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Unlicensed Use in the 6 GHz Band: Columbus, Georgia Field Interference Test Results

Technical Brief — *Information & Communication Technology (ICT) Program, Power Delivery and Utilization Sector*

Research Question

The Federal Communications Commission (FCC) Report and Order (R&O) 20-51 allows unlicensed device operation in the upper and lower licensed 6 GHz fixed service (FS) microwave radio bands. This research conducted field testing to measure impacts on an incumbent FS system from nearby unlicensed low power indoor (LPI) devices. The LPI devices used in the testing were off-the-shelf commercial products that had obtained certification from the Wi-Fi Alliance (WFA) and were granted an FCC equipment authorization.

Key Insights

The primary, high-level conclusion is that **indoor locations along the FS centerline at distances up to 5.6 mi (9 km) with unobstructed visibility and low building entry loss provide opportunities to be a source of harmful interference from RLAN devices.** Detailed findings are:

- LPI devices were found to cause impacts greater than the FCC-established interference protection criterion (IPC) of -6 dB I/N, when operating co-channel to the FS receive station at three different indoor test locations along the boresight at distances from 902 ft (275 m) to 3 mi (4.8 km).
- Interference greater than the IPC occurred with the LPI devices operating at low speed data rates (10-100 Mbps) and high speed (>750 Mbps). At the two closest locations impacts greater than the IPC were measured with no data traffic, i.e. Wi-Fi beacons only.
- At 5.5 mi (8.9 km) and 5.8 mi (9.4 km), the two farthest indoor test locations, detectable interference was measured below the IPC value. These locations were high-rise buildings with energy-efficient construction.
- Aggregate interference effect was demonstrated and shown to be additive. This was done by operating LPI devices separately and simultaneously at the two distant high-rise buildings. However, the measured impact was small and merits further investigation.

Introduction

The FCC R&O entitled "Unlicensed Use of the 6 GHz Band" was adopted on April 23, 2020, establishing rule changes that permit the operation of unlicensed radio local area network (RLAN) devices in the U-NII-5 and U-NII-7 bands [1]. These new unlicensed bands (U-NII-5 and U-NII-7) coincide with licensed lower 6 GHz (L6) and upper 6 GHz (U6), where incumbent fixed service (FS) microwave radio systems currently operate. Figure 1 illustrates the situation, with the numbers of incumbent licensees on the vertical axis (color-coded by service type) and the band designations with their edge frequencies along the horizontal axis [2].

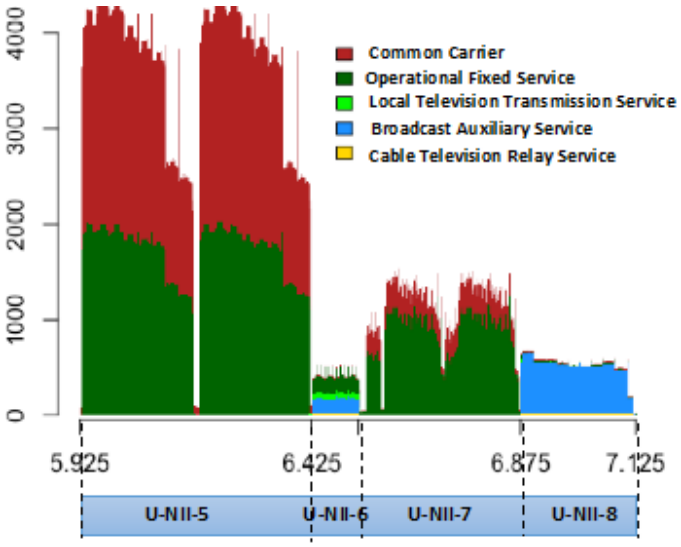

Figure 1. Overlapping U-NII and FS 6 GHz bands [2]

Table 1. R&O RLAN maximum transmit power [3]

Device Class	Operating Bands	Maximum EIRP	Maximum EIRP Power Spectral Density
Standard-Power Access Point (AFC Controlled)	U-NII-5 (5.925-6.425 GHz) U-NII-7 (6.525-6.875 GHz)	36 dBm	23 dBm/MHz
Client Connected to Standard-Power Access Point		30 dBm	17 dBm/MHz
Low-Power Access Point (indoor only)	U-NII-5 (5.925-6.425 GHz) U-NII-6 (6.425-6.525 GHz) U-NII-7 (6.525-6.875 GHz) U-NII-8 (6.875-7.125 GHz)	30 dBm	5 dBm/MHz
Client Connected to Low-Power Access Point		24 dBm	-1 dBm/MHz

Table 1 delineates the FCC limits for maximum transmit power for a radio local area network (RLAN) operating in the new U-NII-5 through U-NII-8 bands, as set out in the R&O.

