

Wi-Fi / LTE-U Coexistence and the User Experience

A third-party assessment of Wi-Fi and LTE-U sharing spectrum and its impact on the user experience

Supported by Verizon Wireless and Qualcomm, Inc.

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Background

- Signals Research Group (SRG) conducted a third-party performance analysis of Wi-Fi and LTE-U coexistence.

Channel Selection and Channel Hopping

- Tests the ability of an LTE-U small cell to select the “best” available Wi-Fi channel
- Determine the ability of the LTE-U small cell to detect a new source of interference in the selected channel and to then channel hop to the best available channel

Co-channel sharing Above Energy Detection (AED)

- Quantify the impact on throughput and channel sharing with LTE-U and compare with an additional Wi-Fi access point

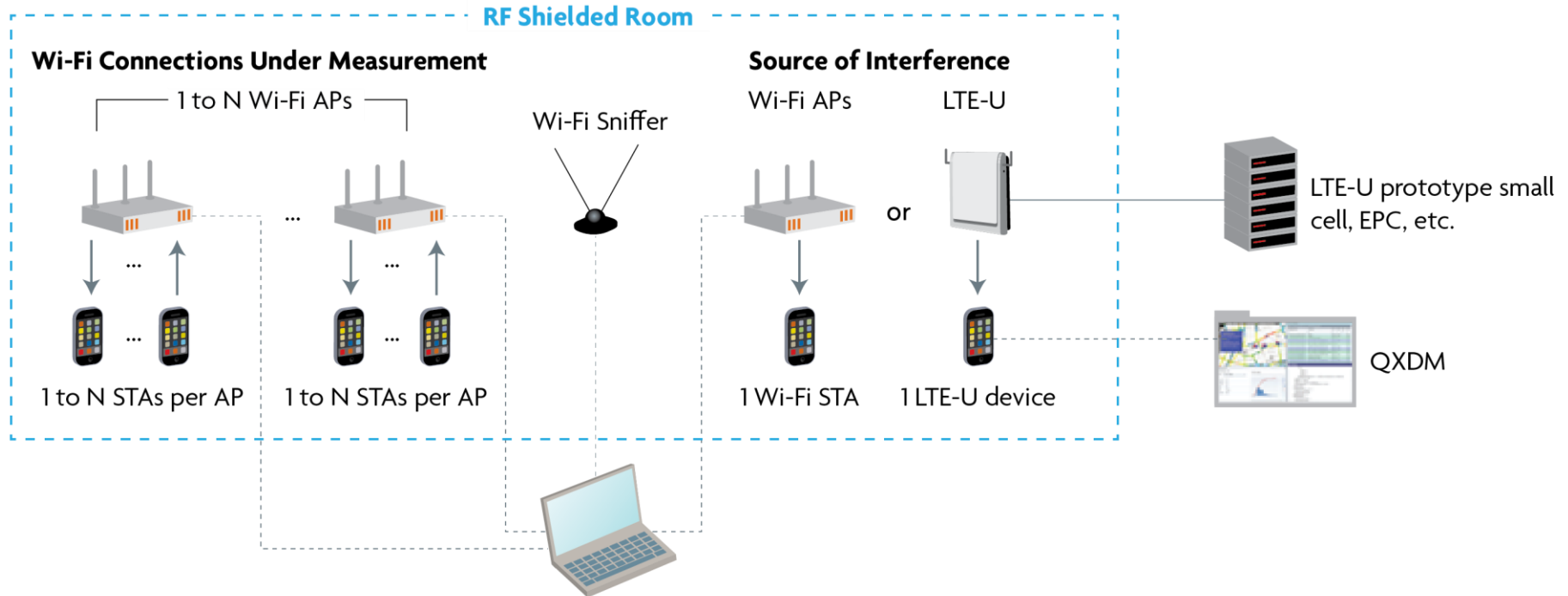
Co-channel sharing Below Energy Detection (BED)

- These tests largely mirrored the tests conducted AED; included 3 different signal quality (SNR) values

User Experience Tests

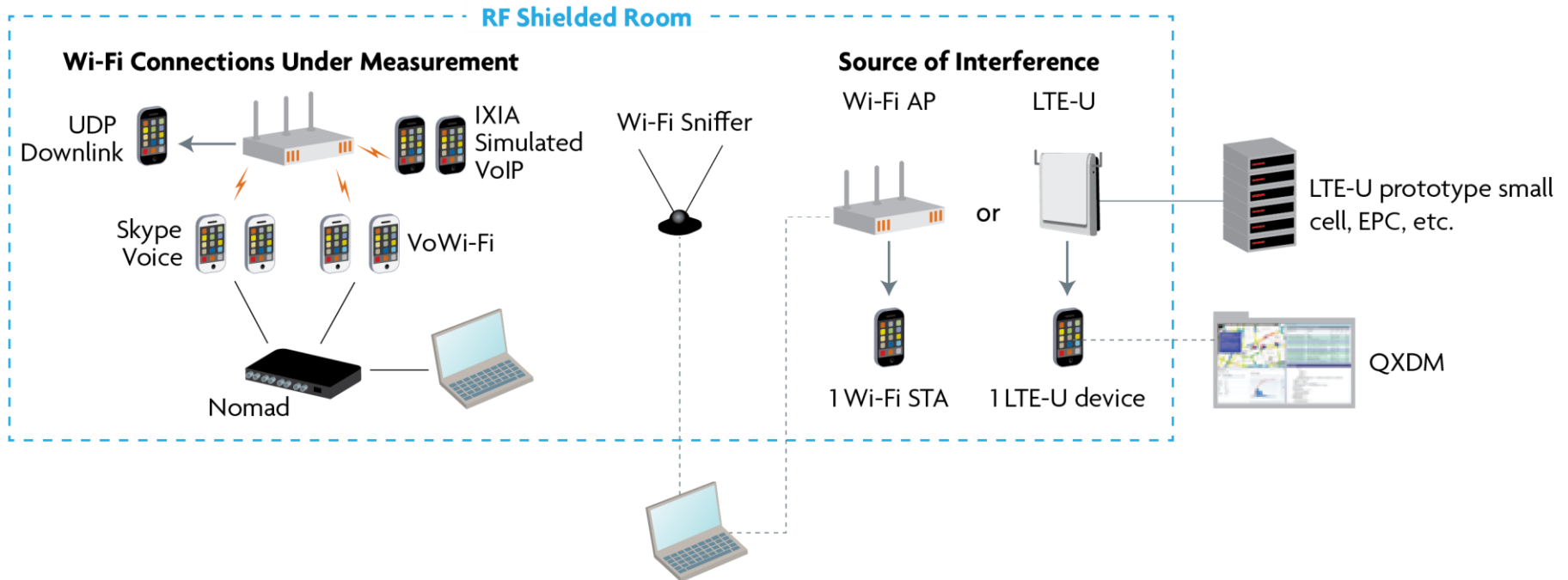
- Performance of time sensitive applications, including VoIP, video chat and video streaming over Wi-Fi when sharing the channel with LTE-U
- Leveraged Spirent Communications Nomad (voice) and Chromatic (video) solutions

