TLPS and Bluetooth® Demonstrations
FCC Technology Center - March 06, 2015

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Contents

1 Introduction

This report contains the findings of the Bluetooth SIG demonstrations performed on Friday March 06, 2015 at the FCC Technology Center, Washington DC.

1. Bluetooth Low Energy (LE) Hearing Aid (HA) demonstration scenario
2. Bluetooth Low Energy (LE) Smart Lighting demonstration scenario

Note: Other Bluetooth SIG defined demonstration scenarios were not executed considering the short amount of time allocated for the Bluetooth SIG to perform these demonstrations.

2 Test Demonstrations Performed

2.1 Bluetooth Low Energy (LE) Hearing Aid (HA) Demonstration Scenario

2.1.1 Overview

Hearing Aid demonstrations by the Bluetooth SIG showed that the packet loss experienced by Bluetooth hearing aids jumped from 10% to almost 20% with TLPS present. (Packet loss over 10% would cause significant audio disruption for the user).

Results are obtained using the test procedure documented in section 3.2.2 of the “Bluetooth vs Globalstar TLPS Test Plan Overview_Draft04” [1]. Data is collected for three separate test sequences executed in succession as follows:

a. One HA pair is worn on the ears of a human subject and an iPhone is placed in a pants pocket. An audio stream is initiated on the iPhone using the music player. The human subject walks about the room for 300 seconds while audio packet statistics are recorded by the iPhone. Upon completion, the audio packet statistics are downloaded from the iPhone.
b. One HA pair is worn on the ears of a human subject and an iPhone is placed on a table. An audio stream is initiated on the iPhone using the music player. The human subject walks about the room for 300 seconds while audio packet statistics are recorded by the iPhone. An Ellisys protocol analyzer [2] is simultaneously recording all Bluetooth traffic at this time. Upon completion, the audio packet statistics are downloaded from the iPhone and the Ellisys air trace is saved.
c. A single HA (left ear device in this case) is placed on a table with a microphone attached to the audio receiver to record the streamed audio over Bluetooth LE. The iPhone is handheld by a human subject. The human subject walks about the room for roughly 2.5 minutes while the streamed audio playback is recorded. Upon completion, the audio recordings are saved and exported to a .wav format using Audacity [3].

Each test sequence is executed first with access points running on channels 1, 6, and 11 enabled, and then with 1, 6, 11, and 14 respectively. Table 1 lists hardware device information for each test sequence.

Setup	Name	Model #	Serial #	Version
3.2.2.a	iPhone 6	MG542LL/A	DNPNFS64G5MC	iOS 8.1.3 (12B466)
	Halo RIC13	24HALOXF13	14769166	FW 3.0.0.64
	Halo RIC13	24HALOXF13	14769164	FW 3.0.0.64
3.2.2.b	iPhone 6+	MGAX2LL/A	F2LNLKZLG5QF	iOS 8.1.3 (12B466)
	Halo RIC13	24HALOXF13	14769162	FW 3.0.0.64
	Halo RIC13	24HALOXF13	14769144	FW 3.0.0.64
3.2.2.c	iPhone 6+	MGCK2LL/A	FK2NTGCFG5QF	iOS 8.1.3 (12B466)
	Halo RIC13	24HALOXF13	14769142	FW 3.0.0.64

Table 1: Device Information

2.1.2 Packet Error Rate (PER) Test Results

Table 2 lists the recorded packet counts extracted from the iPhones for test sequences 3.2.2.a and 3.2.2.b. Packet counts are only tabulated for the iPhone-to-HA link as the traffic in this direction contains the audio frames that are played back in the HA audio receivers. Data is not collected for the HA-to-iPhone link as missed packets in this direction are of little to no consequence to quality of service since they contain only acknowledgements.

- **The total number of packets sent is calculated as**:
  Total Packets Sent = (Total Samples) – (Missing Samples) + (Missed Packet Total)
- **The packet error rate is calculated as:**
  PER = (Missed Packet Total) / (Total Packets Sent)
  Calculated PER results are plotted in Figure 1

Setup	HA Side	Enabled Access Points	Total Samples	Missing Samples	Missed Packet Total	Total Packets Sent
3.2.2.a	Left	1_6_11	40144	614	4198	**43728**
3.2.2.a	Right	1_6_11	40147	752	4928	**44323**
3.2.2.a	Left	1_6_11_14	40150	1289	9348	**48209**
3.2.2.a	Right	1_6_11_14	40153	1610	10199	**48742**
3.2.2.b	Left	1_6_11	40143	980	5496	**44659**
3.2.2.b	Right	1_6_11	40143	808	5622	**44957**
3.2.2.b	Left	1_6_11_14	40147	2098	10901	**48950**
3.2.2.b	Right	1_6_11_14	40143	2232	11193	**49104**