General Approach

The incumbent system used for this field test was a L6 link, using Nokia equipment, owned and operated by Southern Company Services in Columbus, Georgia. The interfering RLAN signal sources used were commercial off-the-shelf products that had obtained certification from the Wi-Fi Alliance (WFA) and granted an FCC equipment authorization. The LPI devices were temporarily deployed at various indoor locations along the centerline of the FS path, without terrain or building obstructions.

Fixed Service Fade Margin

The FS link had a design fade margin of 35 dB when using high data rate quadrature amplitude modulation (1024-QAM). At the start of each test run, the link fade margin was baselined by reducing the far-end microwave terminal transmit power using a step and vernier attenuator until the bit error rate (BER) increased to the threshold value of 10^{-6}.

AFC Considerations

The R&O rules require that standard power RLAN access points be under the control of an automatic frequency coordination system (AFC). The AFC is to protect incumbent FS receivers from harmful interference from standard power RLAN access points (AP's). The calculations must be performed using the location of the RLAN AP and information from the FCC Universal Licensing System (ULS) database about nearby incumbent FS systems. Three different path loss models are specified for the calculation depending on the distance between the RLAN and the incumbent FS. The results of these calculations are to be assessed on the basis of the interference protection criterion (IPC) of -6 dB interference to noise (I/N) [4].

The end result is that the AFC provides a list of available frequencies to the AP. For each frequency range, the maximum permissible power at the AP's geographic coordinates is specified in 3 dB steps, starting with 36 dBm and stepping down to (at least) a minimum level of 21 dBm.

Standard power AP's will be required to "access an AFC system to determine the available frequencies and the maximum permissible power in each frequency range at their geographic coordinates prior to transmitting." [5]

While this field test used only low-power non-AFC controlled devices, the results have relevance to standard-power AFC controlled devices, which may be located indoors. AFC system development is in process, and input parameters to the calculations are being deliberated within the standards development organizations (Wi-Fi Alliance and Winnforum) and the 6 GHz multistakeholder group (MSG). Measured results from this field test could be used as test vectors to validate the final AFC system designs.

LPI Considerations

Low power indoor (LPI) RLAN devices, either AP or client, are exempt from AFC control in the R&O. As detailed in Table 1, the LPI devices operate at lower power than standard power devices. This lower power in combination with building entry loss (BEL) is the primary means of interference protection described in the R&O. The BEL value of 20.5 dB was identified by the FCC as the median value that supported a conclusion of omitting LPI devices from AFC control [6].

The test plan included operating the LPI AP's in different indoor positions at each geographic location to experiment with variations in building entrance loss.

