Understanding How to Test 802.11ac Wave 2 MU-MIMO

with Spirent TestCenter WLAN

Introduction

The IEEE 802.11ac standard was introduced in two phases: Wave 1 and Wave 2, with the IEEE ratifying 802.11ac Wave 2 as a wireless local area network (WLAN) standard in November 2013 [1]. As the industry has begun to adopt the Wave 2 products for either carrier and enterprise deployment or consumer home applications, understanding 802.11ac Wave 2 becomes increasingly critical for equipment manufacturers and service providers who want to tap into the opportunities presented by today's connected world. The relevant stakeholders who invested in IEEE 802.11ac Wave 2 products are now eager to know what exactly these Wave 2 enhancements do, and how Wave 2 performance is presented to customers. Therefore, testing and validating Wave 2 features has become an urgent topic that challenges testing engineers who perform testing in either a lab or a field environment.

In this white paper, we will discuss how to test the Wave 2 features and subsequently provide guidance on test configuration in a lab setting to test access points (APs). The discussion on these tests for the new Wave 2 will be focused on a feature called multiuser multiple input, multiple output (MU-MIMO). Starting with some basic information needed to understand 802.11ac Wave 2 technology, this paper will then detail how to setup test beds to validate the throughput performance gain from various MU-MIMO configurations. The testing methodology presented can also be used to explore the various benefits of implementing MU-MIMO for a complex WLAN network that may involve multiple device clients sharing the same wireless interface. Benchmark or expected throughput performance numbers for specific test cases discussed are also listed as a reference for comparison purposes.

802.11AC WAVE 2 AND MU-MIMO

Since 802.11ac Wave 2 is a superset of 802.11ac Wave 1, it supports all the data rates and features of 802.11ac Wave 1, and it comes with the addition of support for features such as downstream MU-MIMO, 160 MHz-wide channels, and up to 8 spatial streams. Compared with the Wave 1 products, 802.11ac Wave 2 offers a number of the new physical (PHY) and media access (MAC) layer enhancements, as shown in more detail in Table 1 below.

802.11ac Features	Wave 1	Wave 2
Channel bandwidths: 80 MHz mandatory, 160 and 80+80 MHz optional	80MHz	80MHz, 80MHz+80MHz and 160MHz optional
256 QAM	256QAM	256QAM
More spatial streams and antennas: up to 8	2x2 or 3x3	4x4, and up to 8x8
Multi-user MIMO on downlink: up to 4 users, up to 4 streams per user, maximum 8 streams total	Downstream SU-MIMO	Downstream MU-MIMO
Maximum PHY Rate	1.3gbps (3x3, 80MHz)	1.73gbps (4x4, 80MHz) 3.47gbps (4x4,160MHz) 6.94gbps (8x8,160MHz)
Ethernet Uplink Interface	1Gbps	1Gbps, 2.5Gbps, 5Gbps, and 10Gbps

Table 1: 802.11ac Wave 2 Features

The Wave 2 MU-MIMO gains a significant performance boost in the downstream transmission from an access point (AP) to device clients as compared to those of the Wave 1 with SU -MIMO feature [1,2]. This means that the spectrum can be more efficiently used with multiple connected clients able to receive a transmission from an AP simultaneously. Simply speaking, the Wave 1 supports a single user multiple input, multiple output (SU-MIMO) that sends a transmission only to a single client at any time, specifically, in the downstream direction. MU-MIMO can transmit up to 4, Wave 2 clients simultaneously in downstream so that the performance can be improved by a maximum 4 times, as shown in Figure 1.

The performance advantage of MU-MIMO comes from its ability to share the entire available wireless frequency spectrum across multiple client devices simultaneously. Although the Wave 2 MU-MIMO does not change the maximum possible PHY rate in each WLAN connection, it improves the aggregated throughput that each AP can support with an environment where multiple clients are sharing the same AP so that the channel utilization or efficiency is improved. The IEEE 802.11 WLAN is a contention-based protocol and, by transmitting to multiple clients simultaneously, clients are on and off the network fast enough to allow the wireless spectrum to be used by other clients. While most WLAN networks incorporate different client types from 802.11 a/n/ac on 5GHz band, the efficiency of MU-MIMO provides performance not only to the Wave 2 clients but also results in added performance to the legacy clients with 802.11 a/n/ac modes.

Traditionally, access points have been equipped with omnidirectional antennas, which are so named because they send energy in all directions as shown in Figure 2.