Table 2: Summary of Packet Data

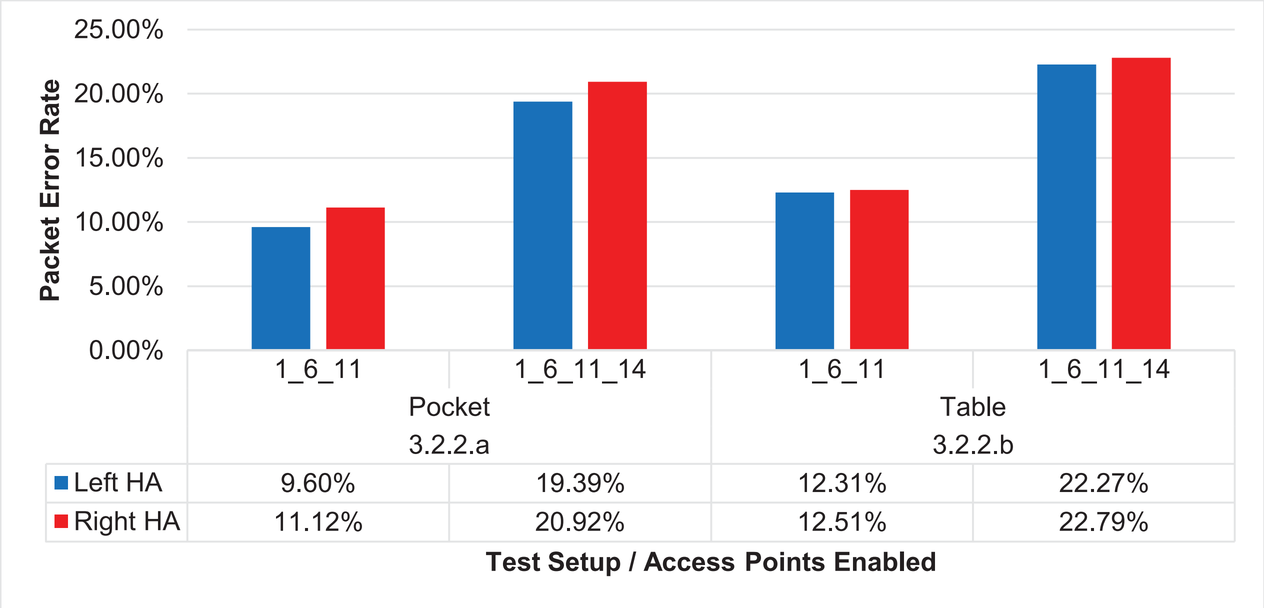
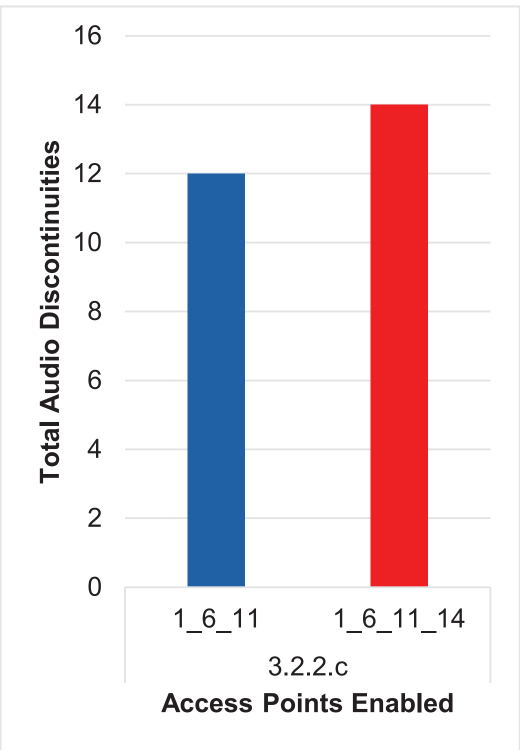


Figure 1: PER versus Test Sequence and Access Points (APs) Enabled

As shown, enabling access point 14 nearly doubles the PER for each test case. Bluetooth LE channel utilization recorded by the Ellisys air trace is plotted in Figure 3 and Figure 4 in *Appendix B* for test sequence 3.2.2.b.

2.1.3 Recorded Audio Results

The recorded audio files from test sequence 3.2.2.c are inspected for audio discontinuities from missed LE packets. Since the test environment dynamics are uncontrolled and the HA audio level can at times exceed the dynamic range of the recording hardware (clipping), an audio discontinuity must be verified audibly and by inspecting the recorded waveform. Figure 2 plots the number of audio discontinuities recorded for each combination of access points enabled and also lists the time position in the audio file where each occurred. As shown, enabling access point 14 results in a 17% increase in the total number of audio discontinuities experienced. Plots of each recorded audio discontinuity are featured in Table 4 and Table 5 of *Appendix A*.



List of Audio Discontinuity Time Positions		
#	*1_6_11*	*1_6_11_14*
1	00:33.6	00:09.2
2	00:55.2	00:45.3
3	00:56.3	00:53.9
4	01:00.8	00:54.4
5	01:03.7	00:55.5
6	01:03.8	00:57.5
7	01:10.8	01:07.8
8	01:12.3	01:07.9
9	01:24.8	01:33.9
10	01:26.2	01:35.8
11	01:28.4	01:40.3
12	01:29.6	01:56.6
13	-	02:09.9
14	-	02:20.6

Figure 2: Summary of Observed Discontinuities in Audio Recordings

It is worth noting that for this test sequence, the HA device was NOT worn on the human ear. When a HA antenna is worn on the human head, there is a significant degradation in antenna efficiency due to the proximity of tissue. Radiated power measurements with the HA device used in 3.2.2.c (presented in Appendix C) show a 10-14 dB degradation in total radiated power when worn on the human ear compared to being placed on a tabletop with attached audio recording hardware. As a result, the iPhone-to-HA link will have a lower average signal-to-interference ratio when the HA is worn on the ear in comparison to the test setup used in the demo. Given this, link degradation and associated disparity in performance is likely to increase (with and without an access point (AP) on Channel 14 enabled) in comparison to the results presented here. The audio recordings themselves are thus not representative of the real user experience and are presented merely as a formality.

2.1.4 Files

Table 3 lists all recorded audio files and Ellisys protocol analyzer air traces.

Filename	Description	Size
322b_1_6_11.btt	Bluetooth air trace recorded with an Ellisys protocol analyzer during the execution of test 3.2.2.b with access points 1, 6, and 11 enabled.	536.31 MB
322b_1_6_11_14.btt	Bluetooth air trace recorded with an Ellisys protocol analyzer during the execution of test 3.2.2.b with access points 1, 6, 11, and 14 enabled.	422.77 MB
322c_1_6_11.wav	Recorded audio for test 3.2.2.c with access points 1, 6, and 11 enabled.	25.327 MB
322c_1_6_11_14.wav	Recorded audio for test 3.2.2.c with access points 1, 6, 11, and 14 enabled.	27.462 MB

Table 3: List of Data Files

2.2 Bluetooth Low Energy (LE) Smart Lighting Demonstration Scenario

2.2.1 Overview

"Smart" lighting demonstrations by the Bluetooth SIG showed that the number of instances where the "Smart" lights failed to receive commands (ON/OFF and Color change) increased about 4 (four) times with TLPS present.