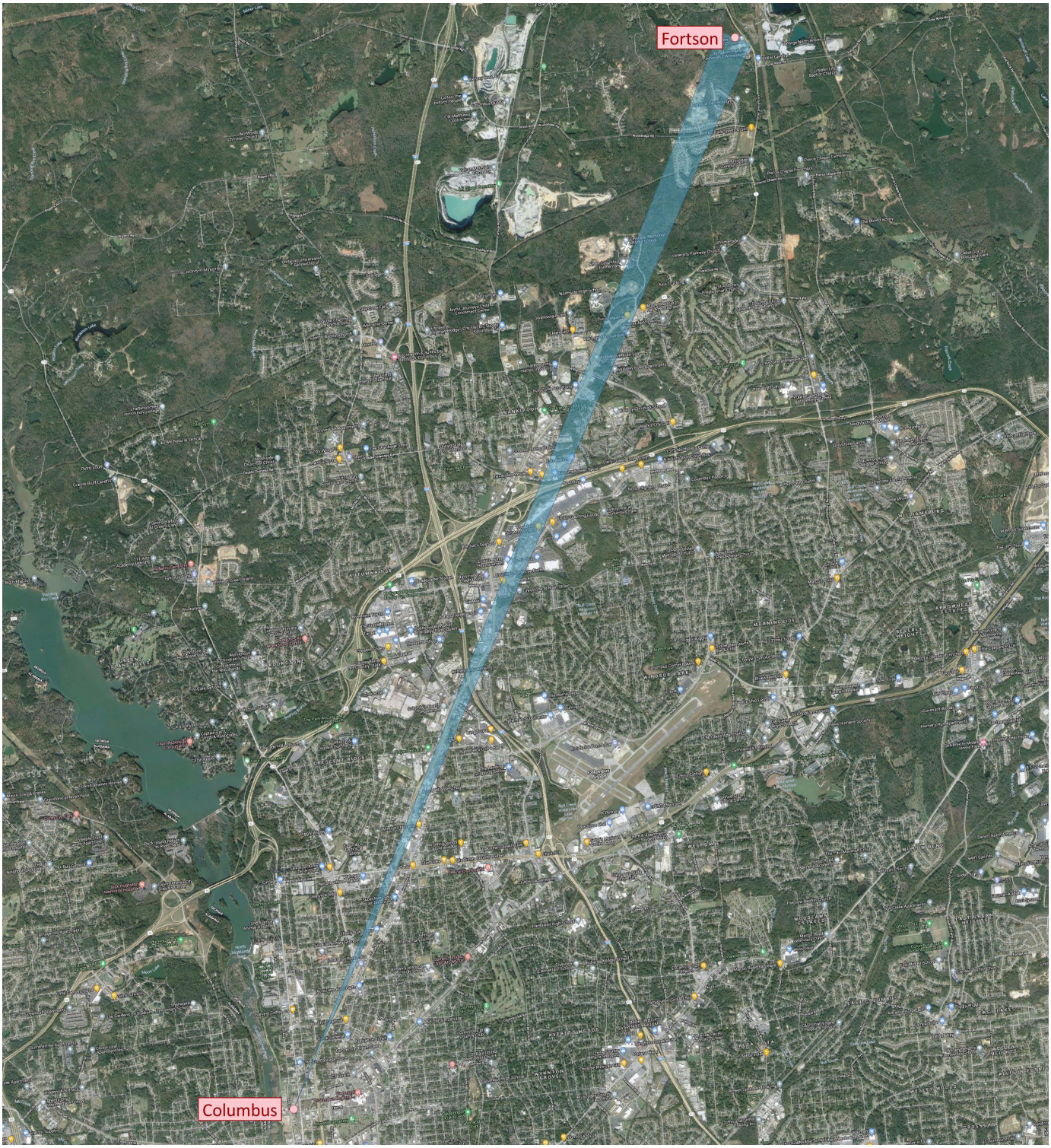

Figure 2. Incumbent FS test link

Incumbent Link

The incumbent FS system used in the test was a 9.5 mi (15.3 km) link between Columbus and Fortson, Georgia that uses a 30 MHz channel. The FS antennas for this link each have a 3 dB beamwidth that is 1.5 degrees wide. The 3 dB pattern for the Columbus terminal is shown in Figure 2.

