60%.

Table 7 Temperature and Humidity Range of Test Facility

Parameter	High	Low
Temperature		
Humidity		

5.2.2 Distance and Test Channel Realization

To facilitate repeatable testing and support the application of absolute performance requirements, the wireless channel between the DUT and STA(s) needs to be well controlled. The test setup implemented SHALL meet the requirements within this section. Various methods to create and control this environment exist and MAY be used for the support of the testing defined in this document, provided the test setup implemented meets the requirements within sections.

The peer STAs are separated from the DUT by the Wi-Fi test channel. This separation can be defined as a specific distance, or as a specific path-loss. The test report SHALL indicate how the Wi-Fi test channel is established. The specific separation is defined in each test, however:

- a. If distance is used, then the peer STA SHALL be placed at the same height as the DUT. Additionally, the test report SHALL indicate the rotational orientation of both the STA and DUT. Both STA and DUT SHALL be placed in their “upright” position, as defined by the manufacturers.
- b. If external antenna is used, the direction of the antenna SHALL be adjusted perpendicularly to the horizontal plane.
- c. If path-loss is used, then the peer STA SHALL be separated from the DUT by the equivalent free space path loss at the working frequency. Free space path loss between isotropic antennas is expressed as $P_L (dB) = 20 \text{ Log}_{10} (f_GHz) + 20 \text{ Log}_{10} (d_meters) + 32.45$. For example, at 2.4 GHz the path loss equivalent to a 1-meter separation is 40 dB, and at 5.2 GHz the path loss is 46.8 dB. The attenuation value for testing SHALL be rounded to the nearest whole dB value.
- d. A channel emulator (e.g., test equipment) MAY be used to implement the test channel.
- e. If the test channel is created using attenuators or a channel emulator, the test equipment SHALL support at least the same number of independent channels as the number of spatial streams being tested.
- f. The attenuators used to create signal attenuation SHALL perform flat attenuation in the frequency bandwidth.

There are several important parameters and conditions that define a test configuration. These are:

- The test environment SHALL be free from interference, and,
- There is a certain path loss between the devices, and,
- There is the ability to modify that path loss in a controllable and repeatable fashion.

There are several ways that such an environment could be implemented. Two possible options are shown below; either of these methods MAY be used to implement the testing defined within the document, or any other method could be used as long as it can be shown to meet the requirements of these sections. To simplify this document, each test case includes only a test setup figure or diagram based on the single chamber implementation.

Within a shielded chamber, RF signals will reflect from the chamber walls, and can appear as interference to the devices within the chamber. Any chamber used in the test plan SHOULD attenuate the reflections by at least 20 dB to minimize the impact of these reflections.

5.2.2.1 Single Chamber Implementation

In a single chamber implementation of the test environment, there is a single shielded chamber used to provide the interference-free environment, and physical separation is used to provide path-loss between devices. For path-loss modification, attenuators are placed on the STA antenna ports.

Note that one difficulty in this implementation is in gaining access to the STA antenna ports, which will not be possible with all STAs.

In this implementation, it is anticipated the single chamber provides the required shielding to meeting the ingress noise requirements. The chamber SHALL be large enough to meet the spacing requirements defined in each test case.

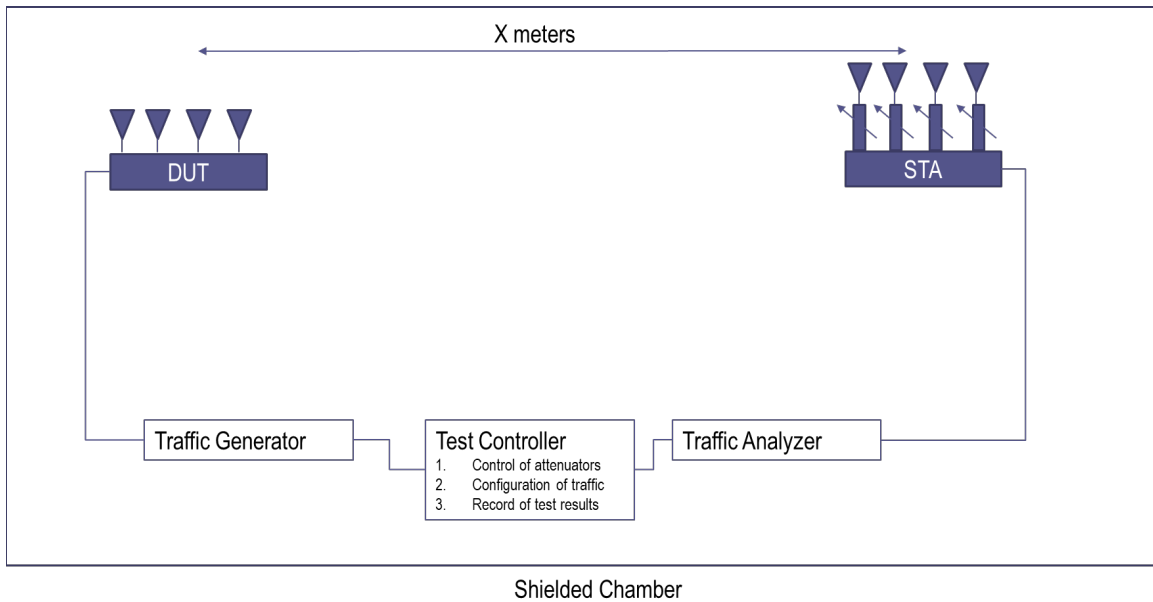


Figure 2 Single Chamber Implementation

5.2.2.2 Multiple Chamber Implementation

In a multiple chamber implementation of the test environment, there are multiple chambers used to provide the interference-free environment. The RF separation between the devices is composed of the free-space path-loss inside the chambers, the RF cabling that connects the boxes, and the variable attenuation. Note that in this implementation the variable attenuation is available without access to the DUT or STA antenna ports. Additionally, a channel fading or multi-path emulator can also be inserted into the RF cable path to better align the test results with those observed in a purely free space environment. The distance ($\text{Distance}_{\text{DUT_Probe}}$) between the probe antennas and the DUT/STA SHALL be less than 0.5 meter.