Test Setup and Lab Configuration



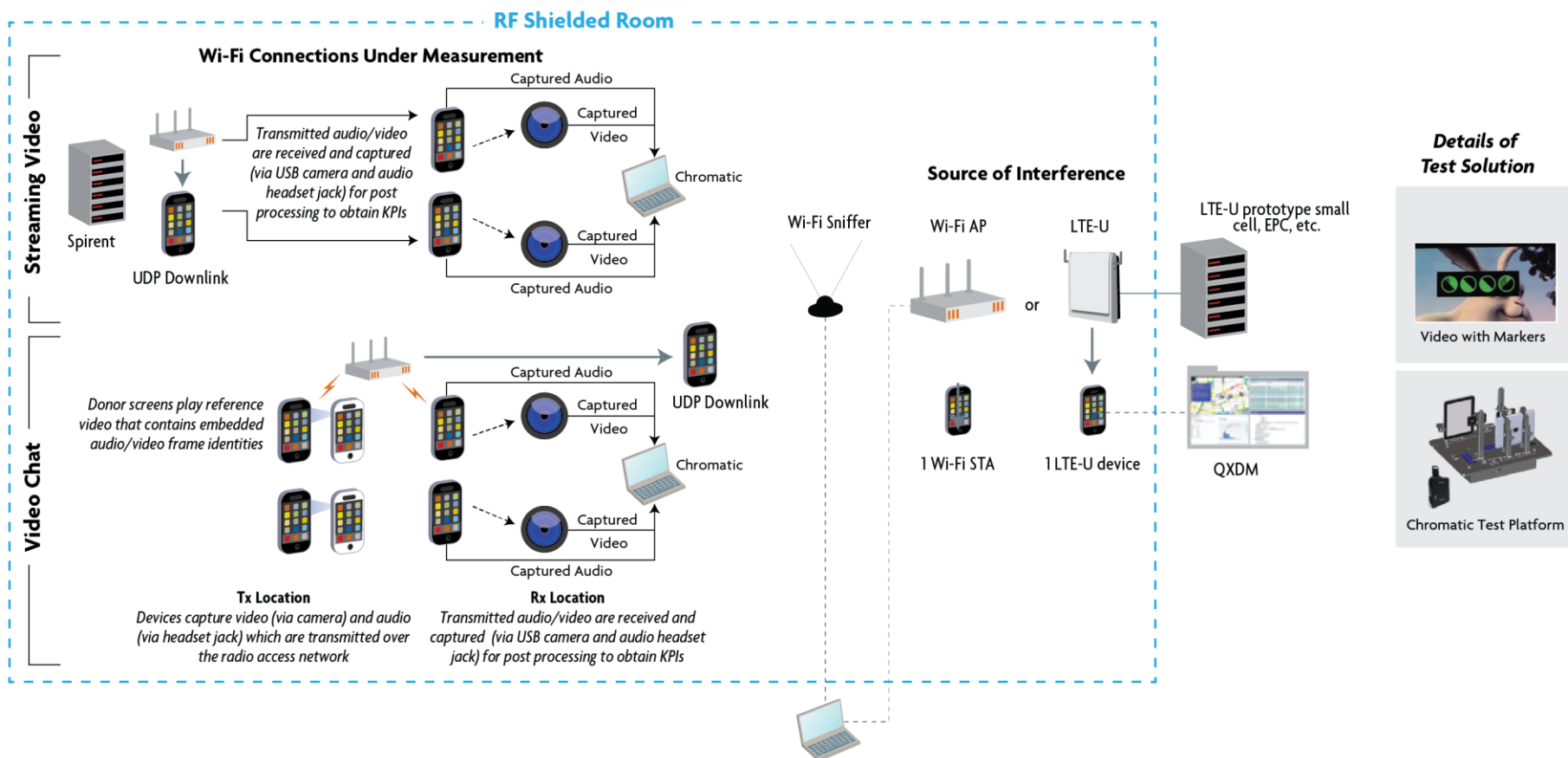
- LTE-U transmitted full buffer UDP downlink traffic on the unlicensed channel
- Used Ixia's Chariot, a Wi-Fi sniffer and QXDM to control and measure performance
- All fairness tests involved the same number of transmitting sources – we swapped LTE-U downlink for an additional Wi-Fi access point (AP) downlink
- Measured performance of Wi-Fi connections under measurement based on aggregate throughput of Wi-Fi APs and channel fairness

User Experience Test Setup - Voice



- Voice tests consisted of six bidirectional VoIP calls (VoWi-Fi, Skype Voice and Simulated VoIP (Chariot)) with background Wi-Fi and LTE-U traffic
- Leveraged the Spirent Communications Nomad User Experience Analytics Platform to measure the voice quality of the Skype and VoWi-Fi calls using the industry accepted POLQA algorithms
- Tests focused primarily on the 3 best Wi-Fi AP models under a wide range of conditions

User Experience Test Setup - Video



- We benchmarked FaceTime, Skype Video and streaming video using various bit rates and resolutions
- Chromatic is a vision-based measurement tool that analyzes video delivery, including freeze time and video impairments

Key Metrics

- We analyzed LTE-U and Wi-Fi co-existence using the following metrics:

Cumulative Normalized Throughput

- Total summation of all Wi-Fi downlink and/or uplink throughput from the transmitting Wi-Fi sources under test
- Excludes the full buffer downlink throughput from the additional Wi-Fi AP as well as LTE-U
- Throughput is normalized to ensure equivalent measurement time intervals / channel allocation times between the Wi-Fi + LTE-U and Wi-Fi + Wi-Fi tests since some Wi-Fi APs seize the channel for more or less time than they allowed based on the number of transmitting sources and the premise (based on CSMA) that they should all get equivalent access time

Transmit Allocation Time

- The amount of time on a percentage basis that each radiating source, including all Wi-Fi APs, STAs, and LTE-U, used the unlicensed channel
- Includes overhead, due to CSMA overhead and time intervals when there weren't any Wi-Fi data transmissions

User Experience KPIs

- Described later, but all based on industry-accepted metrics

Key Observations - Summary

- Unlike many Wi-Fi APs that we tested, LTE-U does everything possible to seek unused / under-utilized channels where Wi-Fi and/or other sources of potential interference do not exist with a preference for a secondary channel (SCH) over a primary channel (PCH)
- When LTE-U must share a channel with Wi-Fi, it makes fair use of the channel – the transmit time is proportional to the total number of radiating Wi-Fi sources that are using the channel
- Introducing LTE-U into a PCH or a SCH that is already occupied by Wi-Fi is largely comparable to introducing another Wi-Fi AP into the channel
- There are some notable exceptions since our testing of multiple Wi-Fi APs and terminals (i.e., smartphones) found that certain Wi-Fi APs and terminals do not appear to behave in a fair manner
- We found that the impact of LTE-U on real-time applications running over Wi-Fi was relatively modest and largely comparable to the impact of introducing a new Wi-Fi AP into the channel

*** The Wi-Fi primary channel is the 20 MHz channel of a wider bandwidth Wi-Fi signal that transmits beacons, as compared to other 20MHz portions (secondary channels) of the wider bandwidth Wi-Fi signal.*