In essence, MU-MIMO works by taking advantage of beamforming to send traffic to spatially diverse locations at the same time. Therefore, beamforming in the downstream direction, from the AP to the client, was an invaluable area of innovation in the 802.11ac standard.

Beamforming focuses energy towards a client, such as directing to the mobile phone shown on the left-hand side of Figure 2. The wedges illustrate the areas where the beamforming focuses increased power, and therefore the signal-to-noise ratio (SNR) and data rates. The mirrored preferential transmission to the left is a common effect of focusing energy in a system with limited antenna elements. However, focusing the energy toward the desired left and right sides of the figure means that the AP's range in other directions is smaller. Beamforming increases the performance of wireless networks at medium ranges. At short ranges, the signal power is high enough that the SNR will support the maximum data rate [3]. IEEE 802.11ac Wave 2 defines that it can generate up to 4 of those beams to support 4 MU-MIMO users at a time.

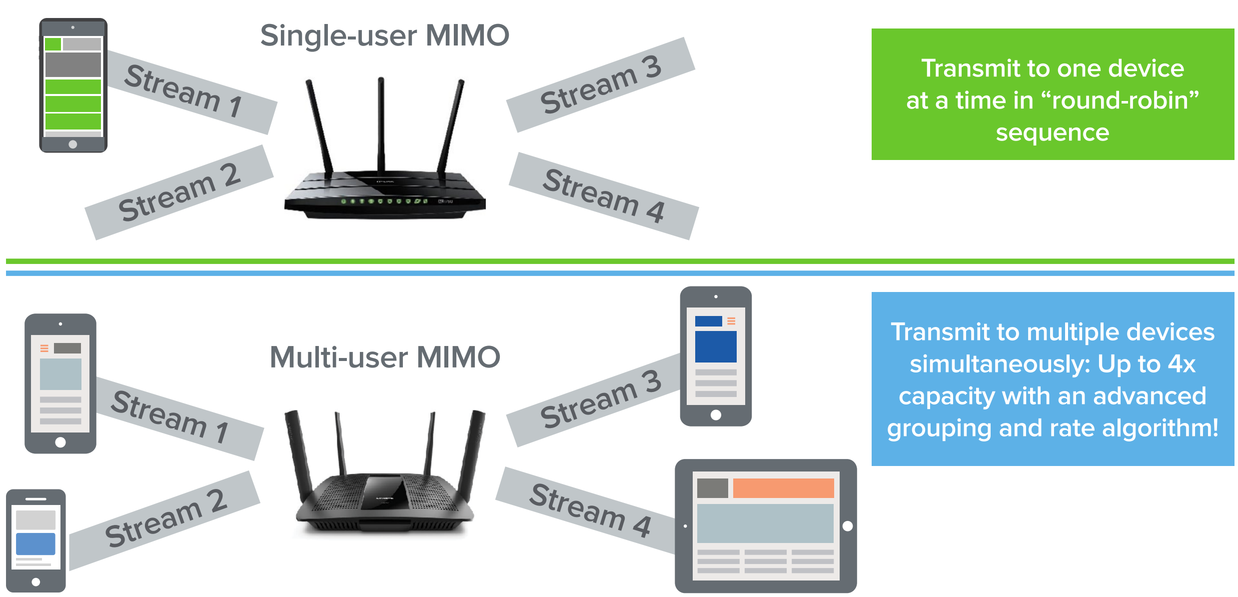

Figure 1: IEEE 802.11ac Wave 1 SU-MIMO vs Wave 2 MU-MIMO

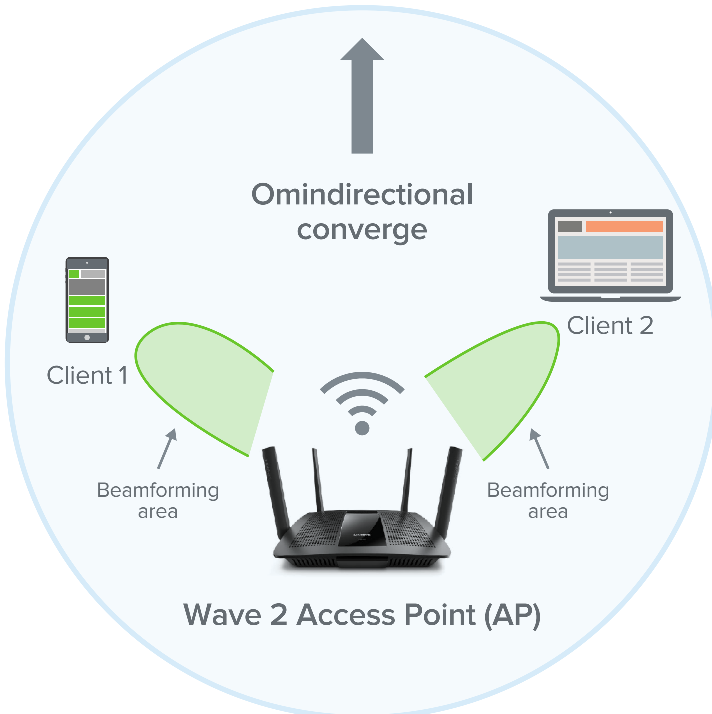

Figure 2: 802.11ac Beamforming Basic

A beamforming process between an AP and a client can be simply described as that the AP is sending higher-level data such as IP packets to the client such as a laptop, shown as the recipient in Figure 3. The process begins by measuring the radio channel in both signal strength and phase between the two devices in a calibration process. Although in general beamforming may be either explicit or implicit, depending upon whether special channel measurement frames are used, in 802.11ac the standard form of beamforming requires the use of channel measurement frames and is therefore only explicit. This channel calibration step in the beamforming process is also called sounding that could be happening for some or all clients being selected for the MU-MIMO transmissions periodically, but how frequent a sounding occurring is more implementation dependent.

