Application Report

TI Wi-Fi Test Strategy Overview

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ABSTRACT

The CC3x20 and CC3x3x devices are part of the SimpleLink™ microcontroller (MCU) platform, which consists of Wi-Fi®, *Bluetooth*® low energy, Sub-1 GHz and host MCUs. All share a common, easy-to-use development environment with a single core software development kit (SDK) and rich tool set. For more information, visit www.ti.com/simplelink.

WiLink™ 8 is a combo device supporting Wi-Fi®, Bluetooth® and Bluetooth Low Energy functionality on a single chip for universal connectivity. The device supports IEEE 802.11 a, b, g, and n bands along with Bluetooth 5.1 and Bluetooth Low Energy.

This application report presents an overview of the strategy employed by TI to test the SimpleLink™ Wi-Fi CC3x20 and CC3x3x devices and WiLink™ 8 combo solutions. The goal of the document is to help developers understand the scope of TI's internal Wi-Fi testing, which helps TI ensure the interoperability and reliability of its Wi-Fi products.

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1 Introduction - Testing Strategy

In the rapidly growing Internet of Things (IoT) world and market, many applications, from personal electronics to industrial machines and sensors, get wirelessly connected to the Internet. These applications cover dozens of use-cases in various environments and serve diverse requirements.

Consumers want the best user experience with their connected devices, so they can securely transfer data over the internet, without interruption of communication. In order to achieve this, developers need to design smart IoT products with great Wi-Fi connectivity, and implement security measures that will protect end-user’s privacy. Thus, some of the important factors when choosing a connectivity device, is the Wi-Fi device's ability to provide reliable performance, security, and a high level of worldwide interoperability.

Due to the importance of these factors, TI invests in making sure that the SimpleLink™ and WiLink™ device families provide wireless connections with best-in-class stability and robustness for real-life scenarios. These investments include a comprehensive testing strategy with dedicated test labs and automated testing processes. Our goal is for Wi-Fi technology to work anytime, anywhere.

This application report describes the test strategy employed for TI's Wi-Fi devices and includes information on the following test categories:

- Interoperability (IOP)
- Performance
- Robustness and Stability
- Functionality
- Pre-Certification
- WLAN-Bluetooth Coexistence
- Mesh (WiLink™ 8 only)
- Multi-Role (WiLink™ 8 only)

2 Interoperability (IOP) Tests

Interoperability measures the ability of a device to work properly, or interoperate, with a wide range of devices from other vendors and provide consistent performance.

TI understands the impact and cost of having an interoperability issue, and established a comprehensive IOP lab with automated testing capability to reduce the risk of interoperability issues occurring. The scope of these tests is beyond that of the standard Wi-Fi Alliance tests.

The TI IOP lab contains more than 200 access points (APs) from different vendors. The access points included in the lab are based on a wide range of different Wi-Fi chipsets and intended to provide a test coverage that is representative of most APs available in the market. A representation of the Wi-Fi IOP lab used at TI can be seen in Figure 2-1.

With these extensive tests TI engineers were able to not only to find and fix numerous Interoperability issues, but also to implement and test various behaviors and algorithms designed to enhance throughput, improve power consumption and the devices' overall performance and stability.