The scenarios included the following:

- A qualitative test of Bluetooth Smart Lighting utilizing Bluetooth LE Mesh technology - see section 3.1.6 of the "Bluetooth vs Globalstar TLPS Test Plan Overview_Draft04" [1]
- A quantitative test of Bluetooth LE Beacons - see section 3.1.7 of the "Bluetooth vs Globalstar TLPS Test Plan Overview_Draft04" [1]
  Note: There was not sufficient time to completely execute this test scenario with the allocated time for the Bluetooth SIG, hence this report does not include test demonstration details for this scenario.

The Bluetooth Smart Lighting scenario heavily utilized the Bluetooth Smart advertising channels (37 at 2402MHz, 38 at 2426 MHz, and 39 at 2480 MHz), where CH 39 resides in TLPS Channel 14 requested spectrum.

In addition, a more data intensive objective test was constructed, however, due to limited time available, these tests were not executed.

2.2.2 Smart Lighting Testing Sequence

1. Five Smart Lighting demonstration devices were placed around the room. Details of these devices are as follows:
    a. Device code H13323v1_VAR1A
    b. Application code – 1.1.9RC5
    c. Transmit power – 0dBm setting (Tx power level = 4)
    d. Advertising scan parameters
        i. Scan duty cycle 25%
        ii. Advertising interval 90msec
        iii. Advertising time 600msec
2. A Nexus tablet with the Smart lighting controller app was used to associate the demonstration devices into the Mesh network, and control LEDs on the demonstration devices.
3. Streaming connections were established on the channels of interest, as noted in the test plan.
4. Bluetooth Classic traffic was generated by creating an A2DP connection between phones and speakers.
5. A test sequence of changing the LED colors or turning LEDs on/off was executed 50 times. If all LEDs on the demonstration devices changed as directed by the app, then this was labeled a PASS. If any one of the LEDs on the five demonstration devices did not change as directed, then this was labeled a FAIL.

2.2.3 Smart Lighting Qualitative Test Results

Test Scenario	Enabled Access Points	Number of failures in 50 tries	% failures
Color changes	1-6-11	3	6%
	1-6-11-14	9	18%
On/Off	1-6-11	4	8%
	1-6-11-14	18	36%

Table 4: Smart Lighting Qualitative Test Results

The increase in failures as illustrated in Table 4 above further shows the TLPS severe impact on Bluetooth LE technology.

The TLPS system was configured by Globalstar to support data transfers of only 3.7Mbps when this Smart Lighting scenario was executed, and a drastic increase in the number of failures and on system performance was evident. However, it is important to note that “higher utilization of the spectrum” would be expected to show even more severe and worse performance.

Due to severely restricted amount of setup and test time, only one test case was executed with a specific output power of the Bluetooth devices, advertising and scan parameters, node configuration, and load on the Wi-Fi and TLPS systems. Further test work is recommended to provide more data pertaining to varying the aforementioned parameters, including automated test tool creation.

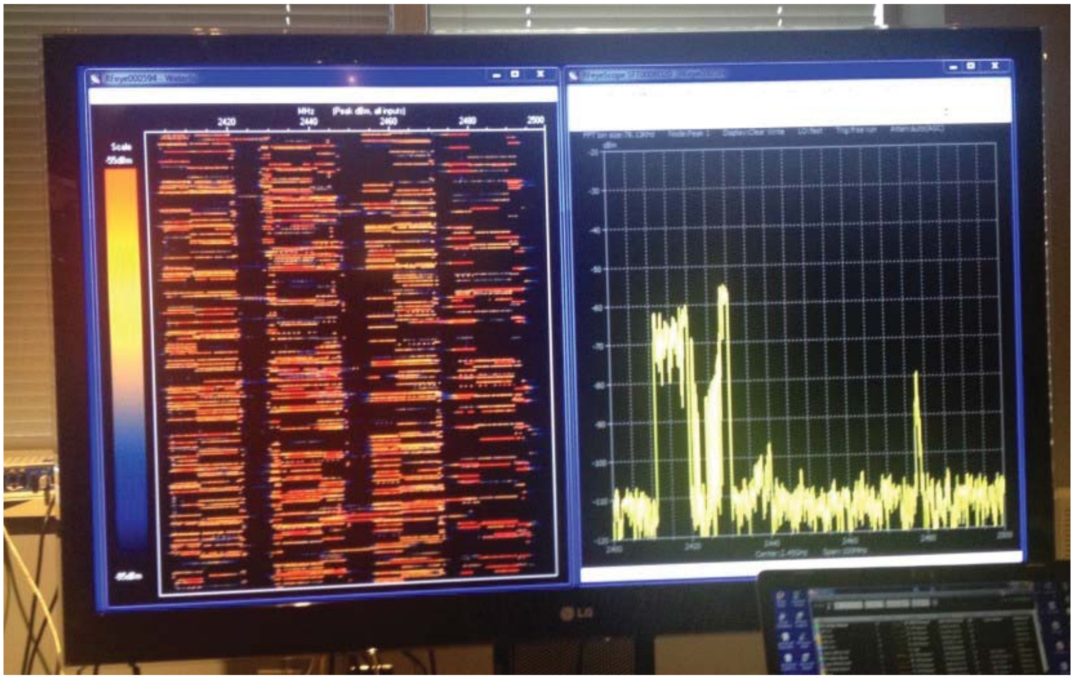
3 Demonstration Test Setup Concerns

Throughout the demonstration event, there were many unknowns about the 4 APs on channels 1,6,11, 14 and equipment provided and "preconfigured" by Globalstar. It was evident that Globalstar had the test configuration perfectly suited and controlled to reflect what best suited their test requirements. In a more adequate and real world test environment, both sides of the equation must have equal access to configure, modify the test parameters, adjust spectrum traffic, adjust the AP streaming traffic/ throughput to the client devices (not only use the preconfigured data stream of 3.7 Mbps provide by Globalstar), adjust output powers, etc.