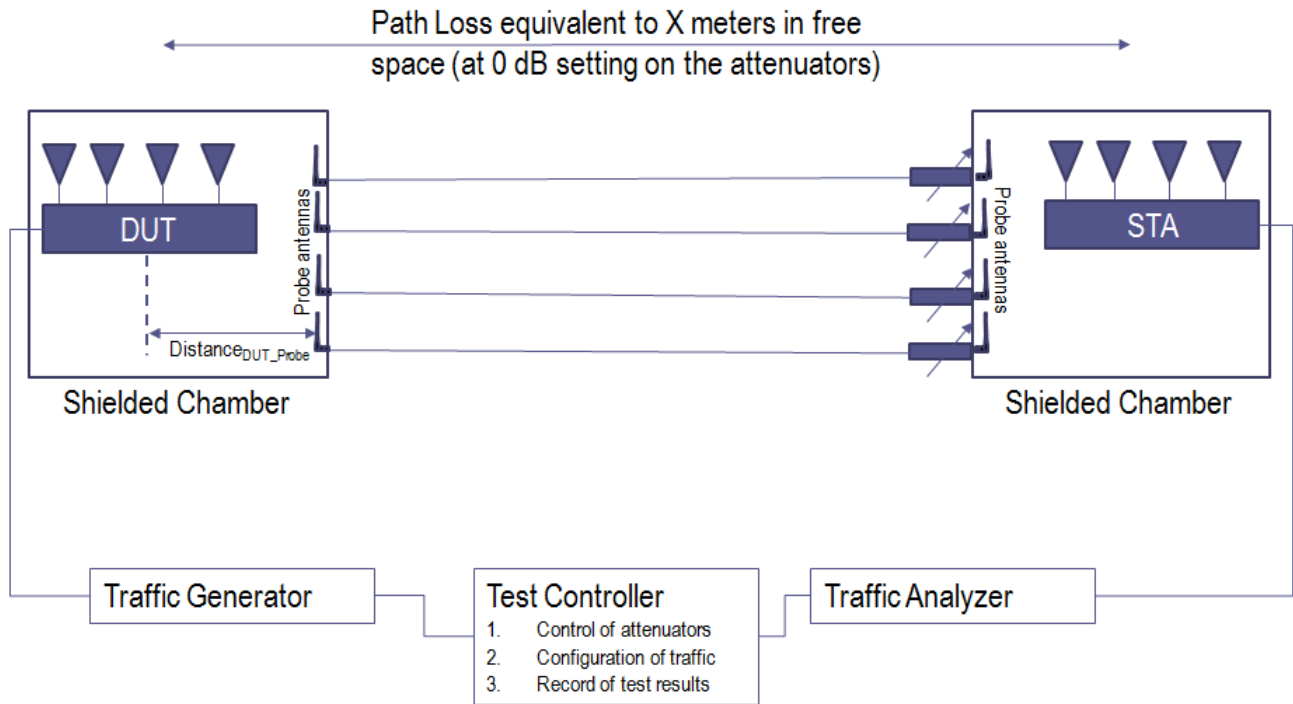


Figure 3 Multiple Chamber Implementation

5.2.3 STA Requirements

The Wi-Fi Station (STA) acts as a peer device within transmitting and receiving data traffic from the Wi-Fi Access Point (DUT). The STA devices used for testing SHALL meet the requirements of this section.

The STA(s) SHALL have at least the same Wi-Fi physical layer capability (i.e., maximum spatial streams supported and antenna number) as the DUT unless the test case specifies the capability of the STA used in the test. The STA(s) MAY support physical layer capabilities exceeding those of the DUT.

The STA device(s) used for testing MAY be real products (i.e., a Laptop or Phone) or MAY be dedicated test and measurement equipment that emulates the behaviour of standard Wi-Fi station.

For tests that required multiple STA devices, the devices MAY be multiple discrete devices or the multiple STA devices may be emulated by a single test and measurement device.

5.3 Device Under Test (DUT) settings

5.3.1 DUT Requirements

The DUT SHALL be able to support at least 2 spatial streams ($N_{ss} \geq 2$ as defined in the 802.11n/ac specification) for Wi-Fi packet transmission.

If the DUT supports multiple Wi-Fi channels, the DUT SHALL select channel 6 for 2.4 GHz frequency band and channel 36 for 5 GHz frequency band. The test report SHALL document the channel used in the test plan. If the channel is not supported due to regulatory issue, a neighbor channel SHALL be selected accordingly. The peer STA/STAs register to the DUT to establish the link.

Note: A fixed channel facilitates good repeatability across the tests in labs.

DUT SHALL NOT use any proprietary implementation beyond the scope of Wi-Fi standard [1], e.g., 256QAM modulation for 802.11n, etc.

5.3.2 SSID setting

The setting for Service Set Identifier (SSID) SHALL be configured as defined in Table 8. SSID for 2.4GHz and 5GHz band SHALL be set up separately.

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
<p>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.</p> <p>Note 2: Defined by test agent.</p>	

5.3.3 Work setting

5.3.3.1 2.4 GHz band

All the DUT supporting 802.11n SHALL set the operating frequency band as 2.4 GHz. The default setting SHALL be configured as defined in Table 9. Unless otherwise specified in the specific test, the DUT SHALL have only the operating frequency under test enabled (not allow to switch to 5 GHz frequency band during the test if the device is configured in 2.4 GHz band).

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
<p>Note 1: 100% is corresponding to 20 dBm, this value indicates the aggregated power of all the chains used for communication by air-interface.</p> <p>Note 2: Defined by test agent or automatically selected by the DUT.</p>	

All of the test cases in this test plan for 802.11n SHALL be conducted in the working frequency of 2.4 GHz. The test plan for 802.11n working in 5 GHz is left for further study.

5.3.3.2 5 GHz band

All the DUT supporting 802.11ac SHALL set the operating frequency band as 5 GHz. The default setting for work mode SHALL be configured as defined in Table 10. If the DUT support dual band in 5GHz, two work settings SHALL be set up separately. Unless otherwise specified in the specific test, the DUT SHALL have only the operating frequency under test enabled (not allow to switch to 2.4 GHz frequency band during the test if the device is configured in 5 GHz band).

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 Performance Tests

Chapter 6 includes a set of test cases for verification of Wi-Fi performance. Test cases are categorized into 5 sets (RF capability, Baseline performance, Coverage, Multiple STAs performance, and Stability/Robustness).

6.1 RF capability

6.1.1 Receiver Sensitivity Test

6.1.1.1 Introduction

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.

This test SHALL be OPTIONAL for the test plan.

6.1.1.2 Setup

1. The test setup (shown in Figure 4) SHALL utilize a shielded chamber (see section 5.2.1 and 5.2.2).
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 4096 octets in STA [3].
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.