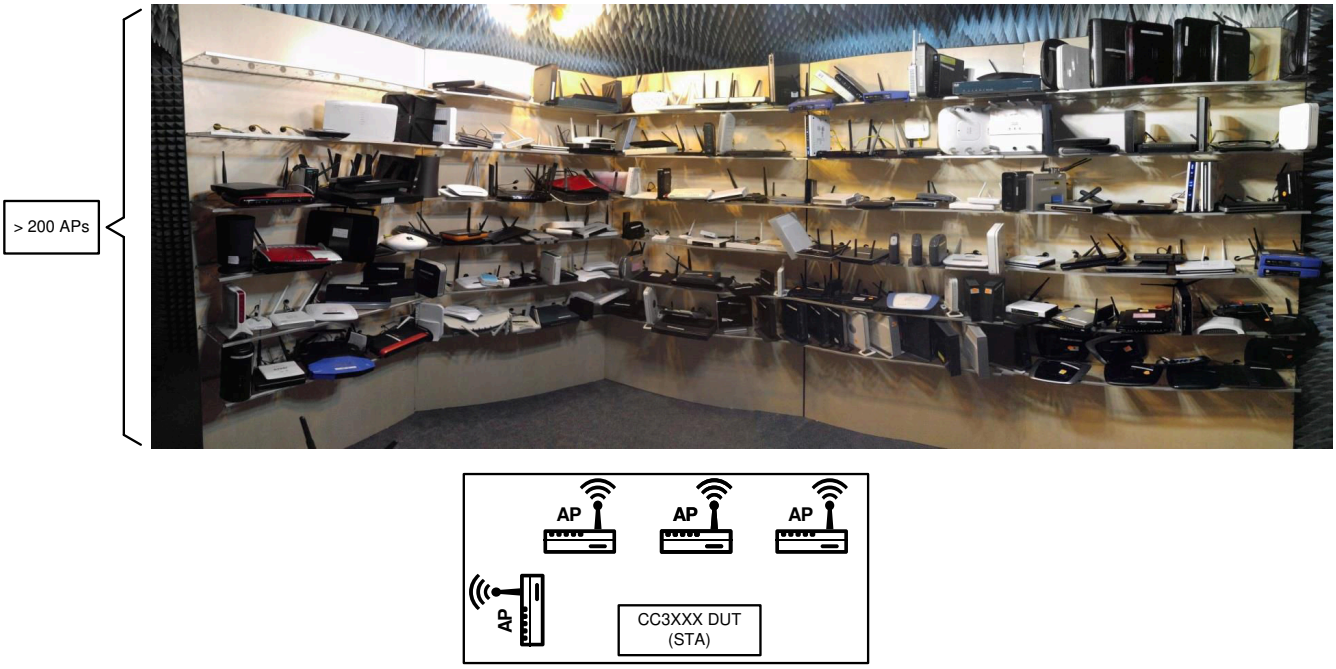

Figure 2-1. IOP Chamber with Over 230+ AP Deployed Worldwide

There are two major test case groups that are run as part of TI's Wi-Fi interoperability testing every SDK release:

- Basic Level
- Long Run

2.1 Basic Level

The basic level test cases are performed across all access points and include the following steps:

1. Connect the DUT (Wi-Fi STA) to the AP.
2. Acquire IPv4 and IPv6 address using DHCP.
3. Open a TCP/TLS connection to a server on the same network (relevant to SimpleLink™).
4. Run traffic for 5 minutes.
5. Measure current consumption.
6. Disconnect.

2.2 Long Run

The long run test cases are performed on selected access points for long periods. The periods are defined per access point, where all of them are longer than 4 hours and for some access points those periods to longer than 12 hours.

The selected access points for those test cases change from time to time based on inputs from inputs from customers and market share estimations for those access points.

These long run test cases include the following steps:

1. Connect the DUT (Wi-Fi STA) to the AP.
2. Acquire IPv4 and IPv6 address using DHCP.
3. Stay connected in power save mode for a defined period with no traffic.
4. Measure current consumption.
5. Send ping to the device from a peer on the same network and wait for a reply at the end of the period.
6. Disconnect.

Test cases shown in Section 4 contain cases that are similar in nature, but involve different traffic patterns or running in a stressed environment.

2.3 Access Point List

The list of access points is updated on a regular basis. Table 2-1 is the list of access points as of March 2021:

Table 2-1. Access Point List from March 2021

Vendor	Models
3COM	WL-450
Actiontec	GT701-WG, MI424-WR, MI424-WR Rev. D, MI424-WR Rev. I, PK5000
Air	Live WL-5450AP
Airlink	AR570W Rev. A
Amped	R10000, RTA15, RTA1750
Apple	AirPort Express 2nd Gen A1392, AirPort Extreme 1st Gen A1034, AirPort Extreme 3rd Gen A1301, AirPort Extreme 5th Gen A1408, Time Capsule 3rd Gen A1355
Arris	TG1672G, TG1682G
Aruba	3200XM AP 105 PS, 800 Aruba AP 125
ASUS	RT-AC66U, RT-N10+, RT-N10E, RT-N12, RT-N13U, RT-N56U, WL-330g, WL-550gE
AT&T	2wire 2701HG-B
Belkin	F5D8230-4 v3000, F5D8231-4 v2, F5D8235-4 ver. 2033, F7D1301 v1, F7D5301 v3, F9K1002v5, F9K1102v1, N1 Vision F5D8232-4 v1000, N1 Vision F5D8232-4 v2000
BellAir	BA20E-11
Bergtek	WR150
BT	Home Hub 4, Home Hub 5
Buffalo	WCR-G54, WER-AM54G54, WHR-G301N, WHR-HP-GN, WZR-600HP2, WZR-D1800H, WZR-G300N, WZR-HP-AG300H
Cisco	AIR-AP1252AG-A-K924G, AIR-AP1252AG-A-K9 5G, AIR-AP1262N-I-K9 24G, AIR-AP1262N-I-K9 5G, AP1231, AP541N, AP541N-A-K9, DPC3825, M10, Catalyst 9130AX
Cnet	CQR-980
Corega	CG-WLR300NM
Devicescape	24G
D-Link	DIR-605L, DIR-618, DAP-1522, DAP-2690, DGL4500, DI-634M, DIR-300 A1, DIR-600 HW B1, DIR-601 HW A1, DIR-615 HW, DIR-615 HW C2, DIR-618 A1, DIR-625 HW C2, DIR-628 HW A2, DIR-635 HW B3, DIR-655 A3, DIR-655 HW A4 NA, DIR-655 HW A4 WW, DIR-655 HW A1, DIR-825 HW B1, DIR-868L, DIR-890L, DSL-G225, DWL-8600AP A1, DAP-2690
Edimax	BR-6428nS, BR-6478AC, BR-6574n
EnGenius	ERB9250, ESR9850, ESR9855G
EERO	B010001
FAST	FW3030Rv2
Fritzbox	7390, 7490, 6842 LTE
Google	Asus OnHub8, TP-Link OnHub, NLS-1304-25
Hawking	HWABN1
Honeywell	WAP-PLUS

Table 2-1. Access Point List from March 2021 (continued)

Vendor	Models
HP	V-M200
Huawei	WS322
ipTIME	N104Q, N604M
Levelone	WBR-6003
Linksys	E1000, E1500, E1550, E2100L, E2500, E3000, E3200, E4200, E900, EA3500 24G, EA3500 5G, EA6350, EA6700, EA7500 V2, EA8500, EA9200, WAP4400N v01, WAP55AG, WAP610N, WRT120N, WRT160NL, WRT160Nv3, WRT300Nv2, WRT310Nv2, WRT320N, WRT400N, WRT54G v5, WRT54G2, WRT54GL, WRT54GX ver. 2, WRT54G-TM, WRT600N, WRT610N, VLP01
Logitec	LAN-W300N/R
Medialink	MWN-WAPR300N
Meru	MC1500 AP300
MikroTik	hAP RB951Ui-2nD
Motorola	Netopia 33447-02, Arris SBG6580
MOXA	AWK-3131A
MSI	RG70A
NEC	Aterm WR7850S, Aterm WR8500N, Aterm WR8700N
Netgear	AC1900, R7000, B90-7550, DGND330v1, DGND3700, Nighthawk AX8 RAX80, orbi RBR50, orbi RBS50, R4500, R6120, R6200v2, R8000, R8500, VVG2000, WGR614v4, WGR614v9, WNDAP350, WNDR3300, WNDR3700 24G, WNDR3700 5G, WNDR3700v1, WNDR3700v3 24G, WNDR3700v3 5G, WNDR3800 24G, WNDR3800 5G, WNDR4000, WNHDE111, WNR2000, WNR2000 v4, WNR3500v1, WNR3500v2, WNR834B, WNR834Bv2, WPN824 v3, WPNT834
Netis	WF-2404
Pace/AT&T	4111N-031
PCI	MZK-MF150, MZK-MF300N, MZK-WNH rev A
Proxim	Orinoco AP-4000, Orinoco AP-700
Ruckus	ZD1106, zoneFlex R510
Samsung	CY-SWR1100
Sapido	RB-1602
Securifi	Almond
SMC	WBRP-G
SonicWall	Sonicpoint-Ne
Speedport	W 921V
Tenda	N3, N30, W307R, W311R, W368R
TP-Link	AC1750 C7 v1.1, aD7200, Archer C9, Deco M5, N900 TL-WDR4900v1, TD-W89841N v4, TL-WDR4300, TL-WNR3500, TL-WR2041N, TL-WR641G, TL-WR702N, TL-WR740N v1, TL-WR740N v2.5, TL-WR740N v5.7, TL-WR740N v5.8, TL-WR741ND, TL-WR800N, TL-WR841N, TL-WR845N, TL-WR940N v2.1, TL-WVR450G, WDR7500 v2, WR541G v4, WR941N v6, WRT740n v.5.7, WRT740n v.5.8, Omada AC1350 EAP225
Trendnet	TEW-625BRP v2.1R, TEW-625BRP v2.2, TEW-637AP, TEW-671BR, TEW-818DRU
Ubiquiti	UniFi AP AC, UAP-AC-PRO
US Robotics	USR5450, USR8054
Verizon	A90-750115-07, MI424WR Rev I
WD	N900-F2F
Xiaomi	Miwifi
ZIO	3300N v2