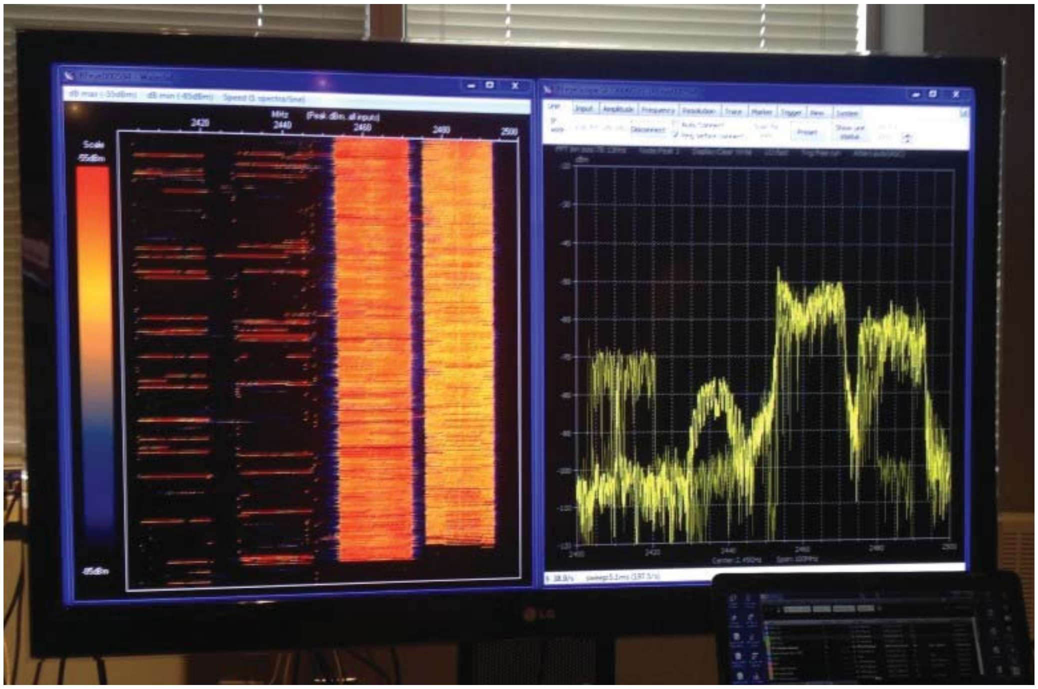
In this manner, the test environment will be manageable and controlled by all parties involved and not only by one party. This will show more realistic and objective test results.

3.1 Demonstration Environment Configuration

- The Globalstar APN configurations for the Bluetooth demonstration were preconfigured to connect and stream data to only one client device at a time at 3.72Mbps. Requests from the Bluetooth test participants to increase the streaming throughput beyond 3.7 Mbps, or to connect to multiple clients, were refused.
- The refusal can be illustrated by examining image 1 (Traffic on Channels 1, 6, 11, and 14 during demo) that shows the loading during the Bluetooth SIG demonstration, and image 2 (Observed during Globalstar setup) shows what was possible. Image 3 (Tablets on table) shows half of the tablets that could have been used to increase traffic, the other half of the tablets are on a table out of view.
  - Image 1:



- Image 2:



- Image 3:

- Image 4 (Crowded small room), shows how dense the demonstration room was with people moving around during Bluetooth SIG testing, and it was very difficult to keep recording demonstration/test data with such distractions. The setup in the room does not reflect a real world test event. Most of the Globalstar participants did seem surprised that the Hearing Aid and Smart lighting demonstrations would take 30 minutes or so per run.
    - Image 4

- Access to the laptop computer used by Globalstar to control and configure their client devices was a closed system and did not allow other test participants to understand what was being configured. The demonstration setup was controlled by Globalstar and was not transparent.

The Bluetooth SIG requests additional, public, properly constituted, *test events* in order to derive quantitative data. The configuration of the test environment can be an agreed effort between Globalstar and the others.