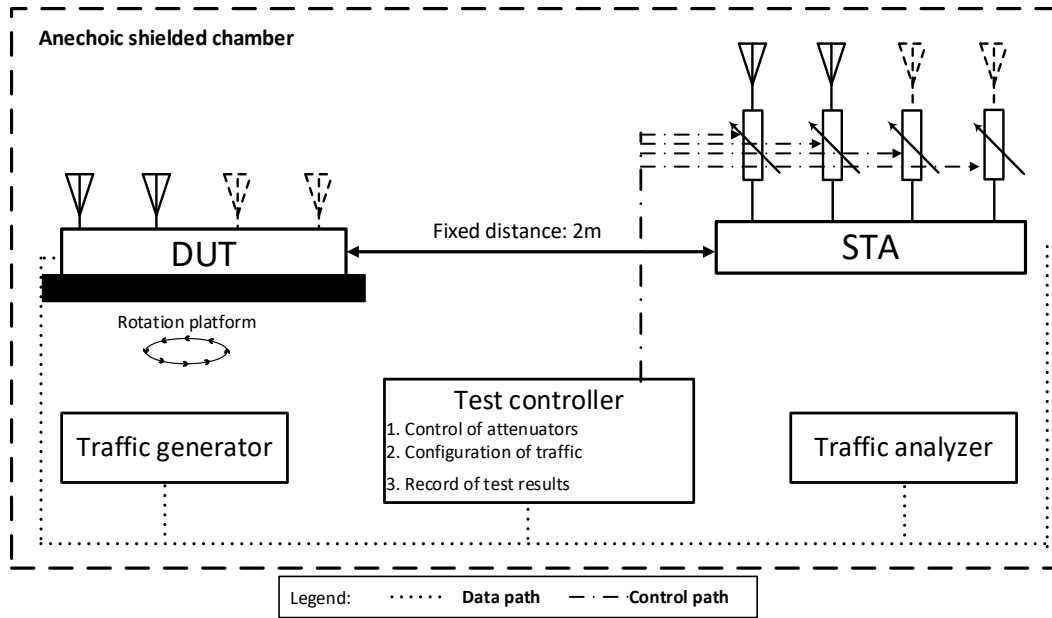


Figure 4 Test Setup for Receiver Sensitivity

6.1.1.3 DUT Configuration

The test SHALL be run using each of the configurations from Table 11 below supported by the DUT. The test SHALL be conducted to the configurations that the DUT supports.

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 (N _{ss} =1) only.	

Note: The test plan considers the common configurations to reduce the testing complexity.

6.1.1.4 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 0 dB.
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.

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
Note 1: The MCS rates are defined in Ref [3]. Note 2: Data rates specified for Long Guard interval, while testing may be performed using either guard interval, as supported by the DUT.				

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
Note 1: The MCS rates are defined in Ref [3]. Note 2: Data rates specified for Long Guard interval, while testing may be performed using either guard interval, as supported by the DUT.				

6.1.1.5 Metrics (Pass/Fail Criteria)

1. 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 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

6.2.1.1 Introduction

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.

This test SHALL be MANDATORY for the test plan.

6.2.1.2 Setup

1. The test setup (shown in Figure 5) SHALL be located in anechoic shielded chamber (see section 5.2.1 and 5.2.2).
2. 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).
3. 32 STAs are prepared and associated to DUT during the test.
4. UDP connection SHALL be used for Ethernet packet transmission in the test.

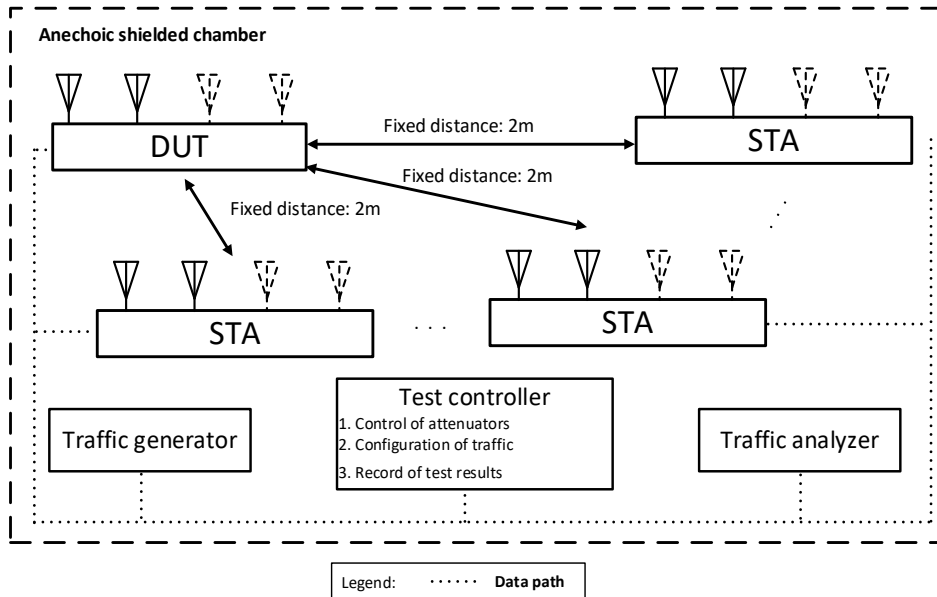


Figure 5 Test setup of Maximum Connection Test

Note: The test result may be slightly affected by the capability of Peer STA. It is recommended STA used in the test have chipsets from at least 2 different vendors.

6.2.1.3 DUT Configuration

The test SHALL run under the following configuration:

1. The DUT works in different modes if applicable:
 - a) 802.11n
 - b) 802.11ac

6.2.1.4 Procedures

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.

6.2.1.5 Metrics (Pass/Fail Criteria)

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

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%.

6.2.2 Maximum Throughput Test

6.2.2.1 Introduction

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).

This test SHALL be MANDATORY for the test plan.

6.2.2.2 Setup

1. The test setup (shown in Figure 6) SHALL be located in the anechoic shielded chamber (see section 5.2.1 and 5.2.2).
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.