Since 802.11ac beamforming is based on explicit channel measurements, both the transmitter and the receiver must support it. The sounding happens before any data traffic so it is also an overhead. The shorter the time a sounding takes, the better the MU-MIMO performance gets. Therefore, sounding timing can be an interesting parameter to pay attention to. Moreover, a MU-MIMO group refers to the clients that are receiving the different downstream transmissions at the same time as the beamforming technology or at the same time sounding is occurring.

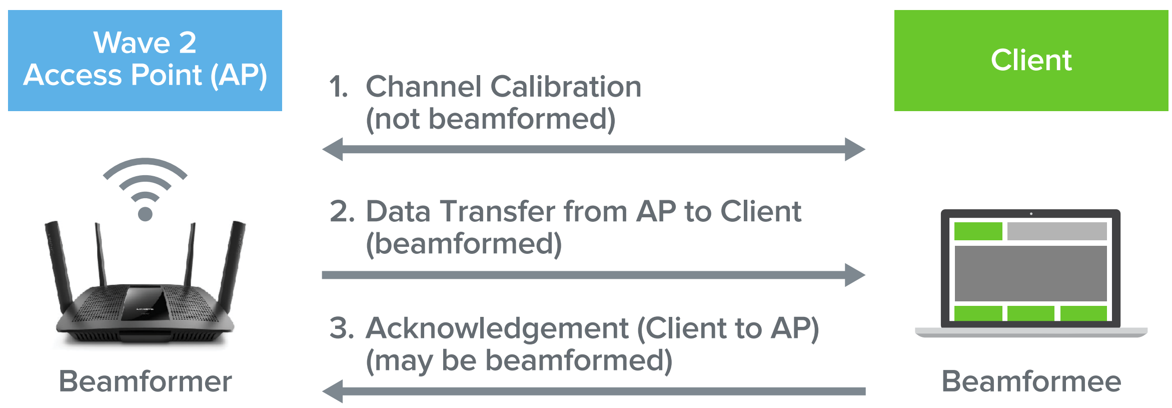

Figure 3: 802.11ac Beamforming Process.

WAVE 2 Testing and Validation with Spirent TestCenter WLAN

Spirent TestCenter WLAN offers multiple hardware platforms that combine both the Wave 2 WLAN interface cards or modules and new 2.5Gbps/5Gbps Base-T Ethernet solutions. These solutions combined, support the highest performing and most realistic multi-client emulation for direct functionality and performance testing of Access Points (APs) available today. More specifically, the following general AP test scenarios can be performed:

- AP Personal and Enterprise security (802.1x) type
- Medium capacity and maximum client loading
- AP stability testing
- AP interwork with various mixes of different 802.11 mode clients
- Benchmark or baseline for throughput, forwarding rate, and latency performance
- RFC-style testing with clients across APs through the RF interface
- Throughput vs packet size, throughput vs client numbers, IPv4, IPv6, DHCP scale and performance, etc.
- Rate vs. range testing