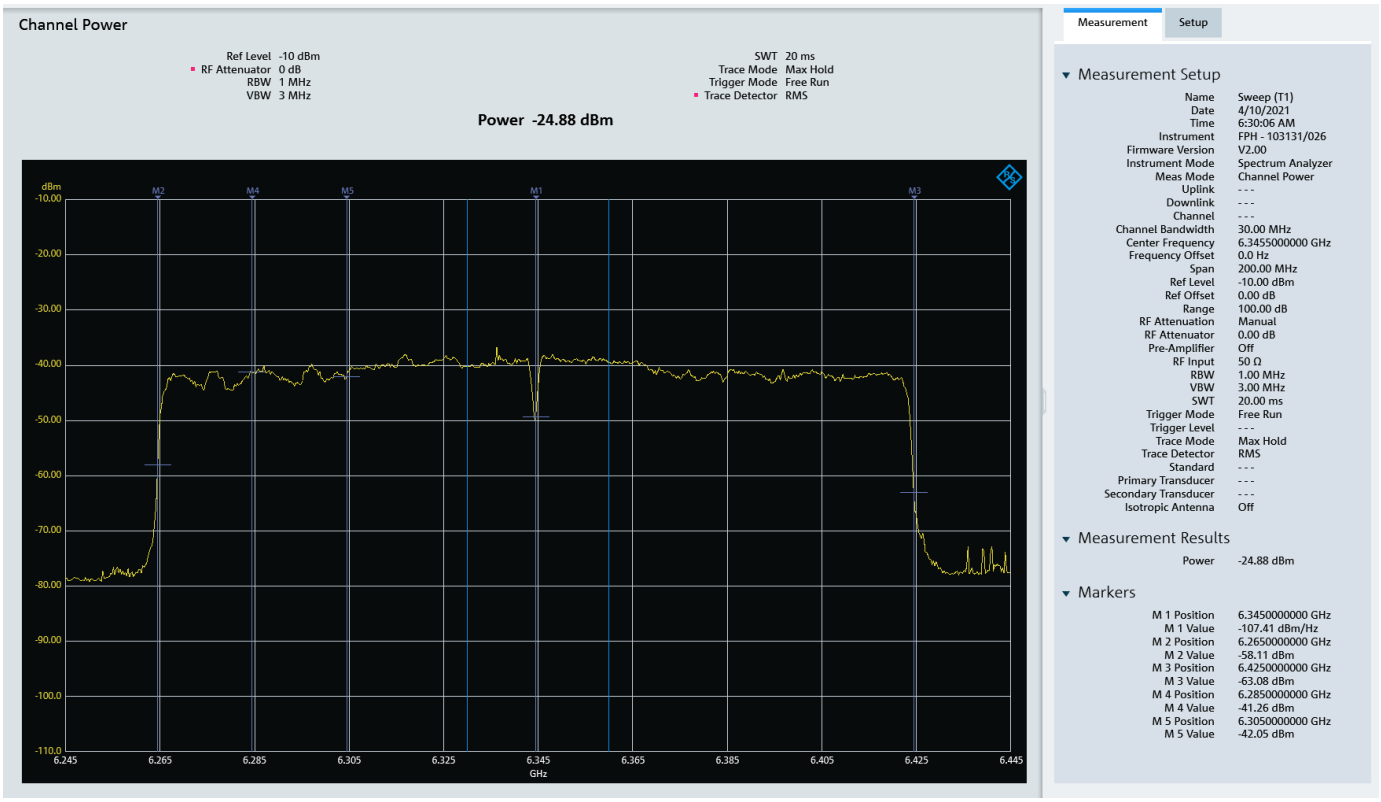

Figure 3. Co-channel fully overlapped 160 MHz Wi-Fi 6E channel

Figure 4. Test point locations map

Potential for Interference

There are four different channel widths in the IEEE 802.11ax standard; 20, 40, 80 and 160 MHz. Considering the possible channel spacings between the RLAN and incumbent channels, there are four potential types of interference. In decreasing order of interference risk, these are:

- Co-channel, fully overlapping
- Co-channel, partially overlapping
- Adjacent channel, no guard band
- Adjacent channel, with guard band

The test plan was designed to examine the worst case of RLAN fully overlapping a co-channel with the FS system and from locations along the beamwidth without building or terrain obstructions.

A spectrum analyzer capture of the Asus router set to co-channel with the Columbus receiver is in Figure 3. The Wi-Fi 6E channel number 77 is 160 MHz wide and centered at 6345 MHz. The vertical blue markers near the center indicate the Columbus 30 MHz channel.

Test Locations

The test plan was also designed to examine the worst case of the RLAN operating from locations along the beamwidth without building or terrain obstructions. Therefore, several test locations with public access were selected along the centerline of the incumbent FS link out to a distance of 6.2 mi (10 km) with visibility to the incumbent receive station. Figure 4 shows the centerline profile of the FS link and the selected LPI test locations.

Table 2 provides detailed information for the selected test locations.

Table 2. Test locations details

Test Location	Address	Latitude	Longitude	Distance
Fred's Tire	1900 2nd Ave, Columbus, GA	32-28-48.6 N	84-59-28.3 W	0.17 mi (275 m)
The Wing Place	3401 Veterans Pkwy, Columbus, GA	32-29-46 N	84-58-48 W	0.99 mi (1606 m)
RnR Tires (Obstructed)	5300 Veterans Pkwy, Columbus, GA	32-31-0.3 N	84-58-3.03 W	2.9 mi (4627 m)
Evangel Temple	5388 Veterans Pkwy, Columbus, GA	32-31-2.6 N	84-57-57.0 W	3 mi (4766 m)
Hyatt Room 503	2974 N Lake Pkwy, Columbus GA	32-33-4.2 N	84-56-48.0 W	5.5 mi (8917 m)
Best Western Room 432	4027 Veterans Ct, Columbus, GA	32-33-16.5 N	84-56-36.2 W	5.8 mi (9396 m)