Sample Results

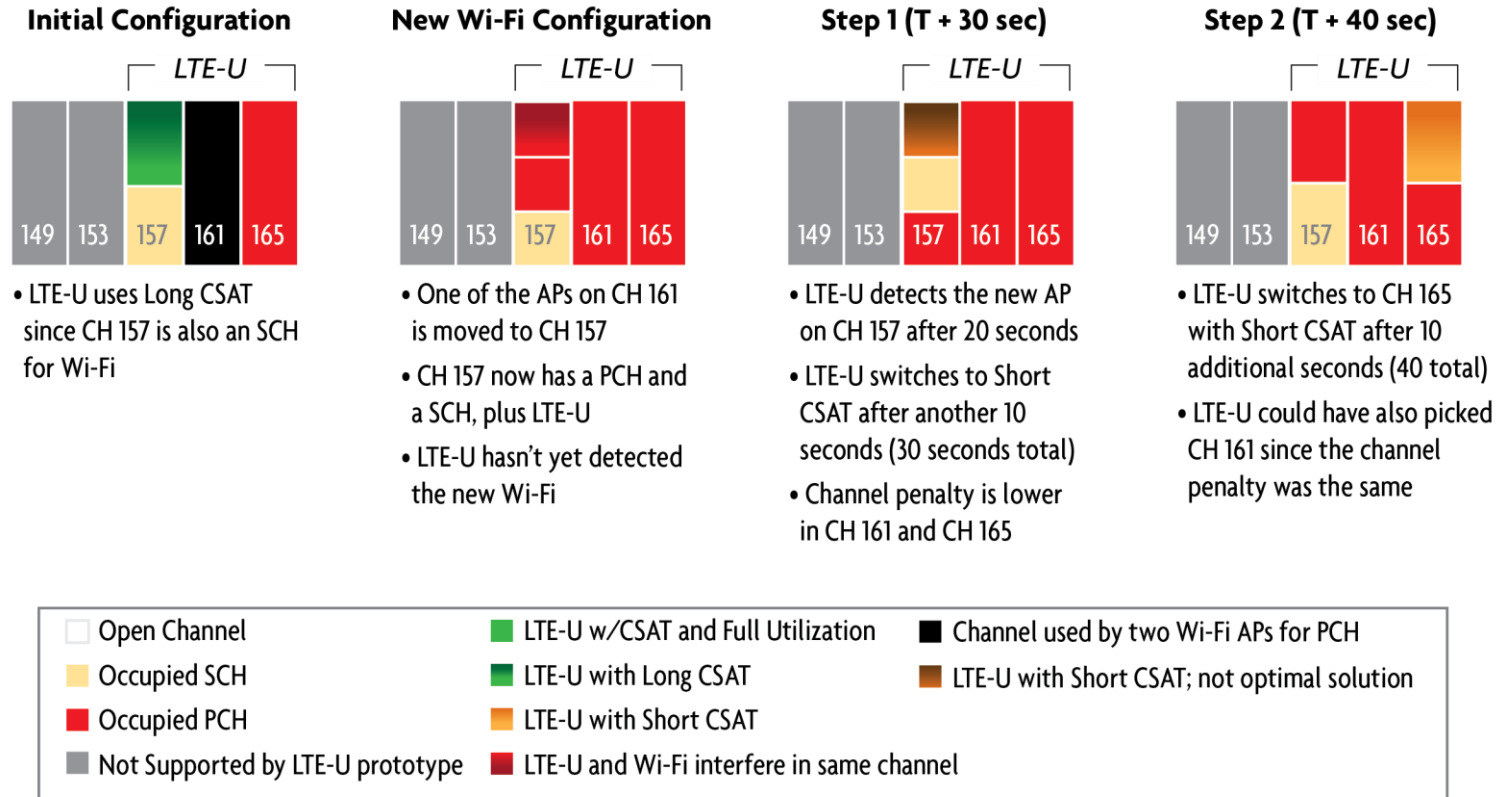
Wi-Fi Access Points and Stations Under Test

- SRG purchased many of the Wi-Fi APs and STAs that we tested, including a mix of 802.11n and 802.11ac products.
- We also leveraged some Wi-Fi products that Qualcomm already had in its lab. We had no insight (at our request) regarding how these solutions performed.
- All Wi-Fi STAs were smartphones from leading manufacturers. We generally had at least two units and up to a dozen units for each smartphone model.
- In the results, we use generic terms to identify the model under test

Smartphones	Access Points
LG G3	Netgear WNDR 4500
LG G4	Belkin AC1200
Samsung Galaxy S5	Asus TM-AC1900
Samsung Galaxy S6	Netgear R7000
HTC One M7	Asus RT66NR
iPhone 5	Cisco Linksys AE6500
iPhone 6	Cisco 3702 (enterprise)
	Aruba 224 (enterprise)

Channel Hopping Results

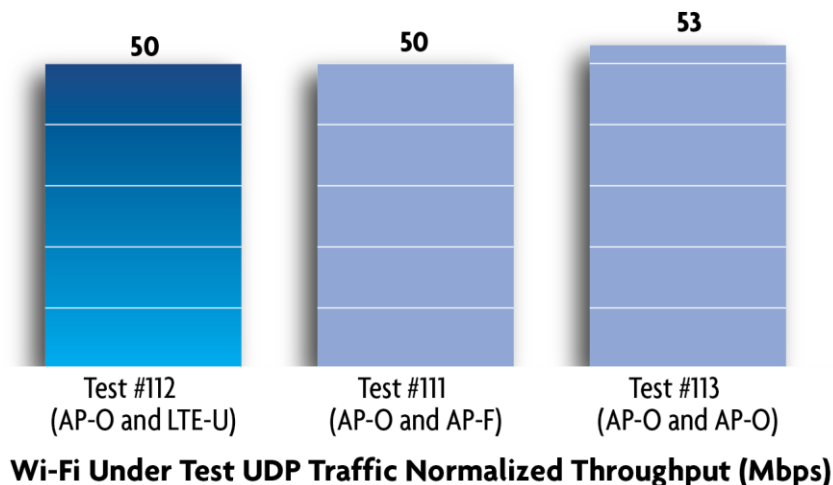
Test Scenario #12



- LTE-U detects the new source of interference and adjusts its duty cycle / transmit time to use its fair share of the channel
- LTE-U switches to another Wi-Fi channel with a lower channel penalty

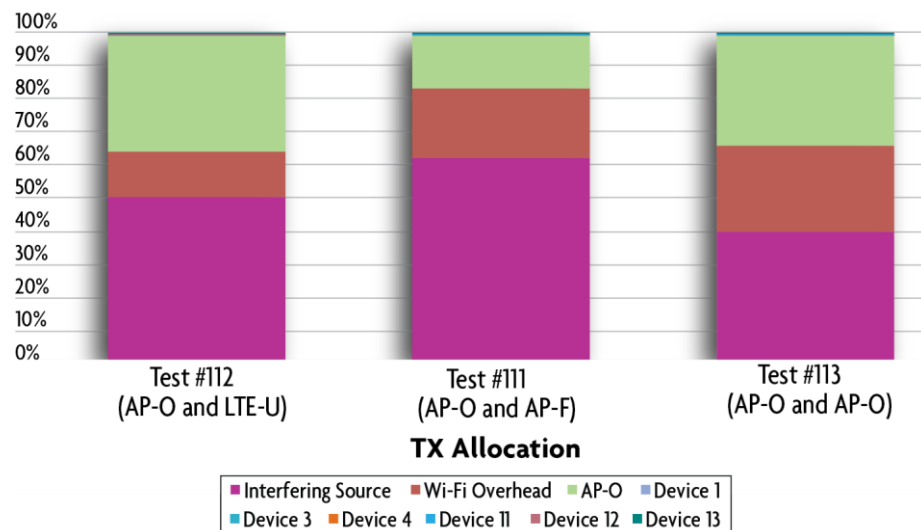
Wi-Fi AP + Interfering Source in PCH with Full Buffer Downlink Traffic and VoIP

Cumulative Throughput of Wi-Fi APs under Test with Interfering Source



- Throughput for Wi-Fi based scenarios is normalized to target allocation time
- LTE-U scenario on par with AP-F and slightly below AP-O scenario
- Some variability in results across tests is natural, indicating all performance results are generally the same