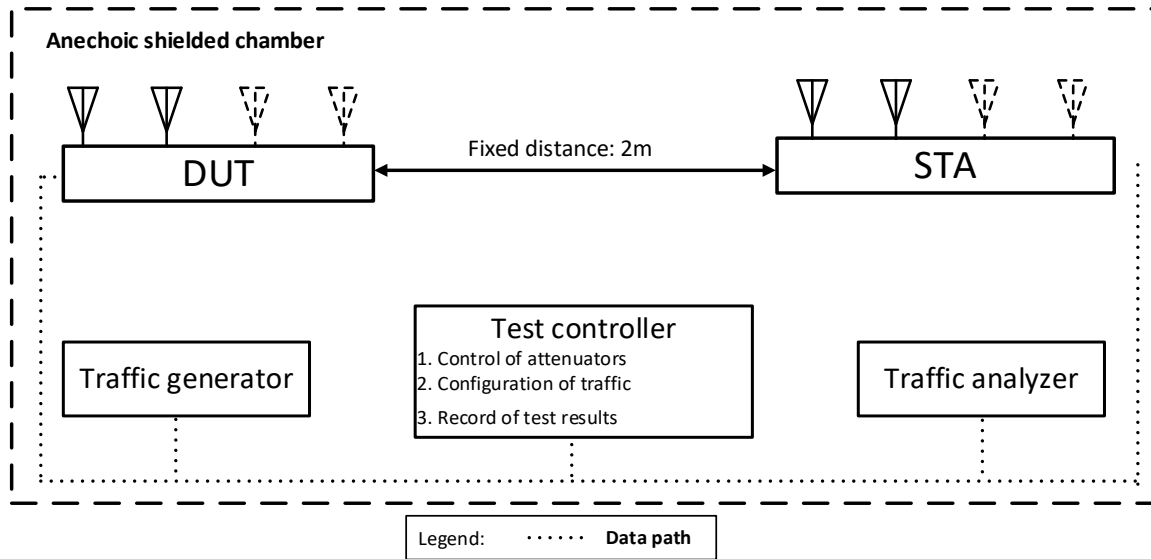


Figure 6 Test setup of Maximum Throughput Test

6.2.2.3 DUT configuration

The test SHALL run under the following configuration:

1. The DUT works in different modes:
 - a) 802.11n
 - b) 802.11ac

The test case SHALL be conducted on all the applicable modes of the DUT.

6.2.2.4 Procedures

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.

Note: The test result MAY be slightly affected by the capability of Peer STA. The test can be conducted with different peer STAs with chipsets from different vendors. The calculated average throughput then can be averaged again in the dimension of chipset.

6.2.2.5 Metrics (Pass/Fail Criteria)

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

1. 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

6.2.3 Airtime Fairness Test

6.2.3.1 Introduction

Wi-Fi signal transmission can be seen as a multicast process since the STAs involved share the transmission medium. Air interface becomes a rare resource when dense connections or high throughput requests exist. Channel condition determines the MCS selection, therefore affecting the data throughput. In general, long distance to travel or obstacle penetration leads to larger attenuation, which makes the data rate in a low level. Occupying excessive air time of STA with small MCS will be unfair to the STAs with large MCS (here, assuming the QoS requirement is similar) when the air resources have already run out.

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

This test SHALL be MANDATORY for the test plan.

6.2.3.2 Setup

1. The test setup (shown in Figure 7) SHALL locate in the anechoic shielded chamber (see section 5.2.1 and 5.2.2).
2. 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).

3. DUT is set to 2.4 GHz operating frequency band with default configuration in the beginning of the test.
4. A Traffic Generator/Analyzer, sending the Ethernet packet to each peer STA, connects to the LAN interface (e.g., GE port) of the DUT.
5. The TCP connection SHALL be used for Ethernet packet transmission in the test.

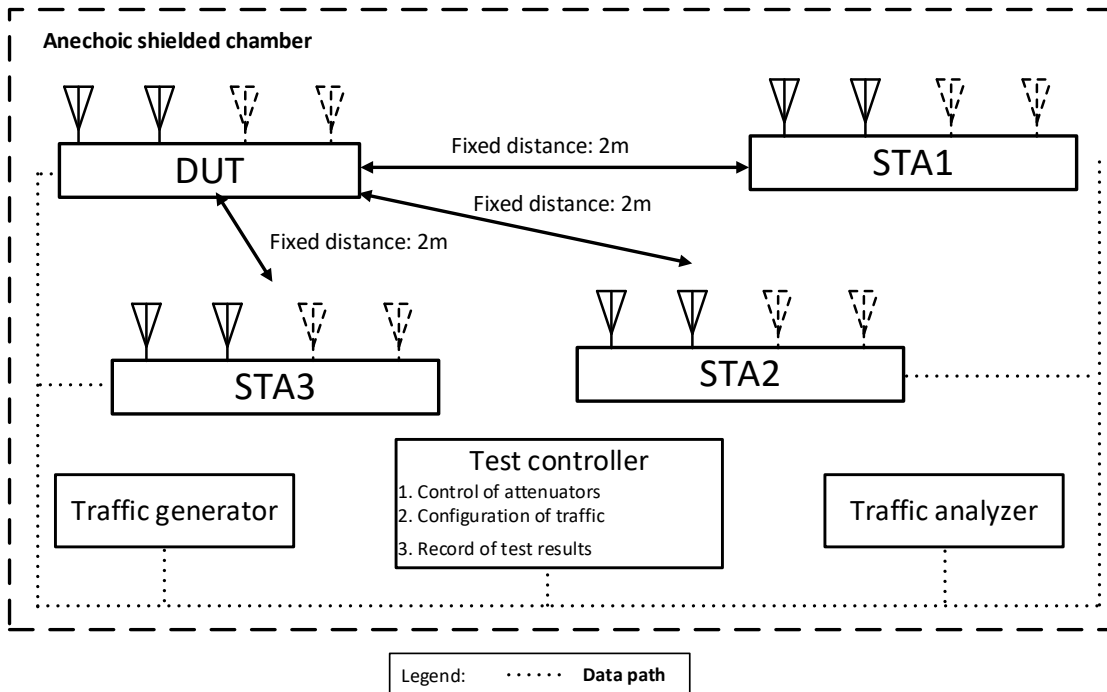


Figure 7 Test setup of Airtime Fairness Test

6.2.3.3 DUT Configuration

The test SHALL run under the default configuration.

6.2.3.4 Procedures

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.