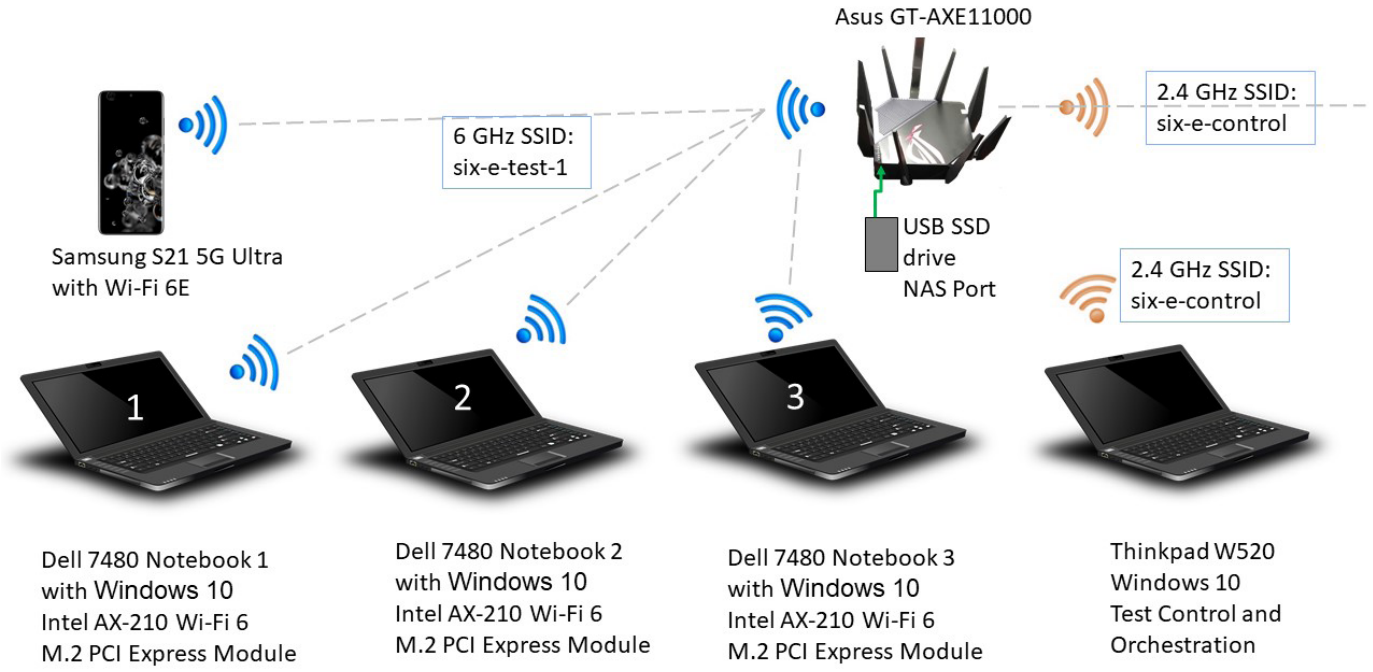

Figure 5. Test network 1

Test Setup

Two different Wi-Fi 6E APs were used in the testing:

1. Asus GT-AXE11000 – Republic of Gamers (ROG) Rapture
2. Netgear RAXE500 – Nighthawk®

In addition, two different types of clients were used to associate and exchange traffic with the APs:

1. Intel AX-210 M.2 PCI Express Module
2. Samsung Galaxy S21 5G Ultra

This equipment was configured into two different test networks. Figure 5 shows the first test network, with the Asus router. Figure 6 shows the second test network, using the Netgear router and clients.

The test setup for the microwave link used an external bit error rate test set to generate traffic at the maximum throughput for the selected modulation index. The majority of the testing used 1024 QAM which provides for a traffic capacity of 230 Mbps.

Test Procedure

A standard test procedure was established to be applied at the various locations. The basic steps were as follows:

1. Measure FS baseline
   a. Note the FS initial received signal level (RSL) and transmit power, then decrease far end microwave transmit power in 1 dB steps until external measuring device indicates BER exceeds the 10^{-6} threshold, and note total transmit attenuation amount as Basesline Fade Margin.
   b. Return far end transmit power to original value.
2. Beacons-only test
   a. Power up RLAN AP in Beacon configuration, ensuring that client devices remain powered off. Verify with local spectrum analyzer that beacon packets are being transmitted and overlap with microwave receiver channel. Capture image and any digital information needed for later analysis.
   b. Observe the FS BER. If the BER has increased beyond the 10^{-6} threshold note harmful interference.
   c. If link is still operational, measure the impacted fade margin by decreasing the far end transmit 1 dB at a time until BER rises above the 10^{-6} threshold. Note the attenuation needed as the Measured Fade Margin.
   d. Return far end transmit power to original value.
3. Low speed data test
   a. Re-configure the AP to Data configuration and power up Client equipment, establishing connection to AP. Use iPerf scripts to generate TCP traffic emulating web browsing between the clients and AP.
   b. Verify the script is transmitting and overlapping the microwave receive channel as expected using the local spectrum analyzer. Capture image and any digital information needed for later analysis.
   c. Observe the FS BER. If the BER has increased beyond the 10^{-6} threshold note harmful interference to link.
   d. If link is still operational, measure the reduction in fade margin by decreasing the far end transmit 1 dB at a time until BER rises above the 10^{-6} threshold. Note the attenuation needed as the Measured Fade Margin.
   e. Return far end transmit power to original value.
4. High-speed data test
   a. Repeat data test but with iPerf scripts that generate TCP traffic emulating video streaming and file backup.

At some locations, testing was repeated with adjustments such as placing the AP in different locations within the building and or leaving exterior doors open or closed.

Figure 6. Test network 2

Beacons-only Test

Figure 7 is a time domain plot of the signal from the Asus router with no clients attached. In this state, the router transmits beacons only with a repetition rate of approximately 20.5 ms. It should be noted that this is much shorter than the defaults used in earlier generations of Wi-Fi, which is 100 time units (TU). A TU is 1.024 ms, which makes the default beacon repetition rate 102.4 ms.

The spectrum occupancy capture of the beacons-only signal from the Asus router is in Figure 8. The router was set for Asus channel 77. The blue markers are the edges of the 30 MHz Columbus FS channel. Note that the beacon-only signal occupies half of the FS channel.

