CELLULAR LONG-TERM EVOLUTION UPLINK IMPACTS ON AERONAUTICAL MOBILE TELEMETRY *

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ABSTRACT

At the request of representatives of Edwards Air Force Base, the National Advanced Spectrum and Communications Test Network (NASCTN) conducted a test campaign to evaluate impacts of advanced wireless services 3 (AWS-3) long-term evolution (LTE) uplink band (UL) (1755 MHz - 1780 MHz) on aeronautical mobile telemetry (AMT) air-to-ground links operating in the compressed L-Band spectrum (1780 MHz – 1850 MHz). The test campaign applied field and laboratory collected LTE UL waveforms, along with Gaussian noise surrogates, to AMT link configurations and conditions in a highly automated testbed. We showcase the test methodology and propose a new key performance metric to aid in the interpretation of non-linear effects in AMT receiver response due to some of the LTE adjacent band emissions. The data and insights presented provide for additional information helpful in establishing and confirming frequency band edge back-off recommendations in the Inter-Range Instrumentation Group (IRIG) 106 Standard.

INTRODUCTION

Federal Communications Commission Auction 97, the advanced wireless services 3 (AWS-3), led to new licenses for commercial use in bands previously dedicated to Federal spectrum users [1]. In particular, aeronautical mobile telemetry (AMT) users are now operating in a compressed L-band spectrum of 1780 - 1850 MHz. AMT's spectrum neighbors on the lower bound of operations, at the time of this writing, are cellular operators utilizing 3rd-generation partnership project (3GPP) long-term evolution (LTE) systems in frequency-division duplex (FDD) applications. The AWS-3 auction specifies auction blocks residing in the 1755 - 1780 MHz allocation, abutting the AMT operations, as Mobile Transmit/Base Receive bands [2].

Representatives of Edwards Air Force Base submitted to National Advanced Spectrum and Communications Test Network (NASCTN) a test request to lead a series of scientific investigations into the impact of LTE systems operating in the adjacent band to AMT. To date, NASCTN has published on the subject several key technical notes [3], [4], [5], [6] and data [7], [8] . The final report [4] on ”AWS-3 LTE Impacts on Aeronautical Mobile Telemetry” outlines the test methodology and test campaign on investigating susceptibility and impact of LTE uplink band (UL) signals on various AMT links.

The test campaign applied field and laboratory collected LTE UL waveforms, along with Gaussian noise surrogates, to AMT link configurations and conditions in a highly automated, cabled testbed. The paper here serves to add additional details to the susceptibility and impact analysis when using emulated LTE UL waveforms as is typical of commercial off the shelf signal generators with 3GPP functionalities.

ADJACENT BAND SIGNALS

The test campaign focused on allocating UL signals in the adjacent band such that their band allocation is abutting the AWS-3 to Federal band edge. For this paper the focus is on 4 adjacent band waveforms, one from field recordings of a single UE in the back lobe of the telemetry antenna which includes telemetry front end effects, a single UE recorded under laboratory conditions, one synthesized band limited additive white Gaussian noise (AWGN), and one generated, emulated, LTE UL waveform.

1. *Lab-UE Full 100 RB (49 MHz Filter)*, laboratory recorded UL waveform of a single user equipment (UE) in a 20 MHz allocation connected to a carrier grade LTE network,
2. *Single-UE Full 100 RB (37 MHz Filter)*, field recorded UL waveform of a single user equipment (UE) in a 20 MHz allocation,
3. *AWGN 20 MHz*, a surrogate waveform of 20 MHz band limited additive white gaussian noise (AWGN),
4. *VSG-UE Full 100 RB (emulated)*, an emulated LTE UL signal of a single user equipment in a 20 MHz allocation.

There are notable distinguishing spectrum content features within the waveforms. LTE resource block transmit grants of an user equipment (UE) attached to a carrier grade system are driven by the scheduling properties within a celluar base station, named evolved node B (eNB), and resource loading requests of the eNB. Therefore, to gain realistic scheduling requests akin to what was observed in the field [5] with the laboratory capture, we’ve presented the eNB with background traffic as is described in [6] and matched the data upload rate of the device under test (DUT) UE in the laboratory with that of the field campaign.