6.2.3.5 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 throughput variation of DUT SHALL meet:

For the test in 2.4 GHz frequency band:

- 1) STA1_throughput_1 SHALL be within $(1\pm 5\%)*\text{Mean}(\text{STA2_throughput_1}, \text{STA1_throughput_1})$.
- 2) STA2_throughput_1 SHALL be within $(1\pm 5\%)*\text{Mean}(\text{STA2_throughput_1}, \text{STA1_throughput_1})$.
- 3) STA1_throughput_2 SHALL be within $(1\pm 15\%)*\text{Mean}(\text{STA2_throughput_1}, \text{STA1_throughput_1})$.
- 4) STA1_throughput_3 SHALL be within $(1\pm 15\%)*\text{Mean}(\text{STA2_throughput_1}, \text{STA1_throughput_1})$.

For the test in 5 GHz frequency band:

- 1) STA1_throughput_1 SHALL be within $(1\pm 5\%)*\text{Mean}(\text{STA2_throughput_1}, \text{STA1_throughput_1})$.
- 2) STA2_throughput_1 SHALL be within $(1\pm 5\%)*\text{Mean}(\text{STA2_throughput_1}, \text{STA1_throughput_1})$.
- 3) STA1_throughput_2 SHALL be within $(1\pm 25\%)*\text{Mean}(\text{STA2_throughput_1}, \text{STA1_throughput_1})$.
- 4) STA1_throughput_3 SHALL be within $(1\pm 25\%)*\text{Mean}(\text{STA2_throughput_1}, \text{STA1_throughput_1})$.

- b) The throughput of DUT SHALL meet:

For the test in 2.4 GHz frequency band with $N_{ss} = 2$:

- 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 $N_{ss} = 2$:

- 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

6.3.1.1 Introduction

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.

This test SHALL be MANDATORY for the test plan.

6.3.1.2 Setup

1. The test setup (shown in Figure 8) SHALL locate in the anechoic shielded chamber (see section 5.2.1 and 5.2.2).
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 located in 2 meter to the DUT (46dB attenuation for 2.4 GHz, 53 dB attenuation for 5.2 GHz).
3. Additional attenuation is added in each RF chain of STA to simulate the incremental distance. The specific attenuation values used for testing are defined in 6.3.1.3.
4. 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.

Note 1: The attenuators need to be capable of providing discontinuous attenuation between 0dB ~ 63dB for the selected operating frequency band.

Note 2: A channel simulator, which emulates a specific real environment, MAY be used to replace the simple attenuators for more comprehensive test.

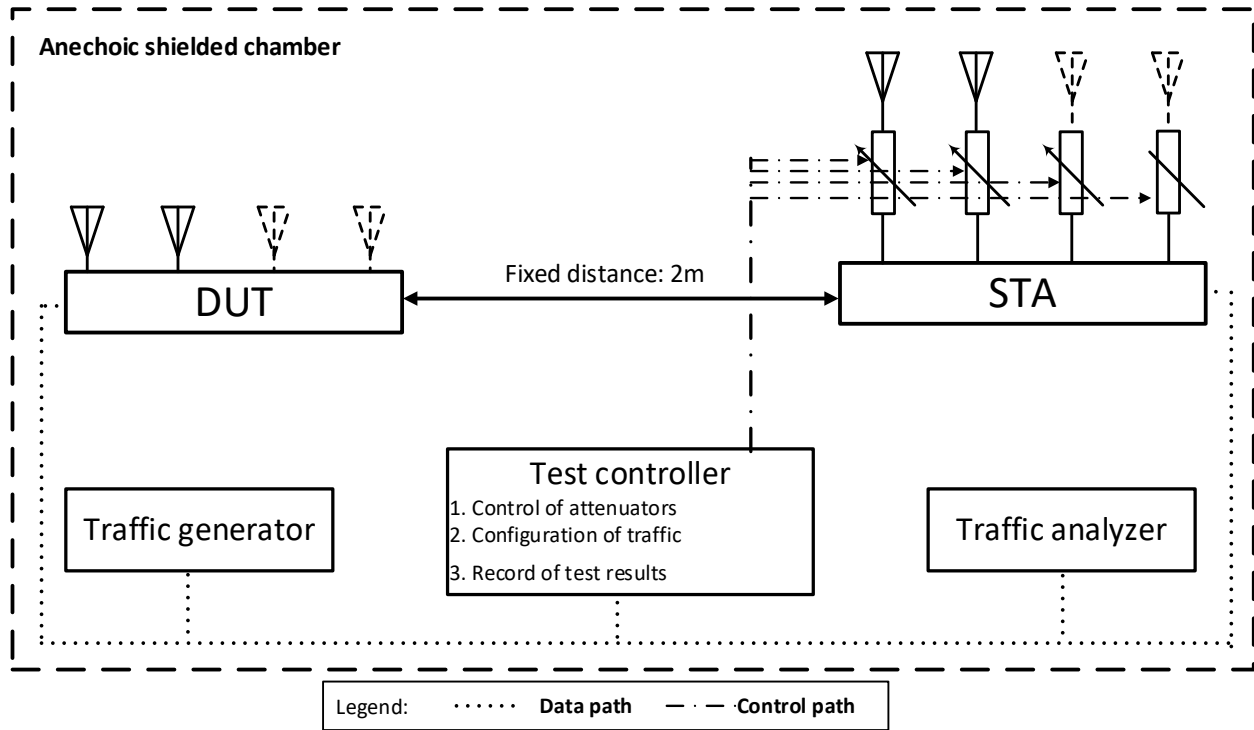


Figure 8 Test setup of Range Versus Rate Test

6.3.1.3 DUT Configuration

The test SHALL run under the following configuration:

1. General configuration for DUT/STA working mode, bandwidth and number of RF chains:

Table 17 General configuration for spatial consistency test

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)
802.11n (Nss=2)	802.11n (Nss=2)	20
802.11ac (Nss=2)	802.11ac (Nss=2)	80

2. Additional attenuation for STA RF chain during the test (see Table 18):

Table 18 Additional attenuation for STA RF chain during the test

Additional attenuation for test of 802.11n
0 dB (default), 10 dB, 21 dB, 24 dB, 27 dB, 30 dB, 33 dB, 36 dB, 39 dB, 42 dB, 45 dB, 48 dB, 51 dB, 54 dB, 57 dB, 60 dB, 63 dB.

Additional attenuation for test of 802.11ac
10 dB, 21 dB, 24 dB, 27 dB, 30 dB, 33 dB, 36 dB, 39 dB, 42 dB, 45 dB, 48 dB, 51 dB, 54 dB.

6.3.1.4 Procedures

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 according to 6.3.1.3 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 in section 6.3.1.3.