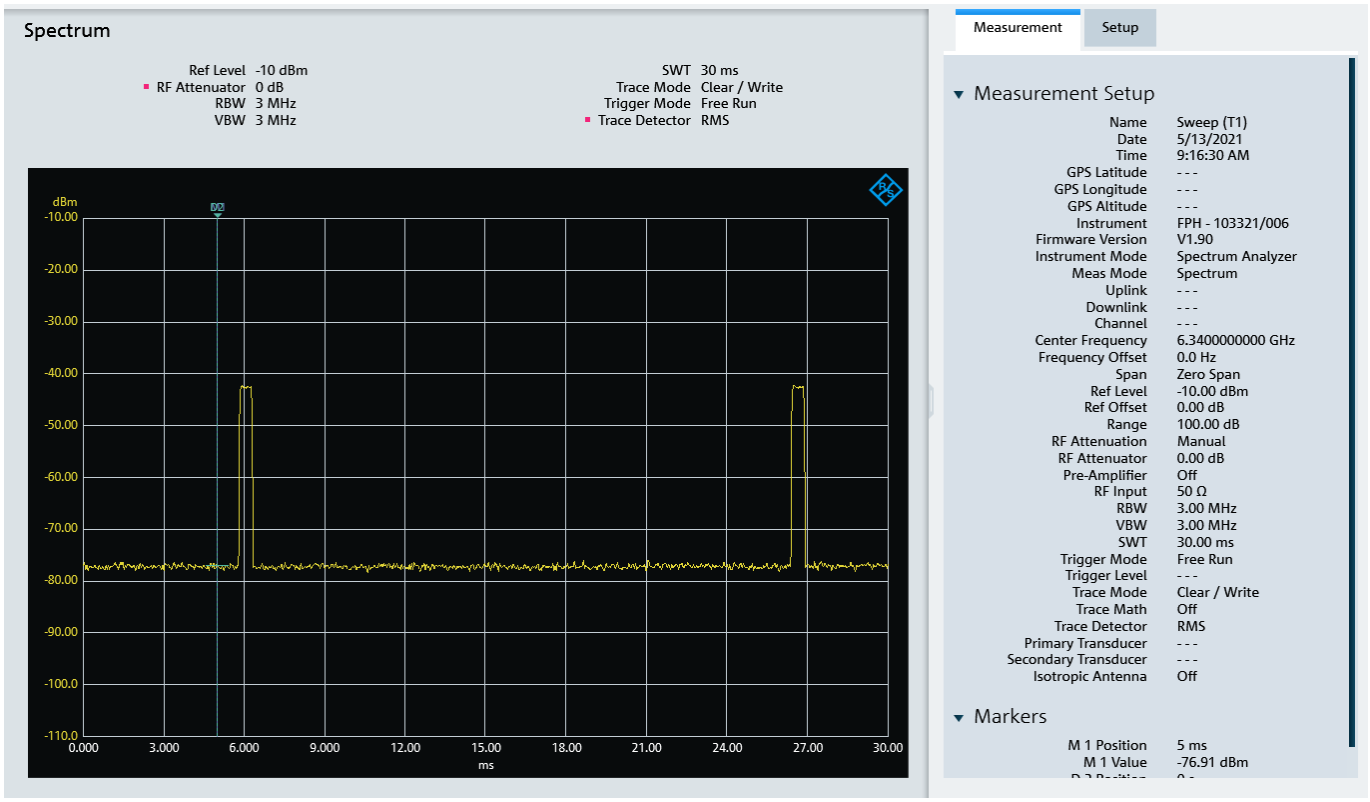

Figure 7. Beacons only time domain plot

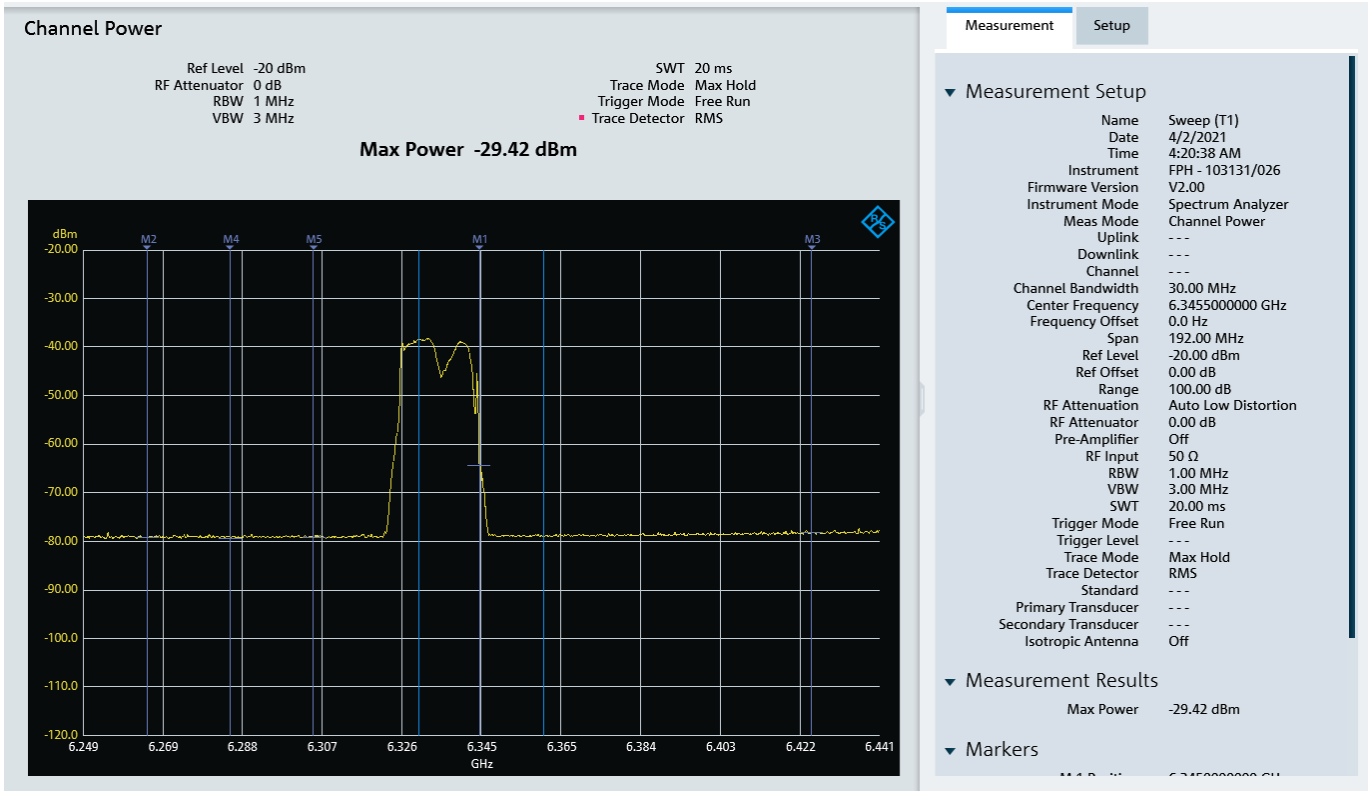

Figure 8. Beacons-only spectrum capture

Summary Test Results

Summary test results are presented in Table 3. Complete results and detailed analysis are available in the full report [7].

The reduction in fade margin (RFM) is the difference between the Baseline Fade Margin determined just prior to each test, and the Measured Fade Margin from each test. The I/N is calculated from the RFM, as explained below. Tests with results greater than the -6 dB I/N threshold are highlighted with orange shading.

The relationship between RFM and I/N is given by the formula [8]:

$$RFM = \{10 \log_{10} [\ 10^{N/10} + 10^{I/10}\ ]\} - N$$

where:

RFM = Reduction in Fade Margin (dB)

N = Receiver Front End Noise (dBm)

I = External Interference (dBm)

For I as power relative to N, N can be set to zero and therefore I is the dB level of power relative to N. Using the measured RFM from the field test results and solving the equation for I provides the values for the I/N columns. For reference, the IPC value of -6 dB I/N is equivalent to a 1 dB fade margin reduction.

Table 3. Summary test results

Test Locations (Modulation of 1024QAM unless noted)	Date	Baseline Fade Margin	Beacons Only			Low Bandwidth Data (10-100Mbps)			High Speed Data (>750Mbps)			Data Rate Tested over MW Link (Mbps)