Unlike carrier grade implementations, the emulated waveform was defaulted for the single-carrier frequency division multiple access (SC-FDMA) UL signal to occupy all resource blocks (RBs) simultaneously. While customization of RB utilization is possible in most emulation packages, we defaulted to full occupation of RBs as is common to interference test campaigns [9]. The emulated resource grid is shown in figure 1. This serves to study DUT system response to an emulated LTE signal in an introductory configuration.

The 20 MHz band limited AWGN waveform serves as a surrogate waveform to reference against. In terms of time-frequency occupancy, the waveforms can be sorted from high persistence to low: AWGN 20 MHz , VSG-UE Full 100 RB (emulated) followed by the laboratory capture Lab-UE Full 100 RB (49 MHz Filter), and the field capture Single-UE Full 100 RB (37 MHz Filter).

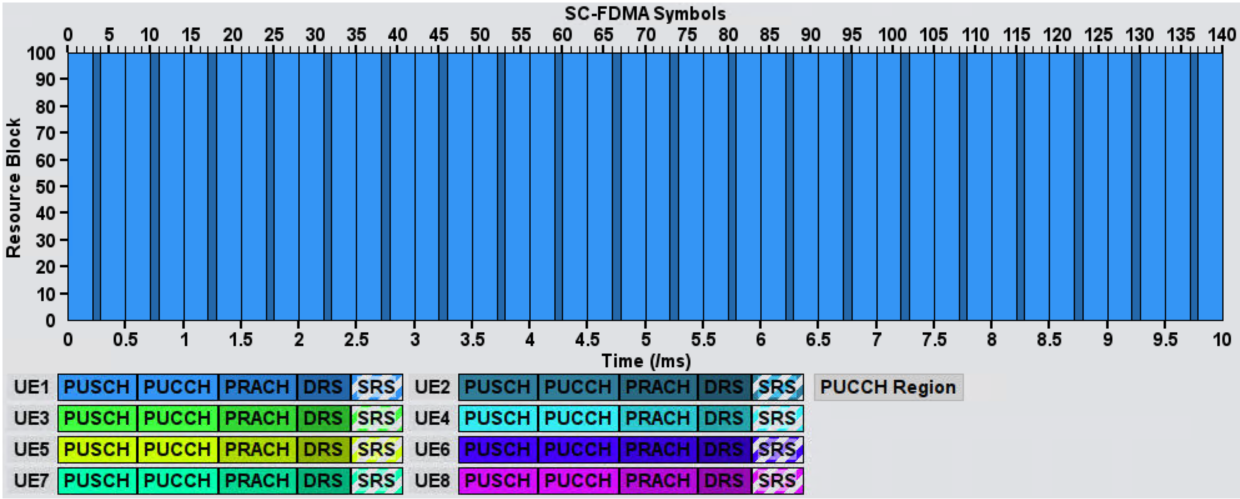

Figure 1: Resource block scheduling for SC-FDMA UL configured in the signal generator. All resource blocks are utilized by UE1 physical uplink shared channel (PUSCH) and demodulation reference signal (DRS) signaling in frequency and time.

Peak and average power values as referenced to the input of the AMT receiver are tabulated in table 1.

TEST DESIGN

The test execution follows the frequency offset experiment outlined in [4] and presents test results of a bit error rate (BER) test as a function of AMT link center frequency. The adjacent band emissions (ABE) waveform remains at a fixed frequency (1770 MHz) such that the waveform allocation abuts the 1780 MHz band edge. The AMT center frequency is shifted from the initial start condition of the signal's 99% occupied bandwidth (OBW) at the lower band edge of the AMT allocation through the IRIG 106 [10] specified band edge back-off frequency (as defined for a 10 W AMT transmitter). The BER test is initiated in our fully automated testbed and is reported by the AMT receiver (RX) under test. To manage test time and resolution in our test we run the BER for 3×10^8 bits.

ABE levels for the LTE waveforms of table 1 are selected to mirror the peak power of the as-recorded in-field waveform (as outlined in [4]), the AWGN 20 MHz average power closely matches the same as-recorded in-field waveform average power. The AMT signal average power is fixed to -79.9 dBm ± 0.8 dB 2 at the plane of the AMT receiver input.

The test here makes use of several AMT link modulation and data rate configurations: pulse code modulation/frequency modulation (PCM/FM) at 1 Mbps, PCM/FM at 5 Mbps, shaped offset quadrature-phase shift keying (SOQPSK) at 5 Mbps, SOQPSK at 10 Mbps, and Advanced Range Telemetry continuous phase modulation (ARTM CPM) at 5 Mbps.