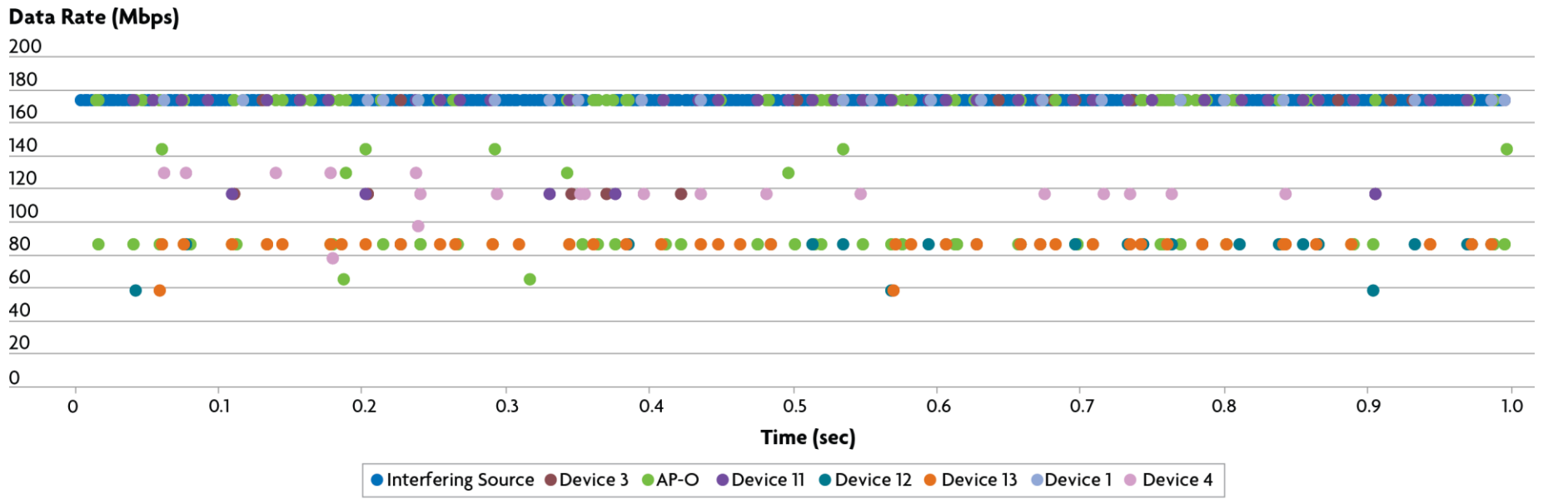
Channel Allocation of Wi-Fi APs and STAs under Test with Interfering Source



- LTE-U used the channel for 50% of the time – its fair allocation
- AP-F took well more than its fair share (62%), which also increased overhead
- AP-O (Test #113) took less than it should have (39%), plus high overhead

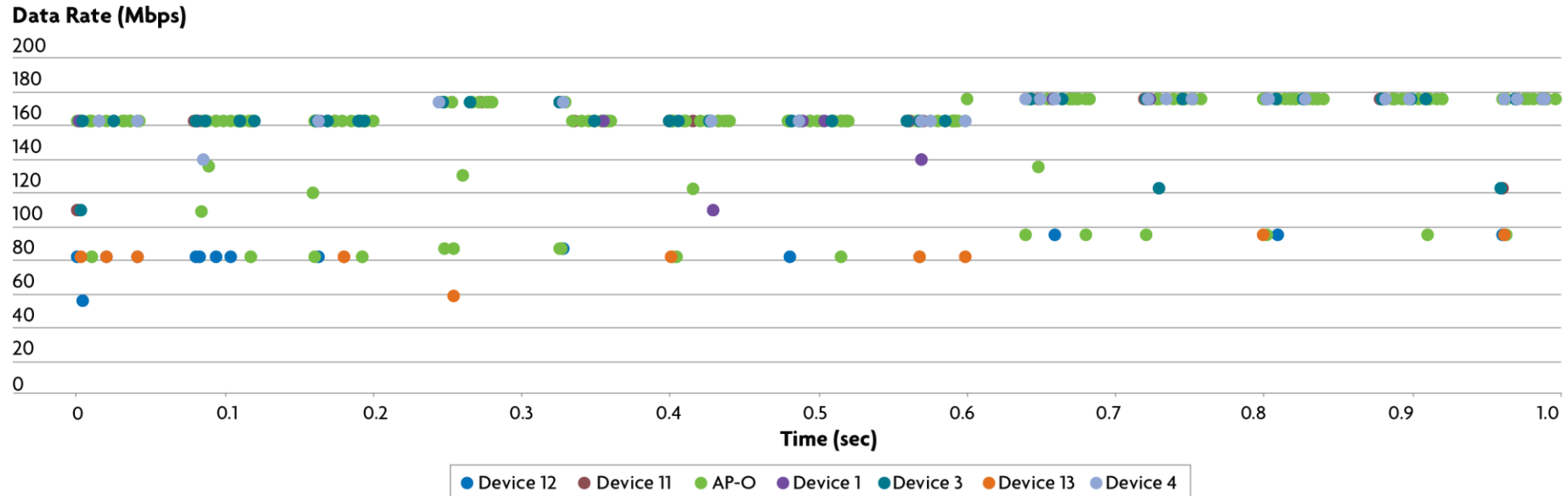
Wi-Fi AP + Interfering Source in PCH with Full Buffer Downlink Traffic and VoIP

Instantaneous Wi-Fi Throughput with AP-O in PCH (AP-F is interfering source)



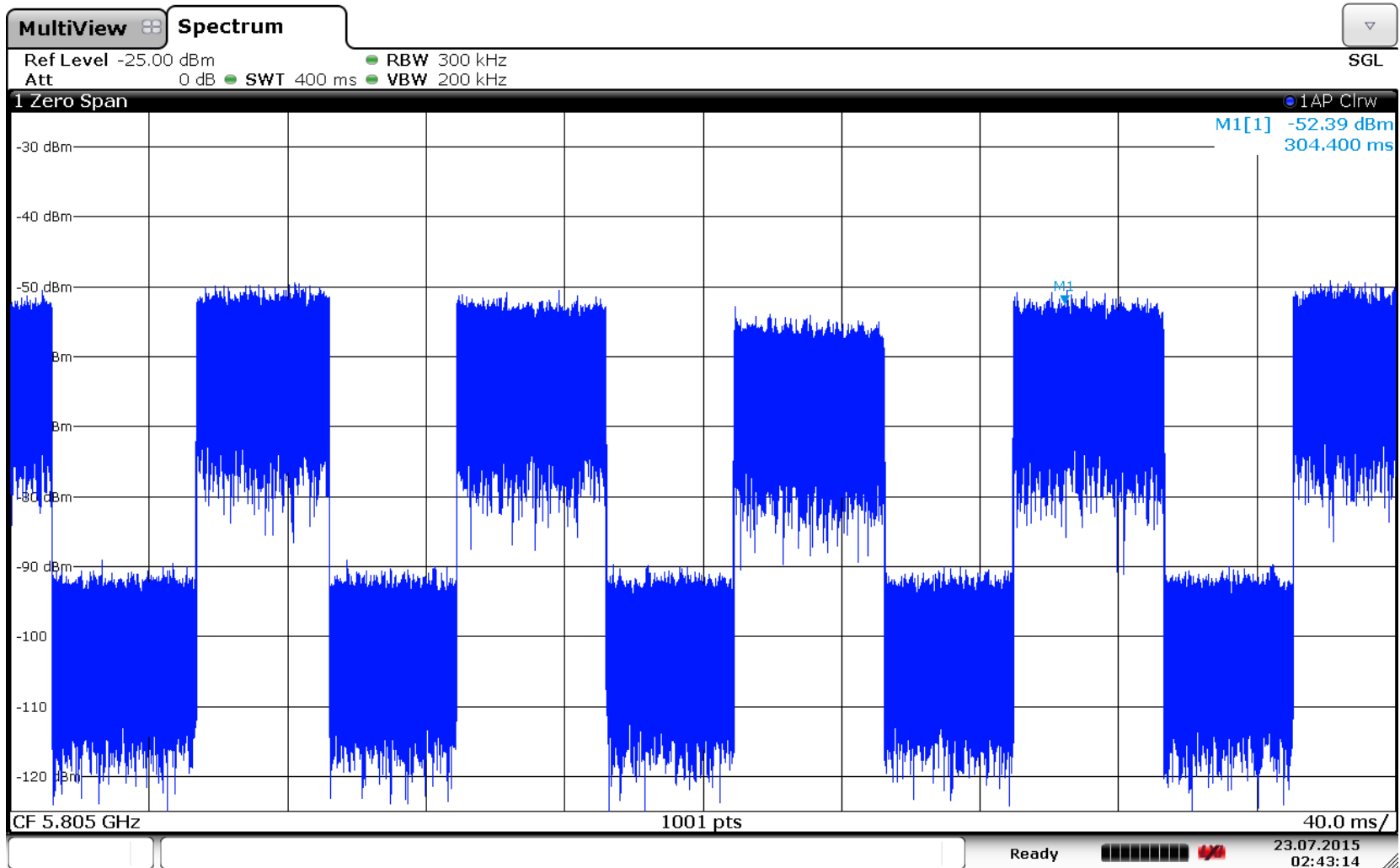
Wi-Fi AP + Interfering Source in PCH with Full Buffer Downlink Traffic and VoIP