			Measured Fade Margin	Reduction in Fade Margin	I/N	Measured Fade Margin	Reduction in Fade Margin	I/N	Measured Fade Margin	Reduction in Fade Margin	I/N	
Fred's Tire ASUS in window	4/12/2021	31.6	30.4	1.2	-5.2	28.5	3.1	0.1	27.8	3.8	1.4	230
Fred's Tire Netgear in window	4/13/2021	31.6	30.4	1.2	-5.2	28.9	2.7	-0.8				230
Fred's Tire ASUS on counter	4/13/2021	31.6							25.2	6.4	5.2	230
Fred's Tire Asus in front of Counter	4/13/2021	31.6	29.6	2.0	-2.5				17.4	14.2	14.0	230
Fred's Tire ASUS rear corner Service	4/13/2021	31.6				5.8	25.8	25.7				230
Fred's Tire ASUS front corner of Service	4/13/2021	31.6	20.8	10.8	10.4	11.0	20.6	20.5				230
Community Center (Obstructed)		31.6										
The Wing Place ASUS in window	4/14/2021	31.6	31.2	0.4	-10.8	17.6	14.0	13.8	15.3	16.3	16.1	230
The Wing Place ASUS on table 6' from window	4/14/2021	31.6	31.6						21.4	10.2	9.7	230
The Wing Place ASUS ceiling 6' from window	4/14/2021	31.6	30.1	1.5	-4.0				15.6	16.0	15.8	230
RnR Tires (Obstructed)	4/14/2021											
Evangel Temple Doors Closed	4/14/2021	31.6	31.6			28.7	2.9	-0.3				230
Evangel Temple Doors Open	4/14/2021	31.6	31.5	0.1	-19.4	27.0	4.6	2.7	25.8	5.8	4.4	230
Best Western Room 432	4/13/2021	31.6	31.6						31.4	0.2	-13.3	230
Hyatt Room 503	4/13/2020	31.6	31.6						31.3	0.3	-11.5	230
Both Best Western & Hyatt	4/14/2020	31.6	31.6						31.0	0.5	-9.0	230