Note: The test result MAY be slightly affected by the capability of Peer STA. The test MAY be conducted with different peer STAs with chipsets from different vendors. The calculated average throughput then is averaged again in the dimension of chipset.

6.3.1.5 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
			39	80	80			
802.11ac (Nss=2)	802.11ac (Nss=2)	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			
			36	150	150			
			39	125	125			

6.3.2 Spatial consistency test

6.3.2.1 Introduction

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

This test SHALL be MANDATORY for the test plan.

6.3.2.2 Setup

1. The test setup (shown in Figure 9) SHALL locate in the anechoic shielded chamber (see section 5.2.1 and 5.2.2), 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. The concrete values are defined in 6.3.2.3.
4. TCP connection SHALL be used for Ethernet packet transmission in the test.

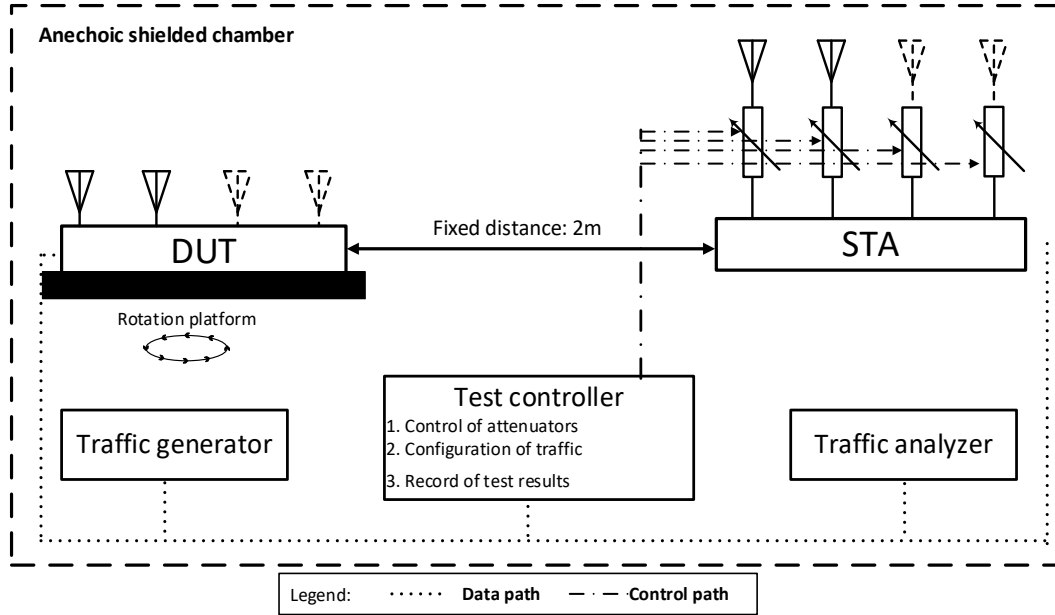


Figure 9 Test setup of Spatial Consistency Test

6.3.2.3 DUT Configuration

The test SHALL run under the following configuration if applicable:

1. General configuration for DUT/STA working mode, bandwidth and number of RF chains:

Table 20 General configuration for spatial consistency test

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)
802.11n (Nss=2)	802.11n (Nss=2)	20
802.11ac (Nss=2)	802.11ac (Nss=2)	80

2. Additional attenuation for STA RF chain during the test:
 - a) STA with strong signals: 10 dB @2.4GHz band, 10 dB @5GHz band;
 - b) STA with medium signals: 38 dB @2.4GHz band, 32 dB @5GHz band;
 - c) STA with weak signals: 48 dB @2.4 GHz band, 42 dB @5GHz band.

6.3.2.4 Procedures

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 according to 6.3.2.3 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.

Note: The test result MAY be slightly affected by the capability of Peer STA. The test MAY be conducted with multiple peer STAs with chipsets from different vendors. The calculated average throughput then is averaged again in the dimension of chipset.

6.3.2.5 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 at each angle SHALL satisfy the requirements in Table 21:

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

- b) The maximum variation during rotation SHALL satisfy the requirements in Table 22:

Note: The variation at each specific attenuation is calculated as the difference between the minimum throughput value and the average throughput value, divided by the average throughput value over all rotations.

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
11n (Nss=2)	11n (Nss=2)	20	30%	30%	30%	30%	30%	30%
11ac (Nss=2)	11ac (Nss=2)	80	40%	40%	40%	40%	40%	40%

6.4 Multiple STAs Performance

6.4.1 Multiple STAs Performance Test

6.4.1.1 Introduction

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.

This test SHALL be MANDATORY for the test plan.

6.4.1.2 Setup

1. The same test setup shown in Figure 8 SHALL be used.
Note: STA in Figure 8 is duplicated by 9 times in this test.
2. 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.
3. A Traffic Generator/Analyzer, sending the corresponding Ethernet packets to each STA, connects to the LAN interface (e.g., GE port) of the DUT.
4. TCP connection SHALL be used for Ethernet packet transmission in the test.

6.4.1.3 DUT Configuration

The test SHALL run under the following configuration:

1. The DUT SHALL use the maximum RF chain capability (Nss = Maximum Nss number).

6.4.1.4 Procedures

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.

Note 1: The test result MAY be slightly affected by the capability of Peer STA. The test MAY be conducted with multiple peer STAs with chipsets from different vendors. The calculated average throughput then is averaged again in the dimension of chipset.

Note 2: Distance MAY be simulated by using attenuators between RF output and antenna of Wi-Fi device.

6.4.1.5 Metrics (Pass/Fail Criteria)

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

- a) Throughput of the Peer STAs SHALL satisfy the requirement in Table 23

Table 23 Throughput requirement of Multiple STAs Performance Test

Wi-Fi configuration (DUT)	Wi-Fi configuration	Bandwidth (MHz)	Throughput_S (Mbps)	Throughput_SM (Mbps)	Throughput_SML (Mbps)

	(Peer STA)		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

6.4.2 Multiple Association/Disassociation Stability Test

6.4.2.1 Introduction

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

This test SHALL be MANDATORY for the test plan.

6.4.2.2 Setup

1. The test setup (shown in Figure 5) SHALL locate in the anechoic shielded chamber (see section 5.2.1 and 5.2.2).
2. 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.
3. UDP connection SHALL be used for Ethernet packet transmission in the test.