Instantaneous Wi-Fi Throughput with AP-O in PCH (LTE-U is the interfering source)



- LTE-U On/Off cycle is clearly evident
- LTE-U will use a 40 ms on duration when sharing with Wi-Fi on the primary channel
- Wi-Fi seems to recover fine after LTE-U transmission stops
- Wi-Fi + Wi-Fi behavior is very comparable to above, but without the periodic LTE-U transmissions

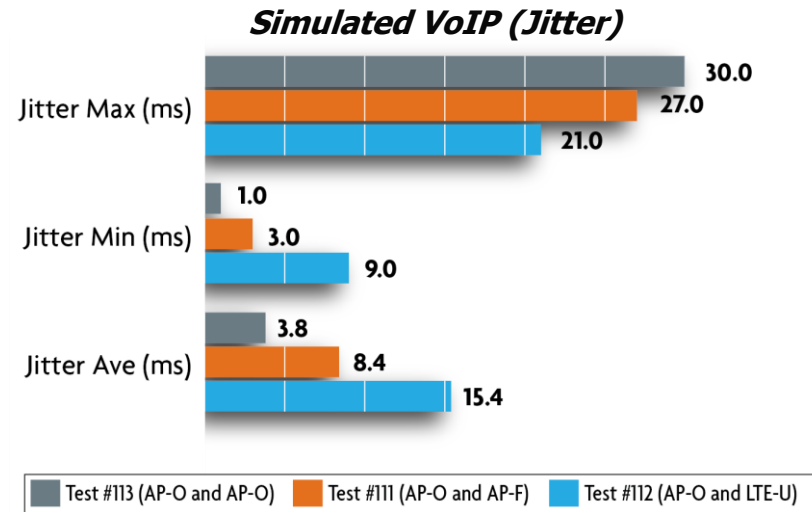
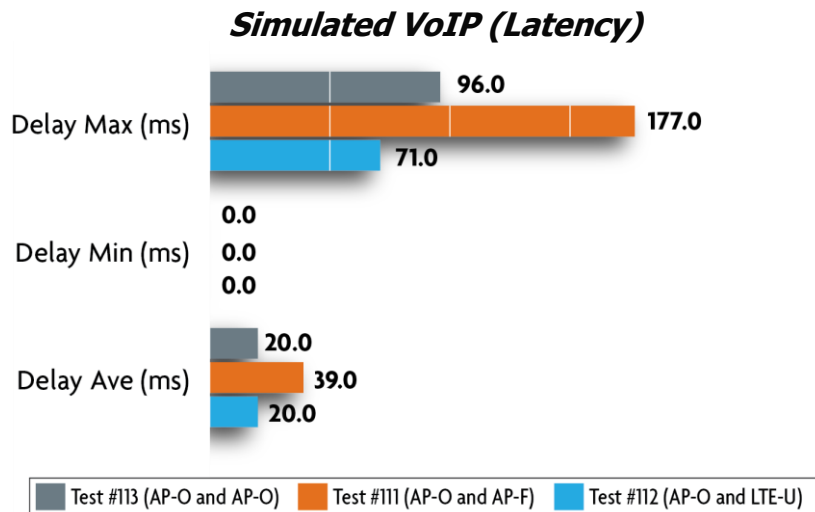
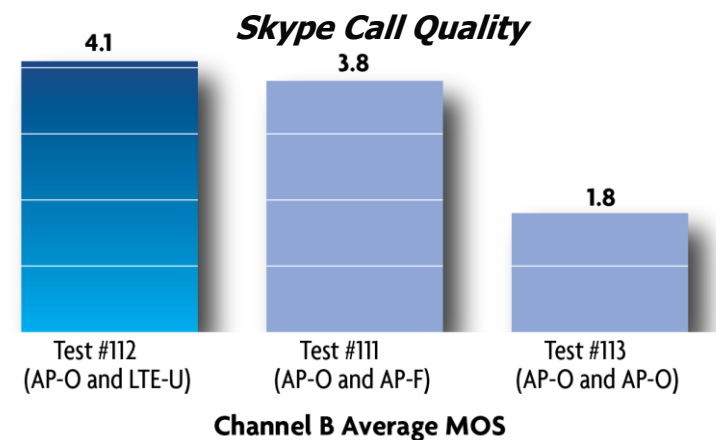
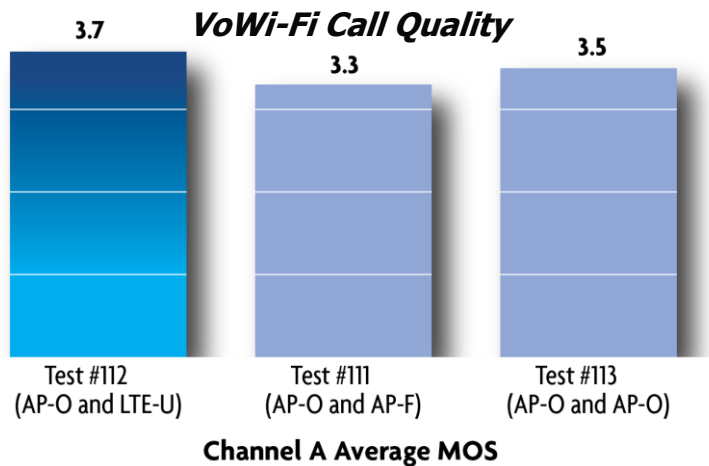
LTE-U Channel Sharing in Action



- Rohde & Schwarz FSW spectrum analyzer confirms LTE-U behavior when sharing a primary channel

VoIP User Experience Results

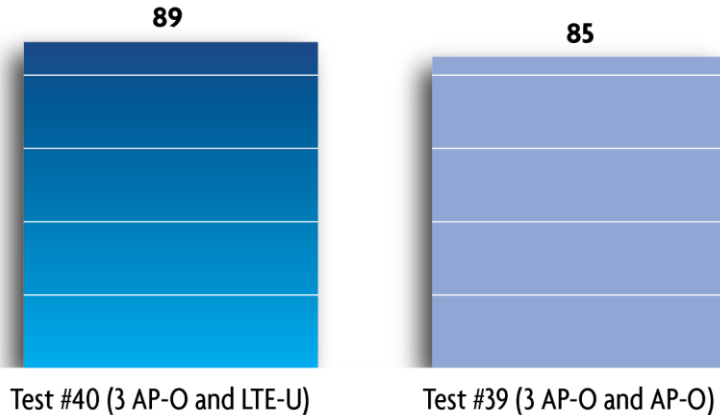
Test Scenarios #111 - #113 (cont'd)



- The LTE-U scenario achieved the highest call quality for both VoWi-Fi and Skype Voice; average one-way jitter and latency within thresholds

3 Wi-Fi APs + Interfering Source in PCH with Full Buffer Downlink and Uplink Traffic

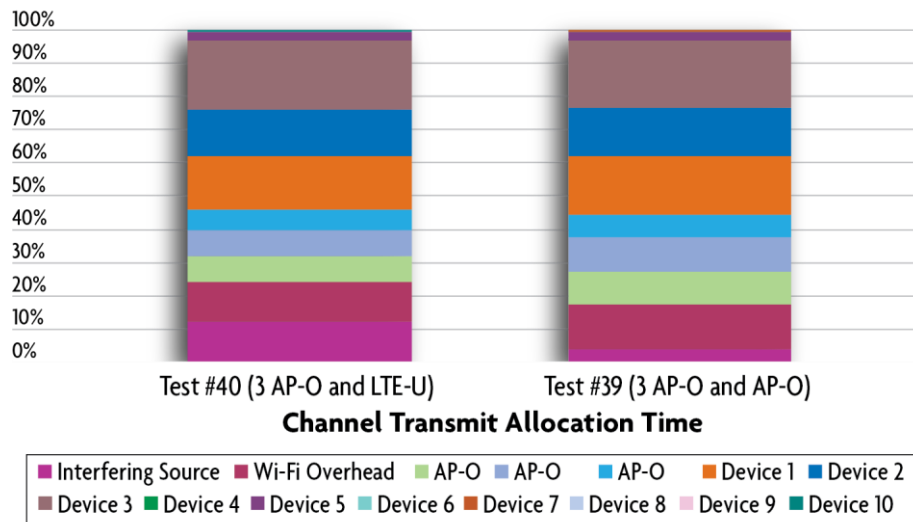
Cumulative Throughput of Wi-Fi APs under Test with Interfering Source