3 Performance Testing

Performance testing verifies that a device meets the expected performance level in all domains. These tests are not intended to find functional defects, but to validate that a new code version will provide consistent performance as compared to previous code versions. Some of the domains that are included in this testing category are throughput, RF performance, and power consumption.

Table 3-1. Performance Testing Domains

Domain	Description
Throughput	Throughput tests measure the maximum throughput over TLS, TCP, or UDP sockets in various configurations such as: • Various WLAN channels in each band (2.4GHz or 5GHz) • Various ciphers
RF Performance	RF performance tests verify transmit and receive characteristics using real life use-cases. The characteristics include: • Maximum transmit power over various channels • RF modulation rates during a real connection (Access Points or Stations) • RX sensitivity in various channels and all RF modulations • Overall performance in congested environment
Power Consumption	Power consumption tests verify the average power consumption of the device in various real-life use-cases.

4 Robustness and Stability

The reliability of a system is a significant factor that plays a key role in the cost-effectiveness of a product. Reliability of a system is defined as the probability that a system, including all hardware, firmware and software, will satisfactorily perform the task for which it was designed, for a specified time and in a specified environment.

Due to the importance of having reliable connectivity, TI invests in running comprehensive tests to make sure that the connectivity will be reliable. These reliability tests include two major test categories:

- Robustness
- Stability

4.1 Robustness Tests

The robustness tests validate the degree to which the device can function correctly in the presence of invalid inputs, stressful environmental conditions, or a large number of iterations.

Some examples of robustness tests:

1. Opening the maximum number of simultaneous socket connections (TLS or TCP) simultaneously
2. Running different types of connections simultaneously with different traffic patterns or behaviors (for example, some connections in maximum throughput, others with low throughput or in burst modes and a few just for maintaining a connection with no traffic)
3. Running different types of connections in a loaded environment
4. 4. Running different types of connections while configuring the network to an extremely dynamic configuration (for example, very short DHCP lease time, very short key exchange, and so forth)

4.2 Stability Tests

The stability tests validate that the device can function as designed for long periods without degradation in performance or interruptions in the service (for example, disconnections).

Some examples of stability tests:

- Running connection with maximum throughput for long periods (in magnitude of tens of hours)
- Connecting and disconnecting from a network repeatedly for long periods (10s of hours)

The period of the stability tests is selected per test case where all tests are longer than 12 hours, and some significant use-cases even extend up to 168 hours (7 days).

These tests run under environments that simulate real life scenarios. Some tests run in a network that simulates home environment, which contains several different devices and traffic types on the network.

5 Networking Stack SimpleLink™ Only

Testing a network stack and the associated protocols is complex and requires multiple test setups and test cases. These tests have to consider real-life scenarios such as handling multiple connections with different throughputs and latencies. Additionally, the tests must consider different behaviors within the network. The network stack tests are performed in each of the supported Wi-Fi roles (Station, Access Point, or P2P) and in different bands (2.4 GHz or 5 GHz).

TI invests in the following tests to maintain a reliable and trustworthy network stack.