4 Conclusion

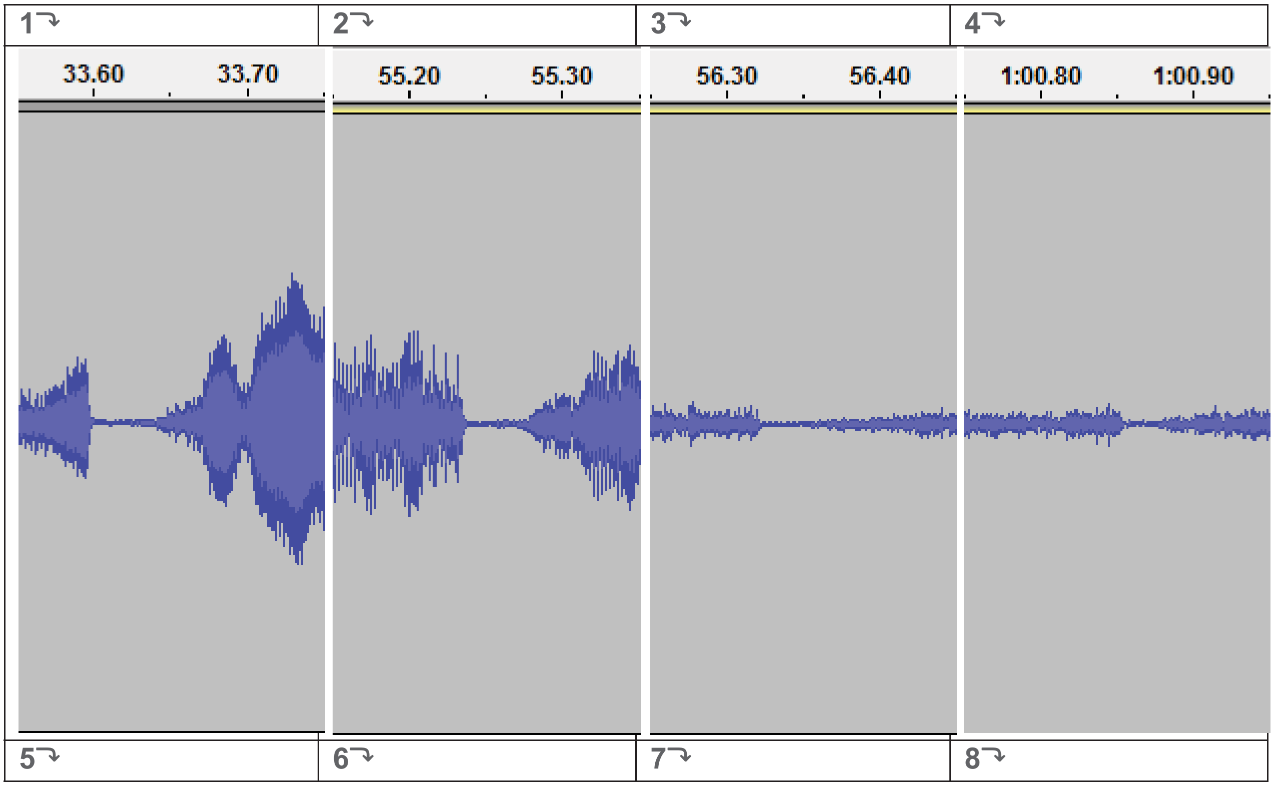
The results of these demonstrations clearly show significant potential impact upon American consumers and users of Bluetooth products by TLPS deployment. Furthermore, the demonstrations firmly indicate and further validate all the Bluetooth SIG concerns raised throughout the Globalstar NPRM process and during the Bluetooth SIG multiple Ex Partes or Comments filings to the FCC. This includes:

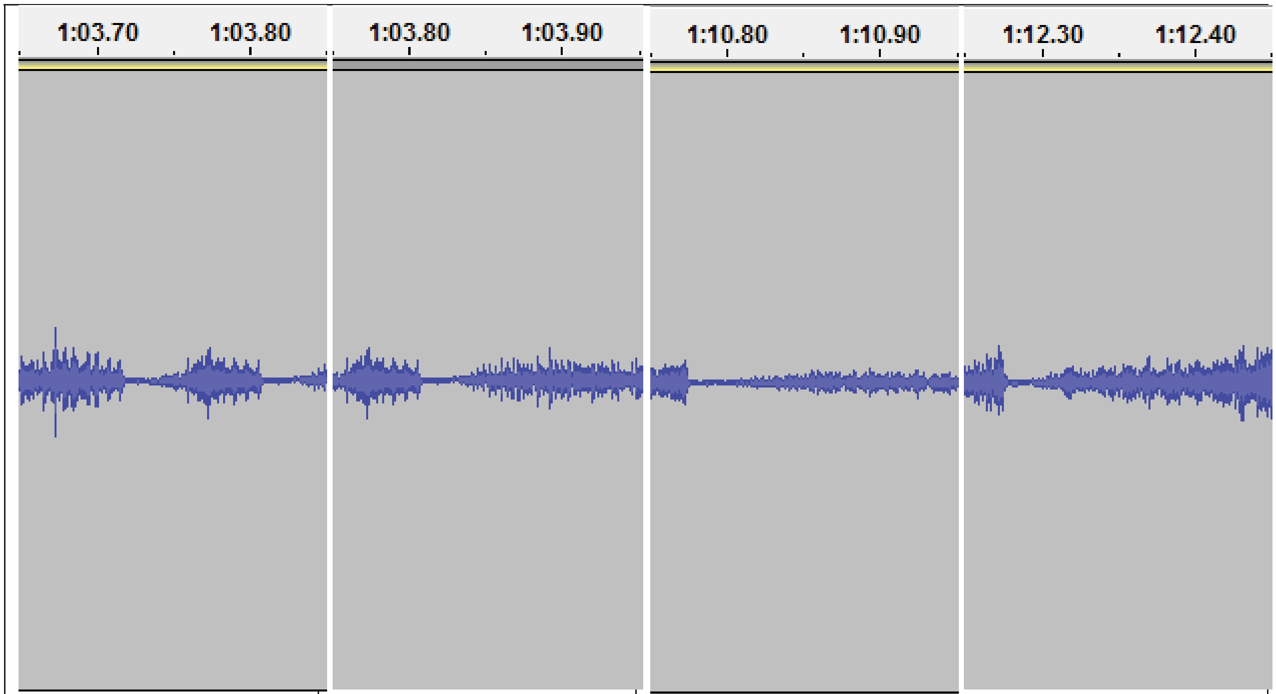
- Proven TLPS interference through packet error loss and PER statistics provided by the HA demonstration.
- Proven TLPS coexistence problems in the 2.4GHz ISM band when utilizing Bluetooth LE advertising channel capabilities as demonstrated by the Smart Lighting demonstration.
- Proven increased congestion caused by TLPS, forcing Bluetooth devices to utilize less spectrum in the ISM band as shown by both HA and Smart Lighting demonstrations.
- Proven disruption to critical and growing markets such as Bluetooth Hearing Aid Medical market, where strict FDA rules are required to ensure high quality of service (QoS) and reliability of medical equipment operating in primary and essential health institutions and hospitals.