6.4.2.3 DUT Configuration

The test SHALL run under the following configuration:

1. General configuration for DUT/STA working mode, bandwidth and number of RF chains:

Table 24 General configuration for spatial consistency test

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)
802.11n (Nss=2)	802.11n (Nss=2)	20
802.11ac (Nss=2)	802.11ac (Nss=2)	80

2. The general configuration SHALL be tested if the configuration is applicable for DUT.

6.4.2.4 Procedures

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.

Note: The test result MAY be slightly affected by the capability of Peer STA. The test MAY be conducted with multiple peer STAs with chipsets from different vendors.

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

6.4.3 Downlink MU-MIMO Performance Test

6.4.3.1 Introduction

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.

This test SHALL be conditionally MANDATORY for the test plan.

6.4.3.2 Setup

1. The test setup (see Figure 7) SHALL locate in the anechoic shielded chamber (see section 5.2.1 and 5.2.2).
2. 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.

3. A Traffic Generator/Analyzer, sending the Ethernet packet to each peer STA, connects to the LAN interface of the DUT.
4. TCP connection SHALL be used for Ethernet packet transmission in the test.

6.4.3.3 DUT Configuration

The test SHALL run under the default configuration except the following:

- a) Downlink MU-MIMO *enable*.

6.4.3.4 Procedures

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.

6.4.3.5 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 Test

6.5.1.1 Introduction

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).

This test SHALL be MANDATORY for the test plan.

6.5.1.2 Setup

1. The test setup (See Figure 7) SHALL locate in the anechoic shielded chamber (see section 5.2.1 and 5.2.2).
2. 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.
3. 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.
4. TCP connection SHALL be used for Ethernet packet transmission in the test.

6.5.1.3 DUT Configuration

The test SHALL run under the following configuration:

1. The DUT SHALL use the maximum RF chain capability (Nss = Maximum Nss number).

6.5.1.4 Procedures

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.

6.5.1.5 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 %.

6.5.2 AP Coexistence Test

6.5.2.1 Introduction

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).

This test SHALL be MANDATORY for the test plan.

Note: This test case implements a simplified scenario where the alien network presents a 50% utilization/contention with the DUT.

6.5.2.2 Setup

1. The test setup (show in Figure 10) SHALL locate in the anechoic shielded chamber (see section 5.2.1 and 5.2.2), DUT and peer STA is in a distance of 2 meters.
2. 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.
3. The host SHALL send the Ethernet packets/IP packets at the maximum rate which the DUT can achieve theoretically.
4. 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, per the configurations described in Table 26. The QoS settings on the alien network SHALL match those on the DUT.
5. TCP connection SHALL be used for Ethernet packet transmission in the test.

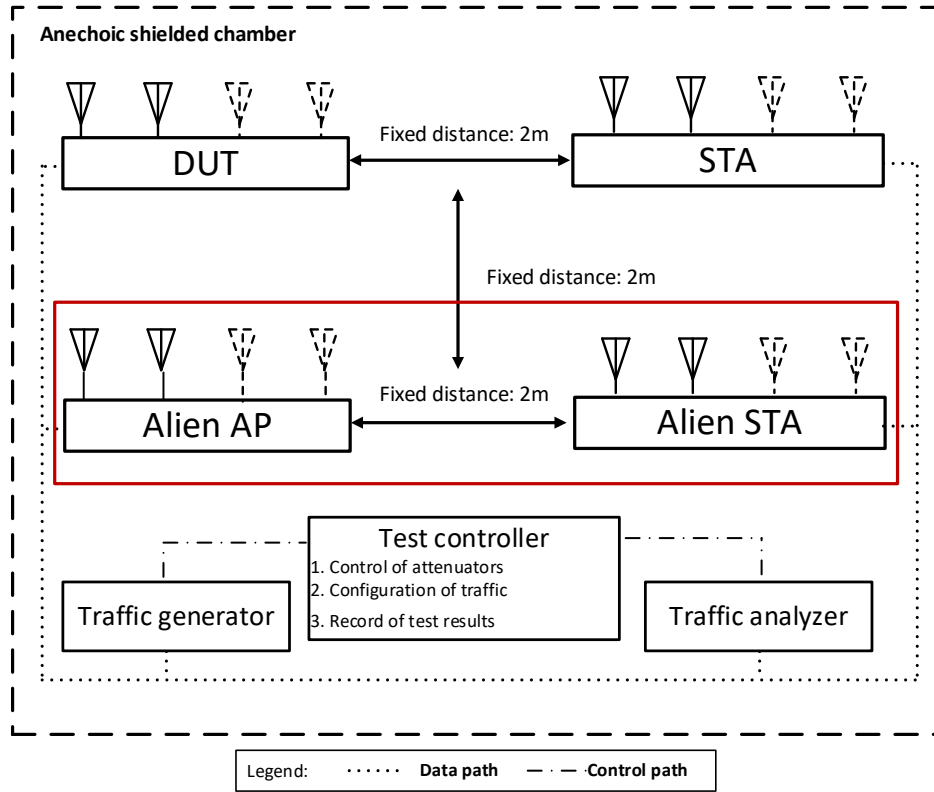


Figure 10 Test Setup of AP Coexistence Test

6.5.2.3 DUT Configuration

The test SHALL run under the following configuration:

1. General configuration for DUT/STA working mode, bandwidth and number of RF chains:

Table 25 General configuration for AP coexistence test

Wi-Fi configuration (DUT)	Wi-Fi configuration (Peer STA)	Bandwidth (MHz)
802.11n (Nss=2)	802.11n (Nss=2)	20
802.11ac (Nss=2)	802.11ac (Nss=2)	80

Note: The channel configuration of alien network MAY use either NSS = 1 or NSS = 2.

Note: The general configuration SHALL be tested if the configuration is applicable for DUT.

2. The alien network SHALL be set to different configurations:

Table 26 Channel configuration in the test

Working frequency	Channel configuration (DUT+peer STA)	Channel configuration (Alien network)		
		Same channel	Overlapping channel	Adjoining channel
2.4 GHz	6	6	7	11
5 GHz	36	36	36 (NOTE)	52
Note: This intends to emulate the effects of an overlapped channel (5 GHz alien configuration is set to use a 40 MHz channel, while the DUT continues to use an 80 MHz channel).				

6.5.2.4 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 SHALL be configured according to Table 26. The alien network will transmit beacon frames according to the default configuration settings of 5.3.3.
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.

6.5.2.5 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 (overlapping 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.							