Table 5-1. Network Stack Test Cases

Test Category	Description
IPv4 or IPv6 Connectivity	Verifies IPv4 or IPv6 behavior and connectivity of client and server sockets, including all the different supported options and capabilities.
Maximum Connections (sockets)	Tests the ability to open the maximum number of sockets (both open and secure) including combinations of different socket types. For example: • Connecting to 16 real webpages and downloading the homepage • Connecting to 6 secure webpages and 10 open webpages and downloading the homepage
Network Applications and Services	Verifies the behavior of internal network applications and services such as DHCP server, mDNS client and server, HTTP server, etc.

Some of tools and methods TI uses to test the embedded network stack of the CC31xx or CC32xx devices include:

- Using industry leading tools such as Ixia's IxANVL to validate protocol implementation
- Connecting and running traffic for several minutes on each of the supported TLS ciphers
- Connecting and downloading content from thousands of different websites
- Verifying standard BSD socket functionality

The TLS stack in the device allows it to establish secure connections to the cloud. As a result, the TLS stack must also be evaluated from a security perspective. TI maintains the embedded TLS stack and updates it to address known vulnerabilities using the following methods:

- Tracking common vulnerabilities and exposures and fix critical issues
- Maintaining a formal process for managing product incident reports. For more information, see: .

Fixes to identified issues are released by TI in service packs on a quarterly basis.

6 Functionality Tests

Functionality tests verify features offered by the device. In most cases these are black-box tests that use the host interfaces and APIs. In these tests the tool activates APIs and verifies the response.

Functionality tests cover the positive and negative tests of a feature based on a defined boundary.

Functional tests performed in two ways:

- SDK testing (SimpleLink) – these tests cover the internal implemented in the Wi-Fi device as well as the driver and SDK libraries
- Dedicated test per functionality – these tests cover WLAN and Network functionality that could not be tested as part of the SDK testing through APIs

7 Pre-Certification Tests

The goal of the WFA Certification is to ensure interoperability among IEEE 802.11 products from multiple manufacturers and to verify the products support the most strict and updated security measures defined. TI performs these certification tests in-house using the test-bed vendor products and the latest WFA Test Suite tools, as defined by the WFA in the relevant test plans.

The included testbeds are listed in Table 7-1.

Table 7-1. Pre-Certification Testbeds

Device Role	Testbeds
Station	• Wi-Fi Certified n • P2P • WPS • Power Saving (IOTLP)(1) • WPA2 Security Improvements • PMF • SAE • WPA3 v2 • MBO(1) • WMM-PS
Access Point	• Wi-Fi Certified n • WPS(2)

(1) SimpleLink™ only
(2) WiLink™ 8 only

8 WLAN-Bluetooth Coexistence Tests

These tests verify the ability to run Wi-Fi and Bluetooth or Bluetooth Low Energy concurrently.

On WiLink™ 8, the internal coexistence mechanism is tested using multiple combinations of WLAN and Bluetooth or Bluetooth Low Energy use-cases run simultaneously. In each use-case, the test verifies the scenario is established correctly and measures relevant performance metrics (for example, throughput, voice quality, and so on). Wi-Fi is tested in various configurations such as SISO/MIMO, 20/40 MHz channels, 2.4GHz or 5GHz bands, and STA/AP/P2P/Mesh roles. Bluetooth is tested in various Bluetooth classic or Bluetooth Low Energy profiles such as HandsFree, A2DP, FTP, Discovery, Peripheral, and so on.

SimpleLink™ Wi-Fi is tested for functionality and performance while in a coexistence configuration with an external Bluetooth Low Energy device. These tests include multiple use-case combinations that cover possible scenarios in target end-equipments. The tests are performed using both a shared and dual-antenna (connected via an external switch) mode. The Wi-Fi use-cases include connections on 2.4GHz or 5GHz, with TCP or UDP connections, and running TX/RX traffic. The Bluetooth Low Energy configurations include various PHYs, PDU sizes, connection intervals, and central or peripheral roles.

9 Mesh Tests (WiLink™ 8 Only)

The purpose of this test is to verify the functionality and performance of the mesh feature. Prior to WiLink™ 8 release, extensive tests were performed to verify the Mesh feature's functionality, performance, robustness, and stability. A subset of the functionality tests is performed during each test cycle.