Wi-Fi Under Test UDP Traffic Normalized Throughput (Mbps)

- Scenario consisted of 3 APs – 3 DL/1 UL; 3 DL/1 UL; and 2 DL/2 UL transmissions plus interferer = 8 transmission sources
- Throughput reflects the summation of all downlink and uplink Wi-Fi transmissions, normalized for target access time
- LTE-U scenario achieved slightly higher throughput

Channel Allocation of Wi-Fi APs and STAs under Test with Interfering Source

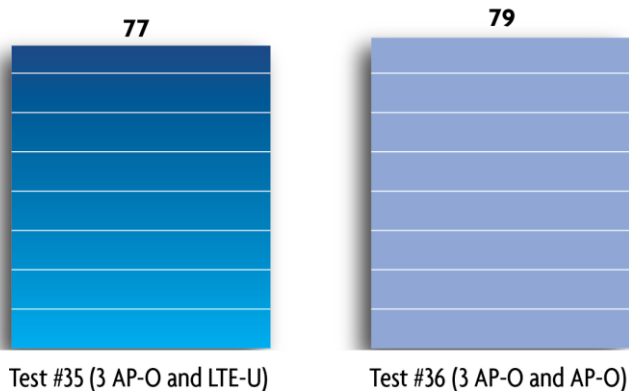


Channel Transmit Allocation Time

- LTE-U uses channel for its fair share (12.5%) based on the number of transmitting sources
- Very evident some Wi-Fi APs / smartphones were more aggressive than others
- "Device #3" took 21%
- "AP-O" only took 6%

3 Wi-Fi APs + Interfering Source in SCH with Full Buffer Uplink Traffic

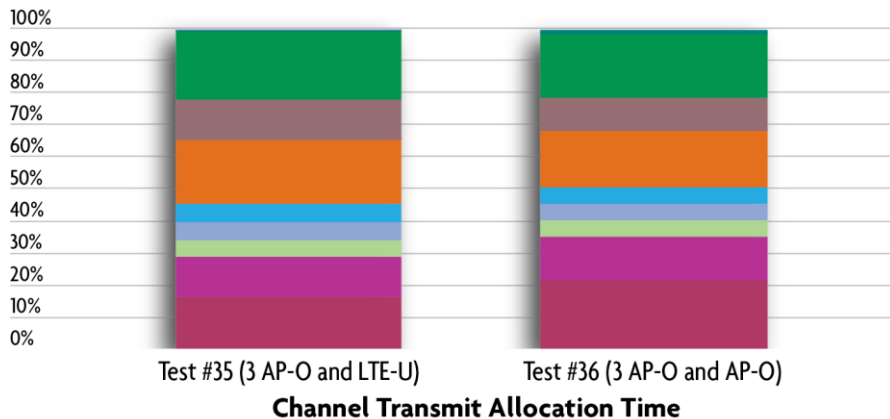
Cumulative Throughput of Wi-Fi Smartphones under Test with Interfering Source



Wi-Fi Under Test UDP Traffic Normalized Throughput (Mbps)

- Throughput reflects the summation of all uplink Wi-Fi transmissions, normalized for target access time
- LTE-U scenario achieved slightly higher throughput, with statistically on par with the Wi-Fi + Wi-Fi scenario

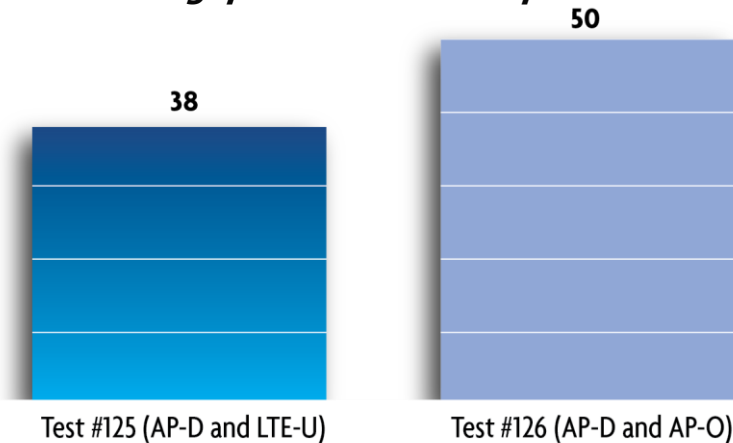
Channel Allocation of Wi-Fi APs and STAs under Test with Interfering Source



- Some smartphones were more aggressive than others – Device #1 took 20% and Device #4 took 21%
- APs only took ~5-6% channel allocation
- Overhead increased with Wi-Fi + Wi-Fi scenario

Wi-Fi AP + Interfering Source in PCH with Full Buffer Downlink Traffic and Video Chat

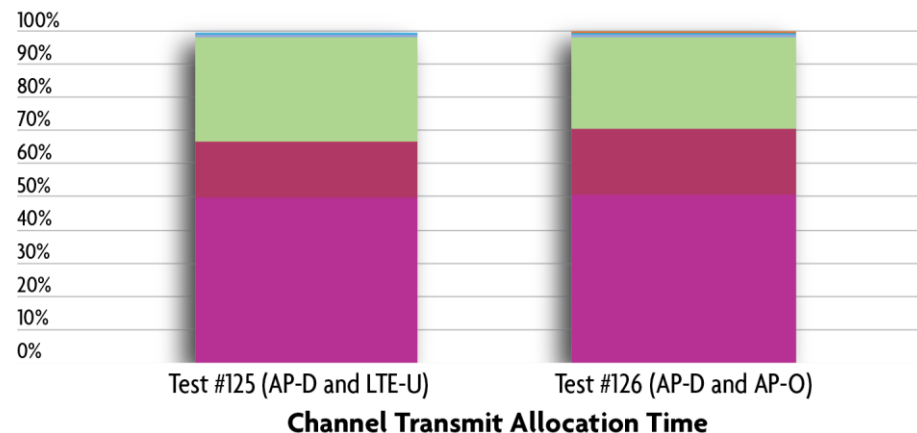
Cumulative Throughput of Wi-Fi Smartphones under Test with Interfering Source



- Throughput favors the Wi-Fi scenario
- AP-D and AP-O were two of the best access points that we tested
- In similar test with AP-N as the interferer (not shown), the LTE-U scenario achieved slightly higher throughput with AP-D

Wi-Fi Under Test UDP Traffic Normalized Throughput (Mbps)

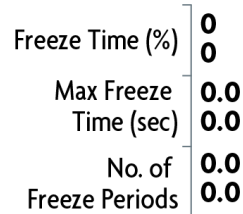
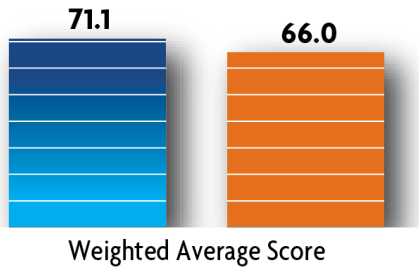
Channel Allocation of Wi-Fi APs and STAs under Test with Interfering Source