Appendix I. Instantiations of Test Setups

Appendix I provides instantiations of test setups as guidelines for execution of the test plan. The selection of the test equipment is out of scope of this document.

I.1 Test setup by using IP packet through TCP or UDP

If TCP/UDP flow is required in the test, the Packet Generator/Analyzer SHALL be IP traffic generator/analyzer. Performance statistics of TCP flow SHOULD be conducted from the TCP flow sender (packet generator) while a performance statistics of UDP flow as a report SHOULD be sent from the receiver (packet analyzer) to sender (packet generator).

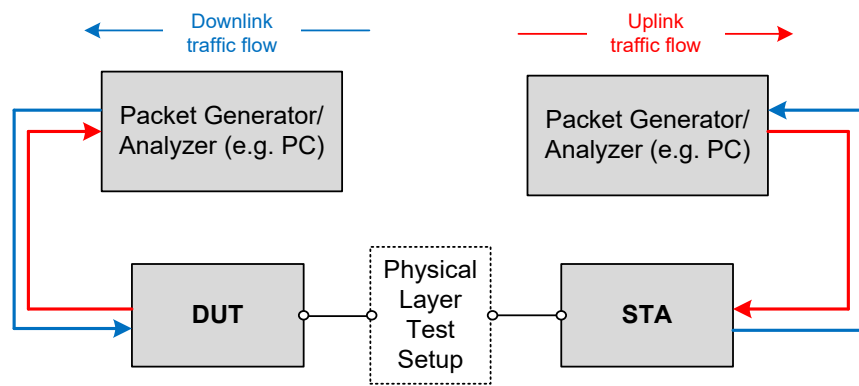


Figure 11 Test setup by using TCP/UDP flows with separate Packet Generator/Analyzer

Figure 11 shows typical examples when TCP/UDP flows are used in the test. Two independent Packet Generators/Analyzers are utilized for packet generation/analysis. In this case, STA/STAs SHALL provide interface to receive/forward packets from/to packet generation/analysis in STA side.

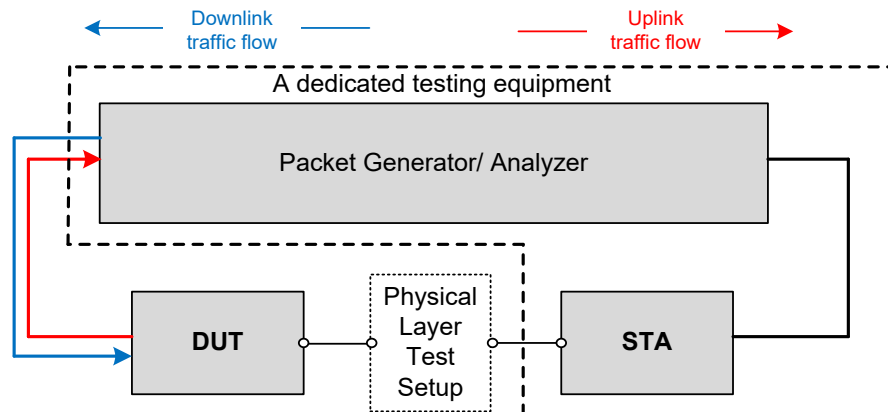


Figure 12 Test setup by using TCP/UDP flows with the dedicated testing equipment

Figure 12 shows another example for usage of TCP/UDP flows. The dedicated testing equipment containing a common Packet Generator/Analyzer and STA/STAs capability is used in the test.

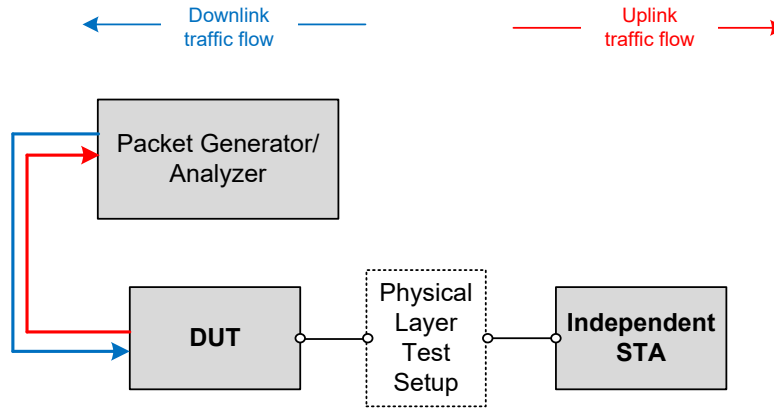


Figure 13 Test setup by using TCP/UDP flows with an independent STA

Figure 13 shows another example for usage of TCP/UDP flows. Independent STA/STAs (i.e., being capable to generate/analyze IP traffic) are used in the test. Additional software SHOULD be necessary to facilitate packet generation/reception within the STA/STAs. The software is out of scope in this test plan.

I.2 Test Setup by Using Level-2 Ethernet Packet

If level-2 Ethernet packet is required in the test, the Packet Generator/Analyzer for DUT side and the Packet Generator/Analyzer for STA side MAY be located in the same box.

Figure 14 shows a typical example when level-2 Ethernet flows are used in the test. A common Packet Generator/Analyzer provide bidirectional packet generation/reception. In this case, STA/STAs SHALL provide interface to receive/forward packets from/to packet generation/analysis in STA side.

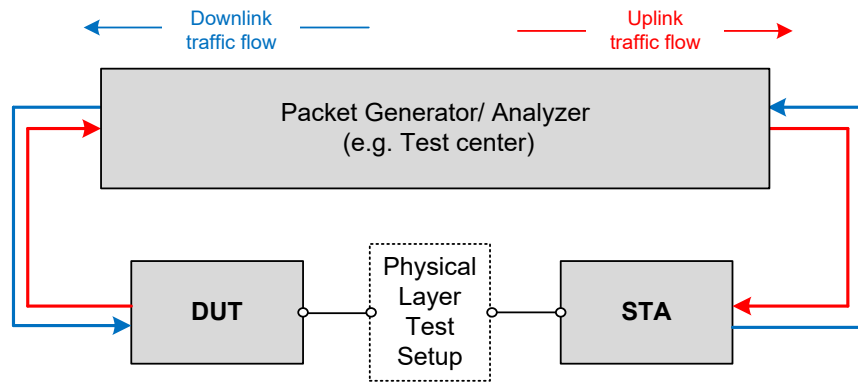


Figure 14 Test Setup by using level-2 Ethernet flows with a common Packet Generator/Analyzer

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