Conclusions

There are several specific, notable findings from analysis of the test results:

- LPI devices were found to cause impacts greater than the FCC interference protection criterion (IPC) of -6 dB I/N when operating co-channel to the FS receive station at three different indoor test locations along the boresight at distances from 902 ft (275 m) to 3 mi (4.8 km).
- Interference greater than the IPC occurred with the LPI devices operating at low speed data rates (10-100 Mbps) and high speed (>750 Mbps). At the two closest locations impacts greater than the IPC were measured with no data traffic, i.e. Wi-Fi beacons only.
- At 5.5 mi (8.9 km) and 5.8 mi (9.4 km), the two farthest indoor test locations, detectable interference was measured below the IPC value. These locations were high-rise buildings with energy efficient construction.
- Aggregate interference effect was demonstrated and shown to be additive. This was done by operating LPI devices separately and simultaneously at the two distant high-rise buildings. However, the measured impact was small and merits further investigation.
- Antenna elevation mismatch between interferer (3.3 ft/1 m above ground level, AGL) and FS (202 ft/61.6 m AGL) did not protect the FS link at close distances (0.6 mi/1 km).

The primary, high-level conclusion is that:

- Indoor locations along the FS centerline at distances up to 5.6 mi (9 km) with unobstructed visibility and low building entry loss provide opportunities for harmful interference from RLAN devices.

Recommendations

These research results lead to the following recommendations for incumbent FS operators. To minimize the impact of future deployment of RLAN devices under the current FCC R&O:

1. Review, verify, and update all existing U6/L6 FS license information. This is critical, because the FCC ULS will be the source of data for the AFC systems.
2. Complete a vulnerability analysis for existing FS systems land use patterns in front of and in the sidelobes of U6/L6 receivers.
3. Consider upgrading U6/L6-vulnerable paths by adding frequency or space diversity.
4. For any vulnerable U6/L6 paths, complete an analysis to examine potential alternatives such as migrating to a different band or replacing existing equipment with fiber optics.
5. Baseline U6/L6 systems performance data including history of fading on existing systems.
6. Modify U6/L6 radio equipment settings to increase resiliency.

Next Steps

The EPRI 161G Telecom project set will continue to work on this project for through 2021. Ongoing work includes:

- Lab testing with microwave vendors to obtain understanding of unlicensed interference detection, identification, and mitigation. This should include further investigation of aggregate effects from simultaneous operation of multiple co-channel interferers.
- Joint leadership of the 6 GHz Multi-Stakeholder Group Workstream 1, which has responsibility for the topic of harmful interference detection, reporting and resolution.
- Participation in the Wi-Fi Alliance working groups developing specifications for the AFC system.
- Evaluation of link data from active 6 GHz systems.
- Review of final AFC systems when available and submission of test vectors for their evaluation.

Utilities are encouraged to participate and support this collaborative R&D through the EPRI Telecom Project Set 161G.

About Project Set 161G

The mission of EPRI's telecom R&D in the Information and Communication Technology research project set 161G is to provide independent, unbiased, science-based R&D to support the electric industry for societal benefit.

This technical brief is intended to provide factual, technical information on the outcome of regulatory changes that affect many electric utilities operating fixed service microwave links in the licensed 6 GHz spectrum.

REFERENCES

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2. Unlicensed Use of the 6GHz Band: Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz. Notice of Proposed Rulemaking. Federal Communications Commission. ET Docket No. 18-295, GN Docket No. 147, Released: October 24, 2018. (pages 4-5) https://docs.fcc.gov/public/attachments/FCC-18-147A1.pdf

3. Unlicensed Use of the 6GHz Band: Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz. Report and Order/Further Notice of Proposed Rulemaking. Federal Communications Commission. ET Docket No. 18-295, GN Docket No. 17-183, Released: April 24, 2020. (Page 9). https://docs.fcc.gov/public/attachments/FCC-20-51-A1.pdf

4. Unlicensed Use of the 6GHz Band: Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz. Report and Order/Further Notice of Proposed Rulemaking. Federal Communications Commission. ET Docket No. 18-295, GN Docket No. 17-183, Released: April 24, 2020. (Pages 27 and 106) https://docs.fcc.gov/public/attachments/FCC-20-51A1.pdf

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EPRI Resources

This report shares key findings with industry stakeholders that may not be EPRI members. This is a summary report, and detailed results are available to utilities participating in EPRI's Project Set 161G.

Information & Communication Technology (ICT) Program

3002022241 June 2021

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