Functionality tests include use-cases such as:

- 32 nodes connection and disconnection
- Connection with maximum number of hops = 6
- Mesh Protocol compliance, aging, and security
- Mesh Multi-Role
- Multicast streams – run up to 32 streams over Mesh nodes

Performance tests include measurements of latency, throughput, and jitter in the following use-cases:

- TCP TX/RX traffic
- UDP TX/RX traffic
- Broadcast and Multicast traffic
- QoS – Video, audio, and BE traffic

Robustness and stability tests run selected use-cases from the above tests over >12hrs or 1000 iterations

10 Multi-Role Tests (WiLink 8 Only)

These tests verify the DUT's ability to run 2 roles concurrently. The tests cover the following role combinations:

- STA-AP
- STA-P2P
- AP-P2P
- AP-AP

Each combination is tested in the SISO20, SISO40, and MIMO antenna modes. Additionally, each combination is tested with the roles operating on the same and on different channels.

In each configuration, throughput is measured in one stream and multiple streams (stream per role)

11 Testing Setup

Most of the Wi-Fi tests described in this document are running on a similar setup. Figure 11-1 illustrates the typical test setup.

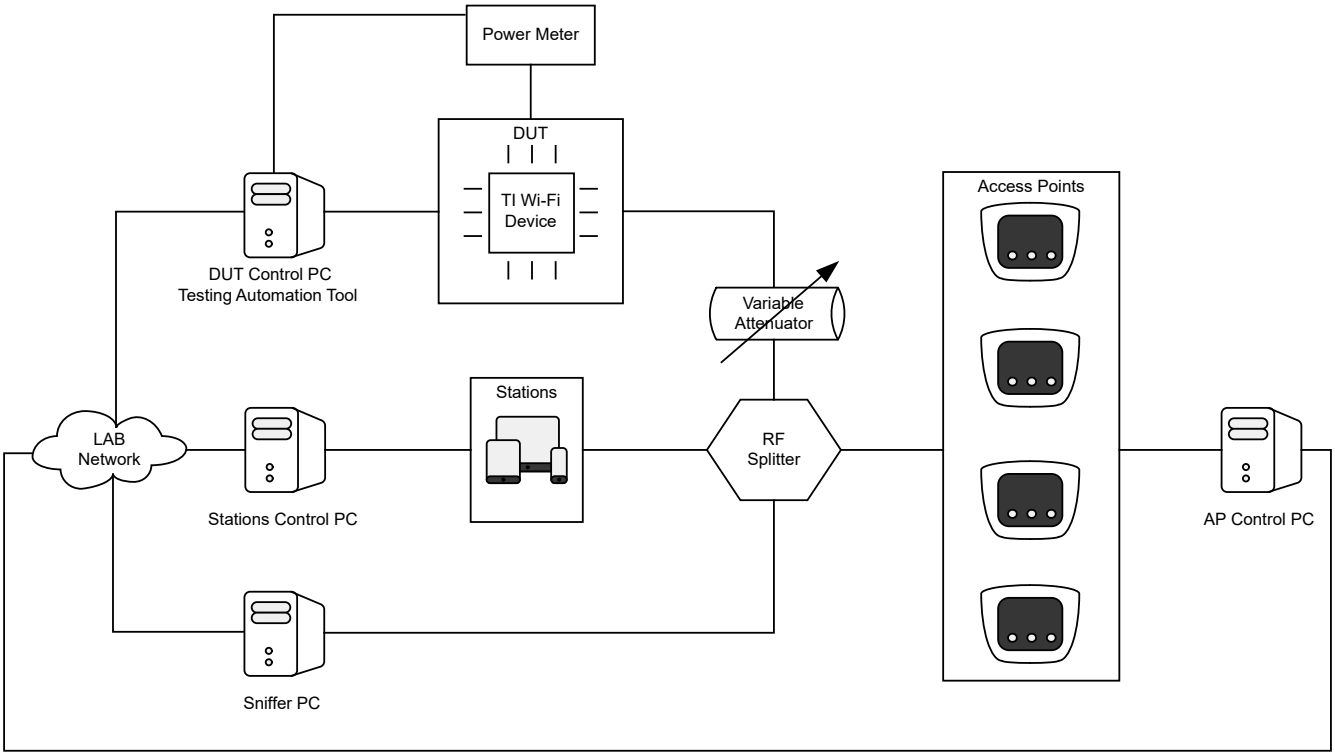

Figure 11-1. General Test Setup Illustration

The test cases are running simultaneously in several setups. The actual setups may vary. Each setup might contain a different number of access points, stations, meters, and tools.