Wave 2 specific test scenarios supported are:

- Validate 802.11ac 1.73Gbps PHY rate with 4x4/80MHz channels or 2x2/160MHz channels
- Test above 1Gbps throughput with 4x4 MIMO
- Validate AP's Wave-2 MU-MIMO capability in downlink
- Provide various flexible MU-MIMO client configurations for testing
- Test the throughput improvement with MU-MIMO clients
- AP MU-MIMO stability and efficiency testing
- AP MU-MIMO sounding timing testing
- MU-MIMO rate vs. range testing

MU-MIMO Test Bed Setup and Configuration

Spirent TestCenter WLAN can be connected to a Wave-2 AP with 4x4 MIMO in a number of ways to test an AP, as shown in Figure 4. As an example described below, we can connect a Spirent TestCenter WLAN with the AP in either an RF cabled conductive mode or Over-The-Air (OTA) mode using a Spirent TestCenter WLAN C1 appliance.

Figure 4a gives the simplest direct RF cable connections between the testing equipment and the AP with 4 SMA connectors. This is most commonly found in lab setups that can test the maximum PHY rate, throughput, and MU-MIMO without other advanced setup in place. But this can only work with an AP that has removable external antennas.

Figure 4b shows how to use a RF chamber so that the AP can be placed inside the chamber in a full OTA mode. The setup can even take a tunable table inside the chamber to test the performance when the AP is in a different orientation and is rotated to any position within a 360-degree range. Otherwise, placing the appliance in an RF chamber can be ideal and necessary when testing WLAN performance to isolate it, so that the AP will not be impacted by other existing co-channel interference or noise sources.

To test the beamforming performance, one can use a setup as shown in Figure 4c with an external Butler matrix that will add a phase shifting to the multiple MU-MIMO clients. This setup provides an RF geometry circuit to emulate different physical locations for the clients.

Figure 4d depicts a setup where the external antennas are placed further apart and in different locations to create an ideal, closer to a real-world environment for the MU-MIMO testing. The 802.11ac beamforming technology will often perform better if the clients are located physically apart and the multiple beams formed for the clients with a minimum of overlapping at any time.