5 Appendix

5.1 Appendix A - Bluetooth LE HA Audio Discontinuity Waveforms

Table 4 plots all audio discontinuity waveforms for test 3.2.2.c with access points 1, 6, and 11 enabled. Table 5 plots all audio discontinuity waveforms for test 3.2.2.c with access points 1, 6, 11 and 14 enabled.





9↷	10↷	11↷	12↷

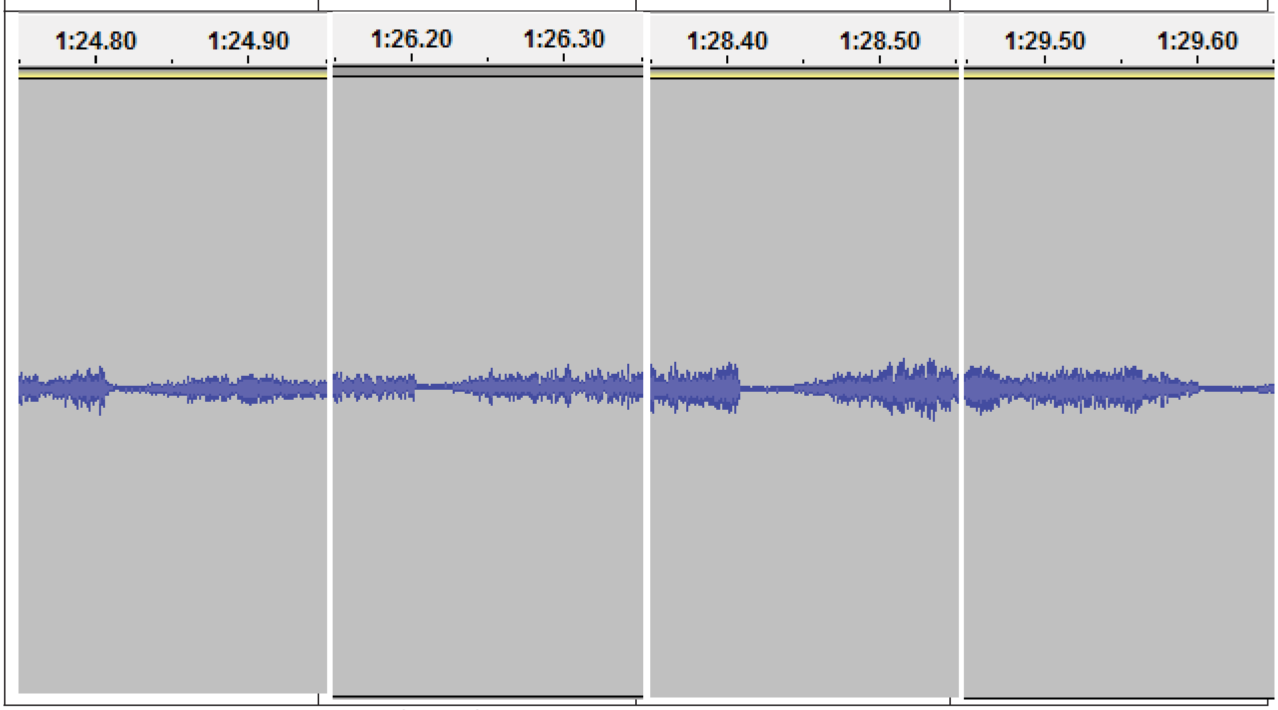
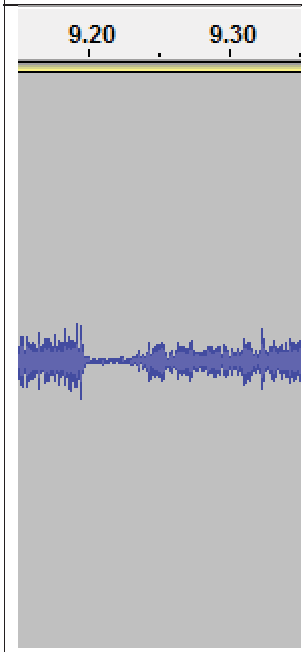
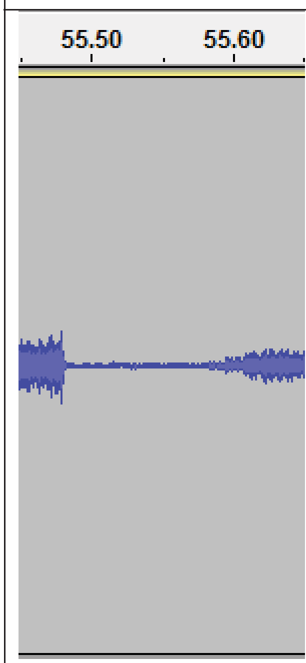


Table 4: Audio Discontinuity Waveforms for Test 3.2.2.c with Access Points 1, 6, and 11 Enabled