Figure 11-2 illustrates the radiated 32 mesh nodes testing setup used for most of the Mesh tests. Some of the tests are run on a conducted setup.

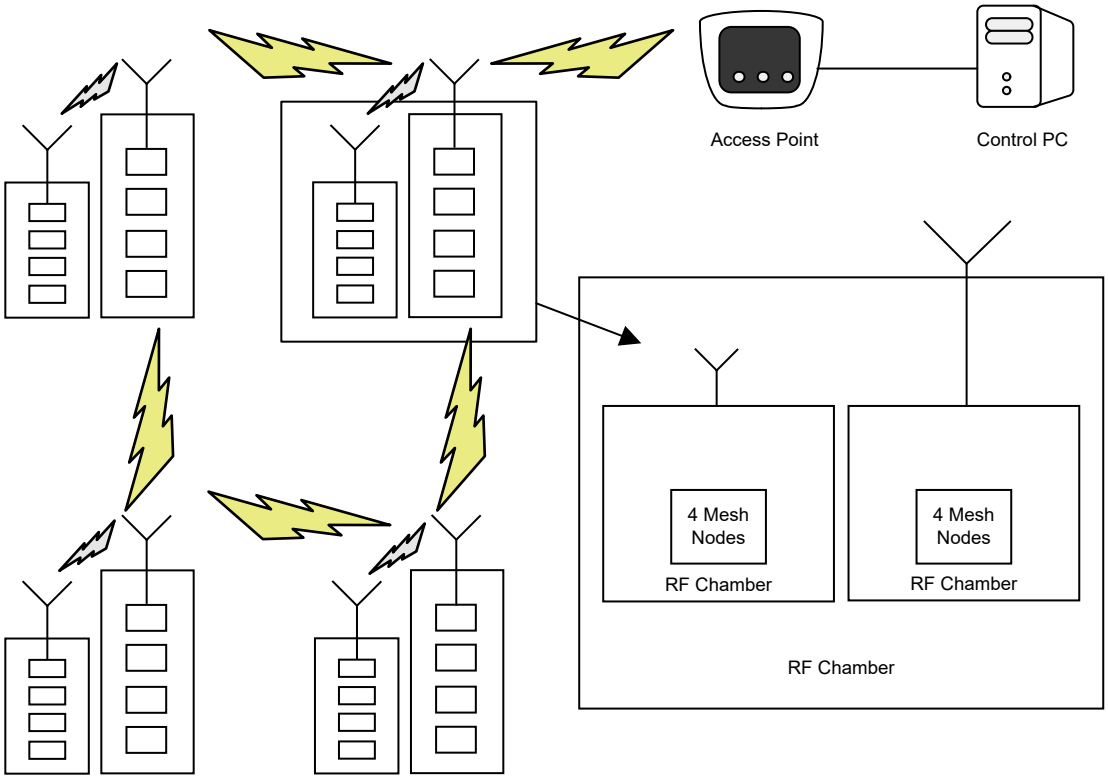

Figure 11-2. WiLink™ 8 32 Mesh Nodes Test Setup Illustration

12 Summary

A comprehensive test strategy is essential for ensuring that Wi-Fi devices have a high level of interoperability, security, and reliability. These factors impact the quality of a Wi-Fi solution and the user experience of a Wi-Fi based product. TI understands the importance of these factors, which is why TI invests in maintaining an extensive test strategy for its SimpleLink™ Wi-Fi devices comprised of interoperability, performance, robustness and stability, networking stack, functionality, and pre-certification tests.

13 References

- Texas Instruments: *Transfer of TI's Wi-Fi Alliance Certifications*

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