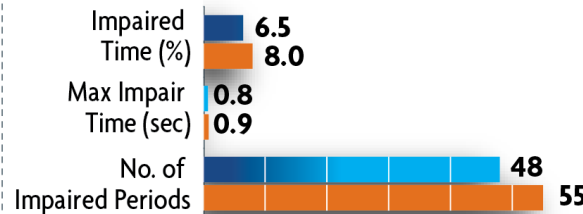
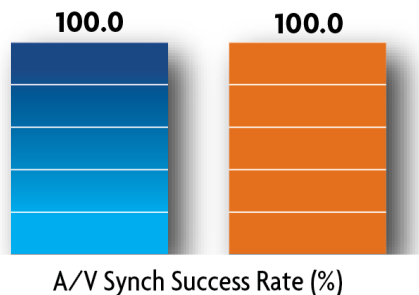
- Both scenarios show fair usage of the channel
- Video Chat application only required modest throughput / channel access time

User Experience Results – Video Chat

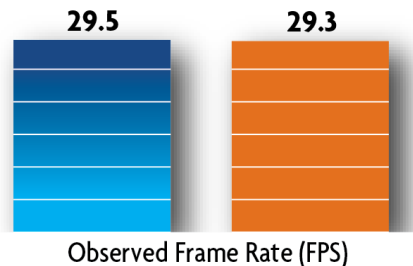
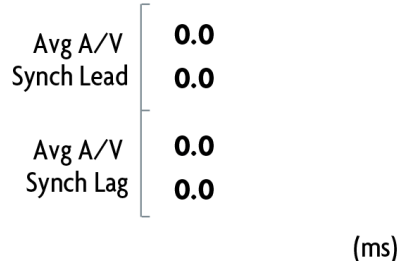
Test Scenarios #125 - #126 (cont'd)



- To the extent the video delivery was impacted, it was due to video impairments and not video freezes



- The Weighted Average Score also takes into consideration variances in the observed fps, which we show on the next slide

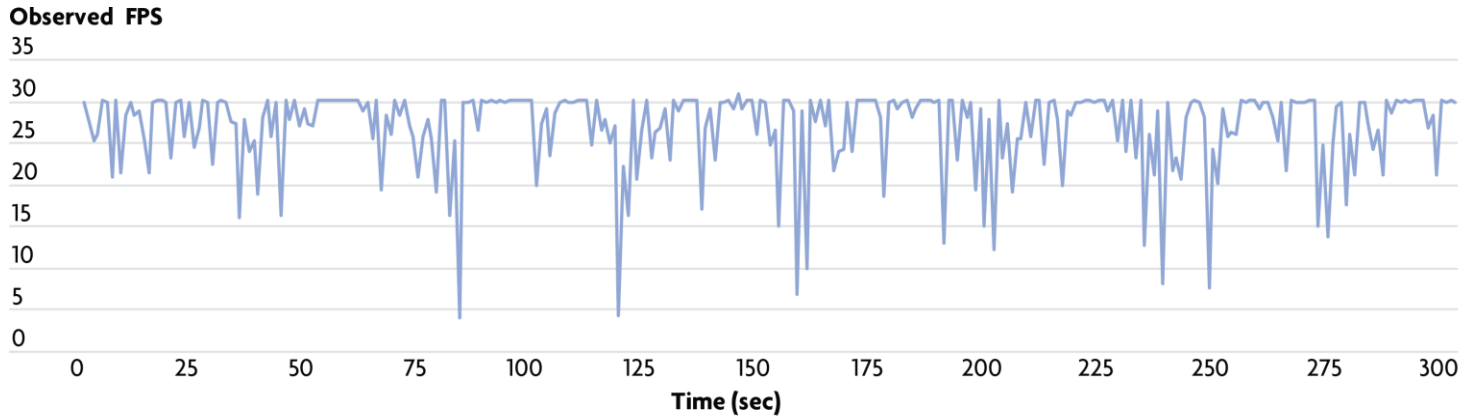


- LTE-U results were slightly more favorable

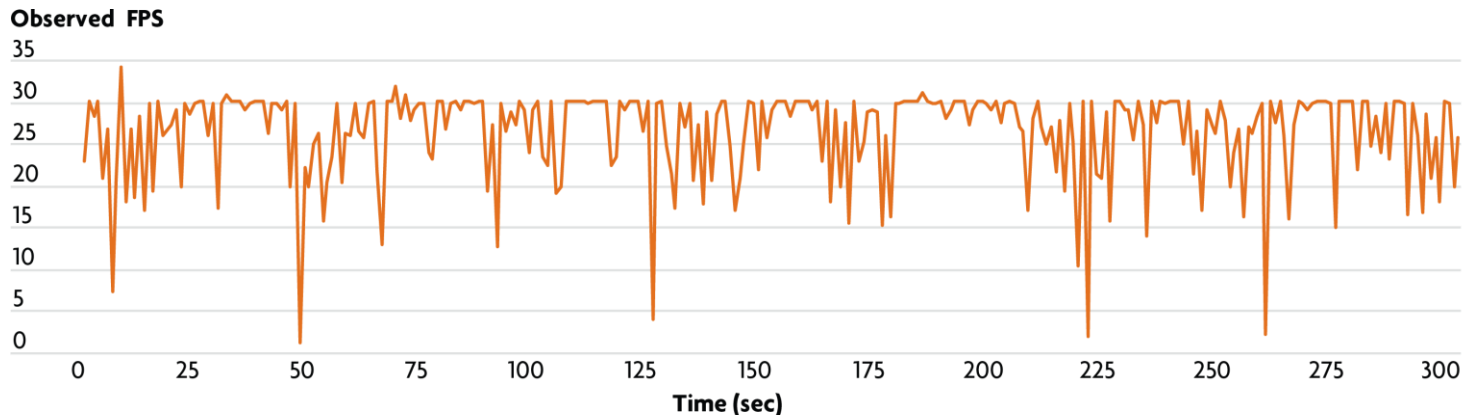
■ Test #125 (AP-O and LTE-U) ■ Test #126 (AP-O and AP-O)

User Experience Results – Video Chat

Observed Frames per Second for Test #125 (Wi-Fi + LTE-U)



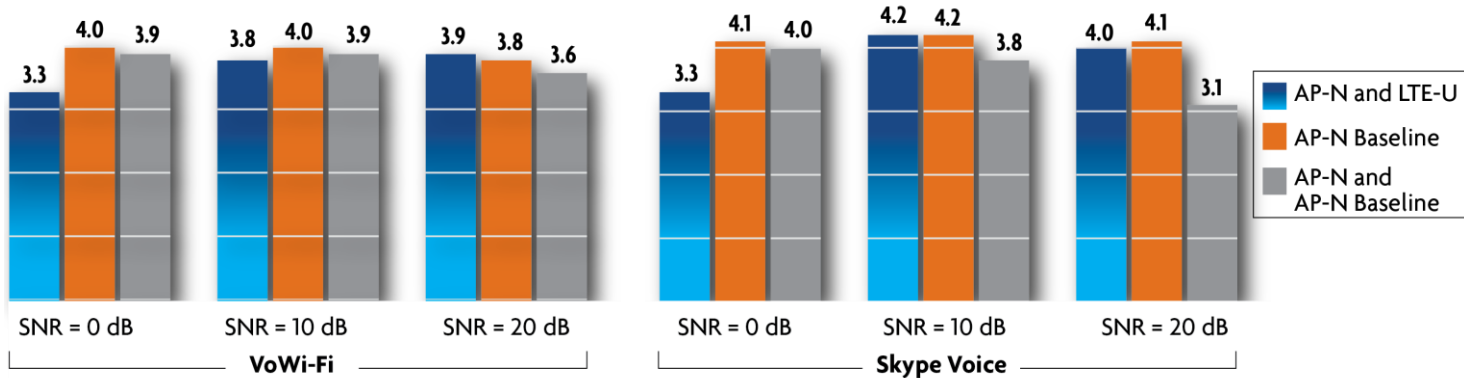
Observed Frames per Second for Test #127 (Wi-Fi + Wi-Fi)