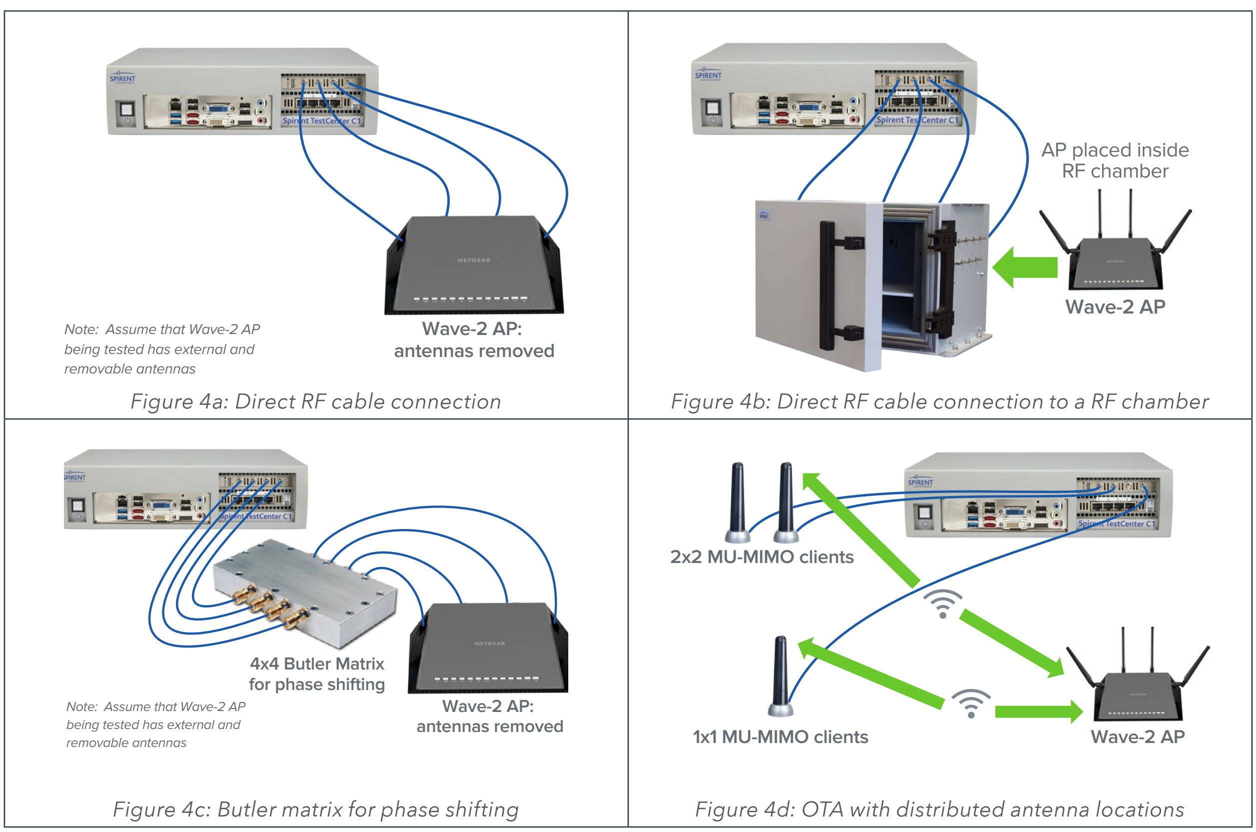

Figure 4: MU-MIMO Test Bed Setup

Needless to say that throughput is more directly linked to the measures of KPIs of user quality of experience (QoE) in a network. IEEE 802.11 WLAN is a contention-based protocol and, it's not un-common that a user who shares the network with many other users is having a perfect physical layer connection, but is encountering an unpleased web accessing due to poor traffic throughput. A 802.11ac Wave 2 AP supports 4x4 MIMO 80MHz channel bandwidth or even 80MHz +80MHz and 160MHz channel bandwidth on a 5GHz frequency band. Although the maximum PHY rate can be exactly calculated given a PHY configuration, the throughput can still be varying with different implementations.

It can be reasonably assumed then that the achievable throughput is around between 80% and 90% of PHY rate for 802.11ac Wave 2, refer to Table 2. One can see that WLAN has the throughput ability to move beyond the 1Gbps barrier with 802.11ac Wave 2. In other words, wireless traffic from clients and access points will exceed the capacity of the 1Gbps Ethernet uplink from an AP that is still commonly used for the most commercial available APs. Unless an AP can support a higher scale Ethernet uplink like the 2.5Gbps/5Gbps BASE-T interface or support internally 1Gbps Ethernet traffic aggregation over multiple 1Gbps Ethernet interfaces, it is difficult to obtain a higher than 1Gbps throughput over wireless with those Wave 2 APs with only 1G Ethernet interface support. Fortunately, the latest Spirent TestCenter WLAN supports all 100Mbps/1Gbps/2.5Gbps/5Gbps/10Gbps rates to cover a full range of the Wave 2 testing for the newer Wave 2 APs that may now come with a higher than 1G Ethernet uplink interface.

802.11ac Wave 2 provides new maximum PHY rates based on the number of spatial streams and modulation as shown in Table 2. In reality, the maximum User Datagram Protocol (UDP) throughput can usually be achieved, assuming the environment is noise and interference free and assuming further there are only a few devices connected to an AP, thus sharing the same air interface medium. Throughput can be dramatically decreased when there are many devices sharing the same AP for the network traffic services.

It can be straightforward to test that if an AP with 4x4 MIMO support can achieve the maximum PHY rate 1.7Gbps when the 4x4 client is connected. Usually, this needs properly setup attenuation for the RF cabled conductive connection so that the Received Signal Strength Indicator (RSSI) is in a decent range (usually -20dBm to -60dBm) for the maximum modulation and coding scheme MCS9 in 802.11ac. Once this is tested and achieved, one can also choose various MIMO modes such as 1x1, 2x2, and/or 3x3 to confirm that the maximum PHY rates and throughput listed in Table 2 under each MIMO configuration can be obtained.

There are many possible multiple client configuration scenarios that make testing and validating the gain from the Wave 2 MU-MIMO feature very complex and challenging, even when in a controlled lab environment. The IEEE 802.11ac standard says a MU-MIMO transmission from a 4x4 AP can support a total of 4 spatial streams that is the summation of multiple MU-MIMO clients having less than 4 spatial streams. However, most commercially available 802.11ac Wave 2 4x4 AP chipsets can only support up to 3 total spatial streams from the multiple MU-MIMO clients, while one spatial stream is left for a beam steering purposes.