Table 1: ABE waveform power levels referenced at the plane of the AMT receiver input connector

Waveform Name	**Average Power**	**Peak Power**
AWGN 20 MHz	-60.0 dBm ±0.8 dB	N/A
Single-UE Full 100 RB (37 MHz Filter)	-60.5 dBm ±1.1 dB	-52.4 dBm ±1.1 dB
Lab-UE Full 100 RB (49 MHz Filter)	-65.4 dBm ±1.1 dB	-52.3 dBm ±1.1 dB
VSG-UE Full 100 RB (emulated)	-58.9 dBm ±1.1 dB	-52.8 dBm ±1.1 dB

Table 2: AMT transmitter signal level referenced at the plane of the AMT receiver input connector for the frequency offset experiment

Test Case	**Average Power**
Frequency Offset Experiment	-79.9 dBm ±0.8 dB

NUMERICAL RESULTS

Numerical results presented in figures 2, 3, and 4 show the BER calculated from AMT RX reported bit errors versus AMT link frequency. For reference, the graphs note the frequency at which the 99% OBW abuts the band edge of 1780 MHz (vertical black dashed line) and the Inter-Range Instrumentation Group (IRIG) 106 [10] calculated band edge back off frequency (vertical red dashed line) for a 10 W AMT transmitter (TX).

We denote BER test results with no recorded errors as ν and ascribe a regression fit that takes into account two test runs. As the tests were limited to 3×10^8 bits, BER estimates of less than 10^{-8} have a large relative uncertainty as compared to the mean uncertainty.

In order for an AMT link to meet the IRIG recommendation in the presence of an ABE, the BER should fall below 10^{-5}. The frequency distance between the black dashed and red dashed lines indicates the frequency margin of the IRIG recommendation. Note that for the set of experiments highlighted here, with the exception of the field capture, the AMT links pass in the presence of the ABE types.

Chapter 4.1 of [4] provides further details on the data analysis, and regression fits.

There are discernible differences in observed ABE impact on the AMT link. For all test configurations, the AWGN 20 MHz surrogate waveform (red fit line) overpredicts the impact from LTE at the 99% OBW and subsequently does not mirror the response of the field-recorded LTE.

The emulated LTE waveform VSG-UE Full 20 MHz (purple fit line) tends to show a sharper response at the lowest frequencies and different fit-line roll off characteristics as compared to the re-broadcasted laboratory and field derived waveforms.

Of particular note, 3 and 4 show that it is important to include the telemetry front-end characteristics in impact analyses. The surrogate AWGN 20 MHz , VSG-UE Full 100 RB (emulated), and laboratory recorded Lab-UE Full 100 RB (49 MHz Filter) waveforms do not incorporate the radio frequency (RF) front-end characteristics that are reflected in the in-field recorded Single-UE Full 100 RB (37 MHz Filter) waveform.