1	2	3	4
			
5	6	7	8
			
9	10	11	12

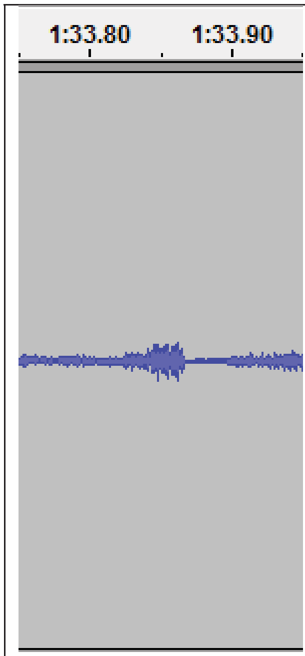
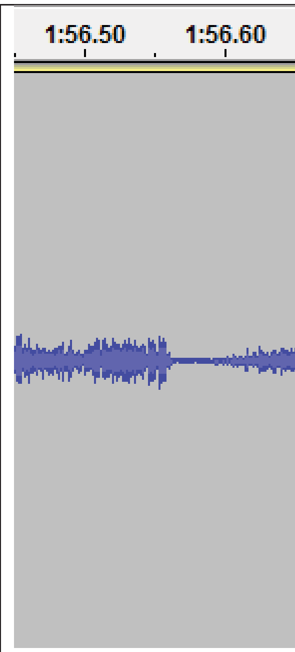
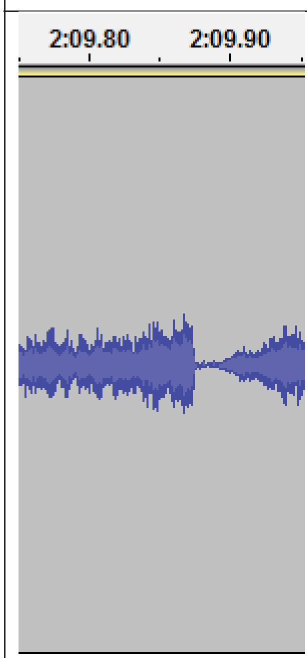
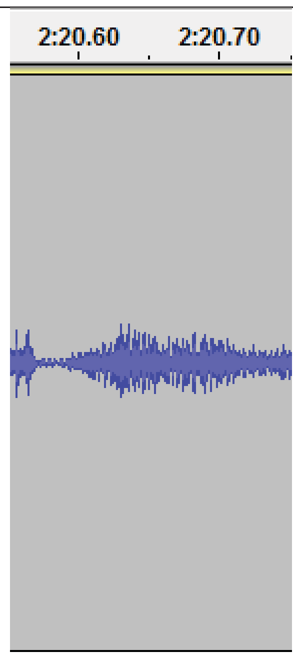
			
13↴	14↴		
			

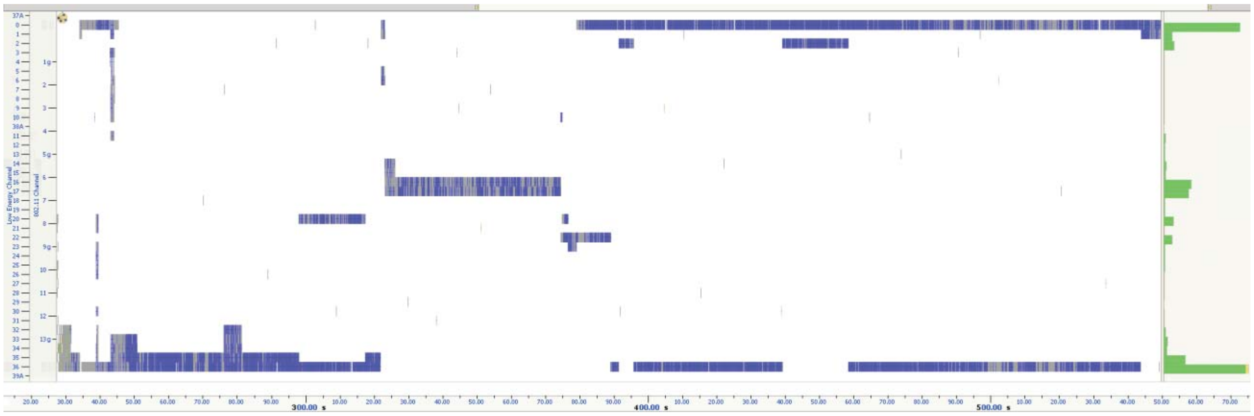
Table 5: Audio Discontinuity Waveforms for Test 3.2.2.c with Access Points 1, 6, 11, and 14 Enabled

5.2 Appendix B – Bluetooth LE HA Traffic Recorded

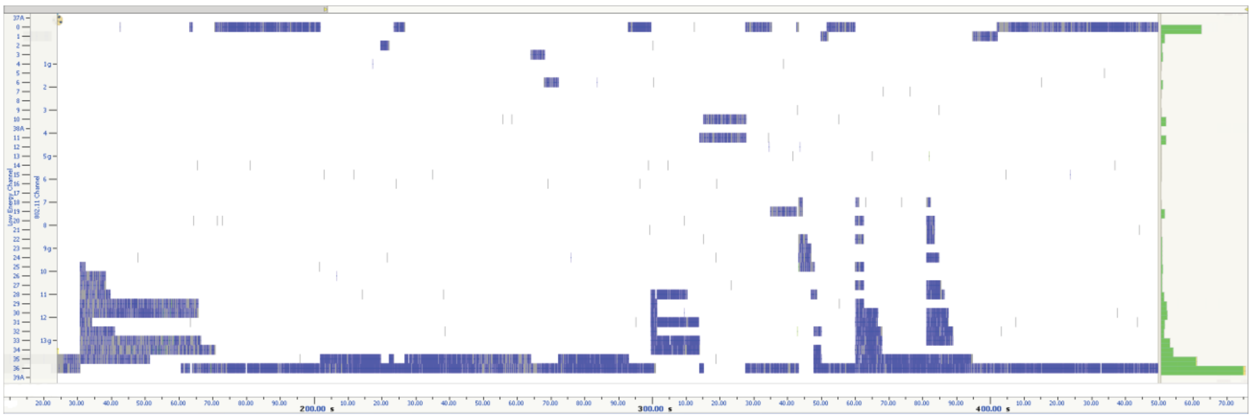
Figure 3 plots Bluetooth traffic recorded for test 3.2.2.b with access points 1, 6, and 11 enabled. Figure 4 plots Bluetooth traffic recorded for test 3.2.2.b with access points 1, 6, 11, and 14 enabled. The plots are filtered to only show traffic during the 300 seconds of audio streaming. A histogram on the right of each plot shows the channel utilization density for each air trace.