Number of Spatial Streams	Maximum PHY Rate (Mbps)	Maximum Throughput (Mbps) (80% MAC Efficiency)
1	433.55	346.84
2	867.1	693.68
3	1300.65	1,040.52
4	1734.2	1,387.36

Table 2: 802.11ac Wave 2 Maximum PHY Rate and UDP Throughput

Number of Device	MIMO Configuration	SU-MIMO Throughput (Mbps)	MU-MIMO Throughput (Mbps)	MU-MIMO Gain
2	1x1,1x1	~350	~700	~2
2	1x1,2x2	~450	~950	~2
3	1x1,1x1,1x1	~350	~950	~3
2	2x2,2x2	~700	~1300	~2
2	1x1,3x3	~650	~1300	~2
3	1x1,1x1,2x2	~400	~1300	~3
4	1x1,1x1,1x1,1x1	~350	~1300	~4

Table 3: MU-MIMO Performance Gain Benchmark

Table 3 shows possible MU-MIMO client grouping cases with various possible mixes of the clients. The first 3 cases of the grouping are supported with the most commonly found off-the-shelf AP products available, and all 7 cases of the grouping represent all possible combinations of multiple client groupings for the MU-MIMO for an 802.11ac Wave 2 AP with 4x4 MIMO. A usually asked question how an AP handles a grouping for MU-MIMO transmission if a mix of many MU-MIMO clients is irregularly, this can also be answered with the test cases designed to be repeatable. It is not difficult to understand that, in a real deployment, the multiple clients are often randomly mixed with both MU-MIMO capable Wave-2 clients and SU-MIMO clients. In those cases, the performance gain from MU-MIMO can be very different amongst varying scenarios and may report different results at different test times.

Assume that an AP can support up to 4 1x1 MU-MIMO clients and other MU-MIMO grouping configurations as listed in Table 3. One can expect the throughput performance gain from MU-MIMO as shown in Table 3, where the first 3 cases of the results can be validated with some commonly found off-the-shelf Wave 2 APs. However, at the time of this writing, it has been hard to achieve and validate test case 4 to 7, until the chipset vendors improve the MU-MIMO algorithms implemented. Nevertheless, various test cases with a mix of MU-MIMO clients and SU-MIMO clients can also be created by using Spirent TestCenter WLAN to further explore the performance enhancement patterns and statistics with the Wave 2 MU-MIMO innovation.

For more detailed information, download the Spirent TestCenter WLAN data sheet at https://www.spirent.com/Products/TestCenter/Platforms/Modules

Conclusions

The emergence of these latest WLAN enhancements available in 802.11ac Wave 2, allows network equipment manufacturers (NEMs) and network operators to upgrade their access points to the latest carrier-grade and enterprise-grade technology, thus improving capacity, performance, reliability, and security. Since end-users expect WLAN technologies to be ubiquitous, it is vital to demonstrate the new 802.11ac Wave 2 capabilities with the latest WLAN multi-client emulation testing tool available on the market today. Spirent TestCenter WLAN Wave 2 solutions can be employed for functionality and performance testing of IEEE 802.11ac Wave 2 Access Points (APs) and end-to-end testing of WLAN ecosystems that include access controllers and gateways.

Testing and benchmarking throughput of sharable traffic for each user within a WLAN network is extremely valuable to the service providers to quantify good quality of service (QoS), in contrast to simply checking the physical layer's connectivity. Remember, it is essential for a successful implementation to define a well-prepared test bed setup which can be especially difficult to do within complex RF environments. Once these test bed requirements are fully understood, it is only then that the test engineer can design a well-defined test plan, then execute to that plan in a fully automated fashion. Finally, a satisfactory assessment of Wave 2 products within a controlled lab setting, that replicates real-world activities, is the only way to assure a high level of QoE and QoS.

References

[1] IEEE 802.11ac™-2013 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–Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz

[2] Next Generation Wireless LANs: 802.11n and 802.11ac: 2nd Edition, by Eldad Perahia and Robert Stacey, Cambridge University Press; June 2013

[3] 802.11ac: A Survival Guide Wi-Fi at Gigabit and Beyond, By Matthew S. Gast, O'Reilly Media, July 2013

[4] Spirent TestCenter WLAN Datasheet, https://www.spirent.com/Products/TestCenter/Platforms/Modules

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