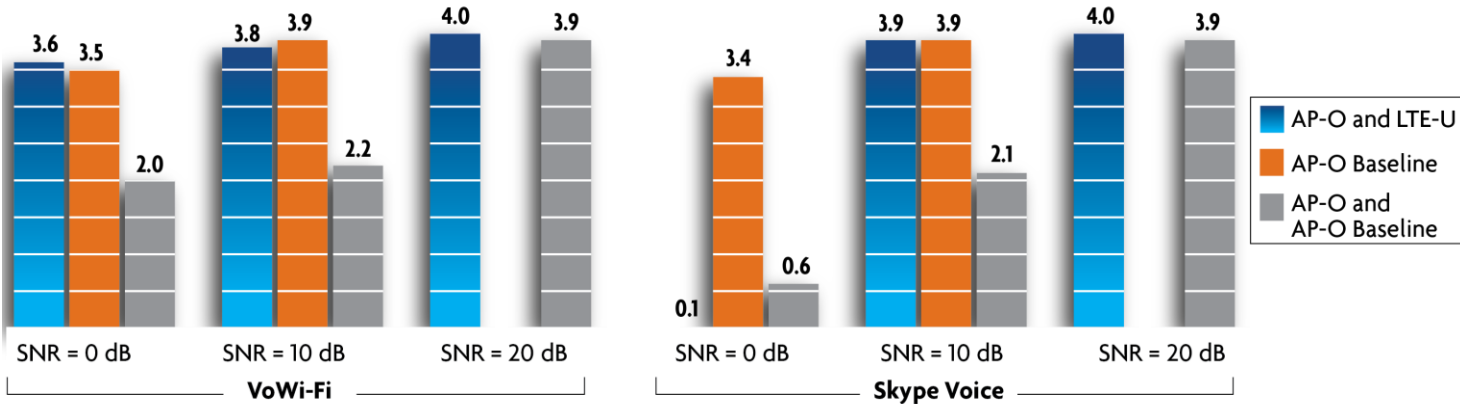
- The observed fps is slightly higher and the standard deviation is lower (4.9 versus 5.4) in the test scenario involving LTE-U as the interfering source

Wi-Fi AP + Interfering Source and Below Energy Detection with Full Buffer Downlink Traffic and VoIP

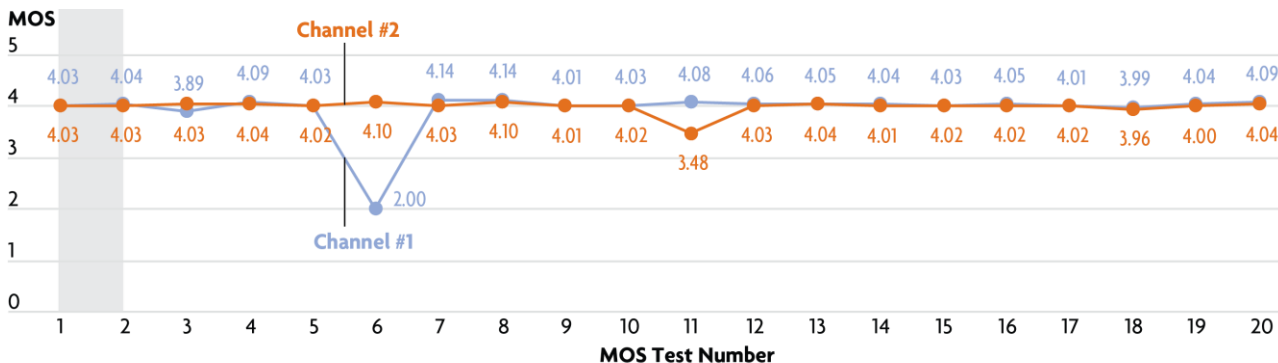
Call Quality with Interfering Source in Primary Channel



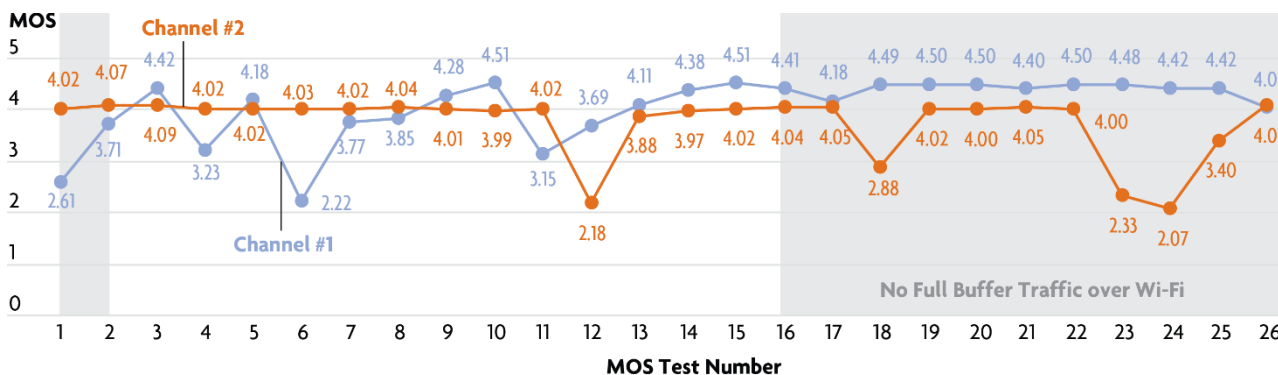
Call Quality with Interfering Source in Secondary Channel



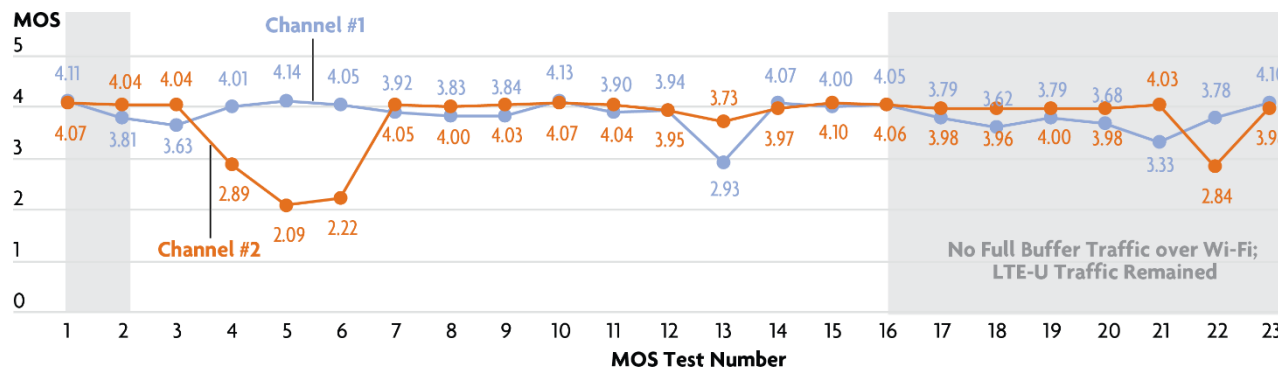
Wi-Fi AP + Interfering Source and Below Energy Detection with Full Buffer Downlink Traffic and VoIP



**VoWi-Fi with SNR = 10 dB
(Single Wi-Fi AP – Baseline)**



**VoWi-Fi with SNR = 10 dB
(Wi-Fi AP is the Interfering Source)**



**VoWi-Fi with SNR = 10 dB
(LTE-U is the Interfering Source)**

Next Steps

- Finish analysis of results
- Publish detailed presentation with a full suite of results and analysis, including more insight on our test methodology
- Webinar on September 22
- Publish a companion whitepaper
- Conduct additional testing with commercial implementation

A graphic of four concentric orange arcs above the dot of the 'i' in 'SIGNALS', resembling a radio signal or Wi-Fi symbol.

SiGNAALS

Research Group

www.signalsresearch.com