When the AP transmitting on 802.11 Channel 14 is not enabled, the upper portion of the 2.4 GHz ISM band today provides the largest portion of interference free bandwidth for wireless communication over Bluetooth LE. Once Channel 14 is enabled this will cause collisions and interruption of the design scheme that is utilized heavily in the industry utilizing the ISM band.

- Figure 3: Bluetooth Traffic Recorded for Test 3.2.2.b with Access Points 1, 6, and 11 Enabled



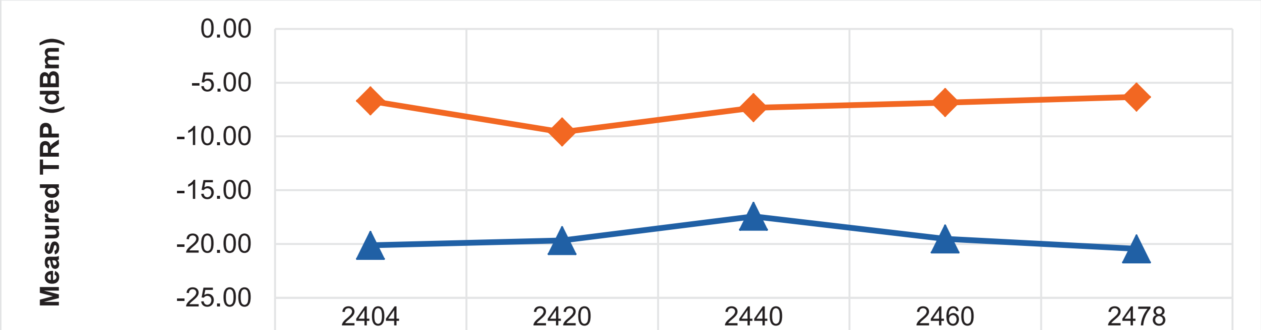
- Figure 4: Bluetooth Traffic Recorded for Test 3.2.2.b with Access Points 1, 6, 11, and 14 Enabled



5.3 Appendix C – Bluetooth LE Radiated Power Measurements

To quantify the difference in HA antenna performance realized in test sequence 3.2.2.c versus a real world use case, radiated power measurements are performed in an anechoic chamber. Figure 5 illustrates the first measurement setup with the HA device placed on a tabletop with connected audio recording hardware as used in test sequence 3.2.2.c. Figure 6 illustrates the second measurement setup with the HA device placed on a human ear as performed in a real world use case. Total radiated power (TRP) is measured at 5 discrete frequencies across the ISM band. Results are plotted in Figure 7. As shown, wearing the HA on the ear reduces the TRP by 10-14 dB in comparison to the HA being placed on a tabletop. The test results for test sequence 3.2.2.c are thus not representative of the real world use case since the signal to interference ratio will be 10-14 dB better when the HA is placed on the table. Figure 8 and Figure 9 plot the measured antenna patterns at 2440 MHz for each setup for informational purposes.

	
Figure 5: Tabletop Measurement Setup (3.2.2.c setup)	Figure 6: On-ear Measurement Setup (real-world)



	2404	2420	2440	2460	2478
Human Head	-20.12	-19.68	-17.43	-19.53	-20.45
Table	-6.71	-9.60	-7.33	-6.85	-6.33

Figure 7: Measured Radiated Power

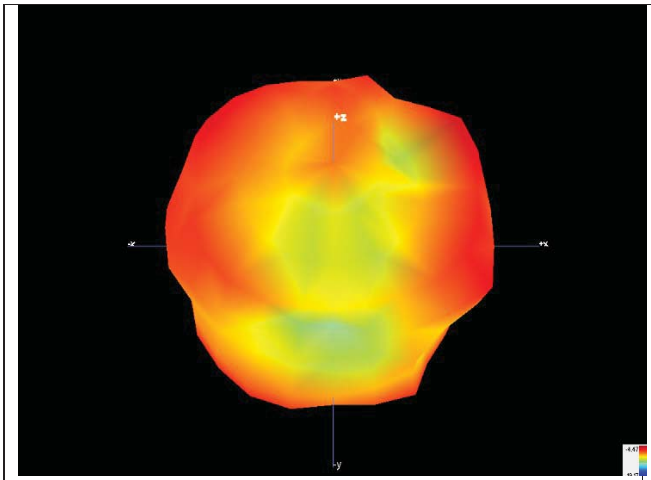


Figure 8: Measured HA Antenna Pattern on Table, 2440 MHz

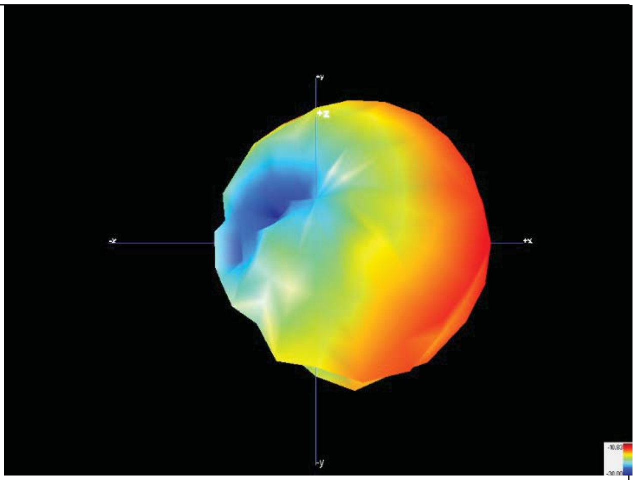


Figure 9: Measured HA Antenna Pattern on Ear, 2440 MHz

6 References

[1] "Bluetooth vs Globalstar TLPS Test Plan_Draft04" TLPS.TP.1.0.0r00
[2] "Audacity: Free Audio Editor and Recorder." www.audacity.sourceforge.net/
[3] "Ellisys Bluetooth Explorer 400." www.ellisys.com/products/bex400/