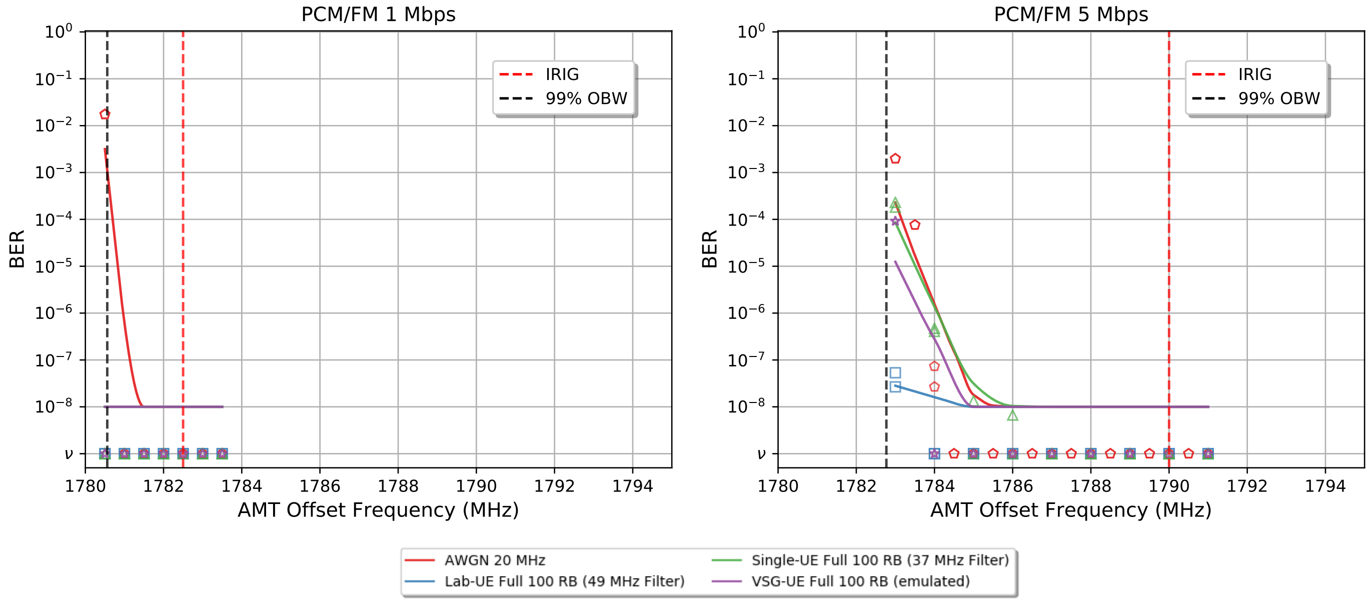

Figure 2: BER vs AMT Offset Frequency for laboratory derived ABE types: PCM/FM 1 Mbps (left), and PCM/FM 5 Mbps (right)

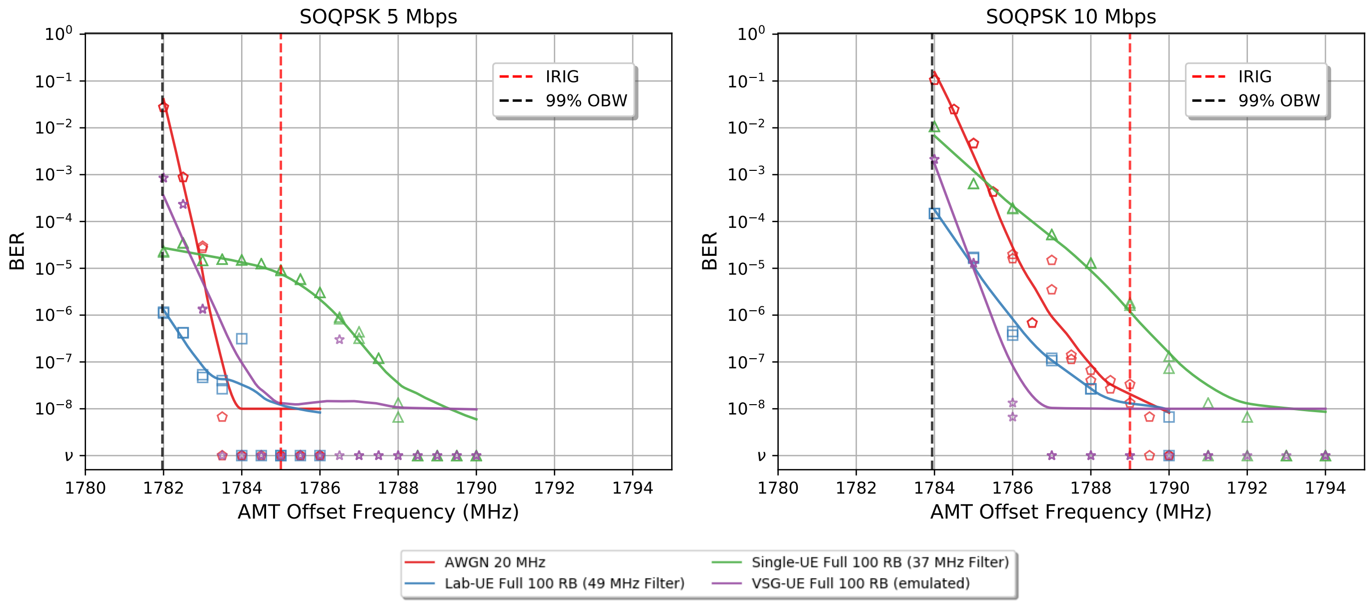

Figure 3: BER vs AMT Offset Frequency for laboratory derived ABE types: SOQPSK 5 Mbps (left), and SOQPSK 10 Mbps (right)

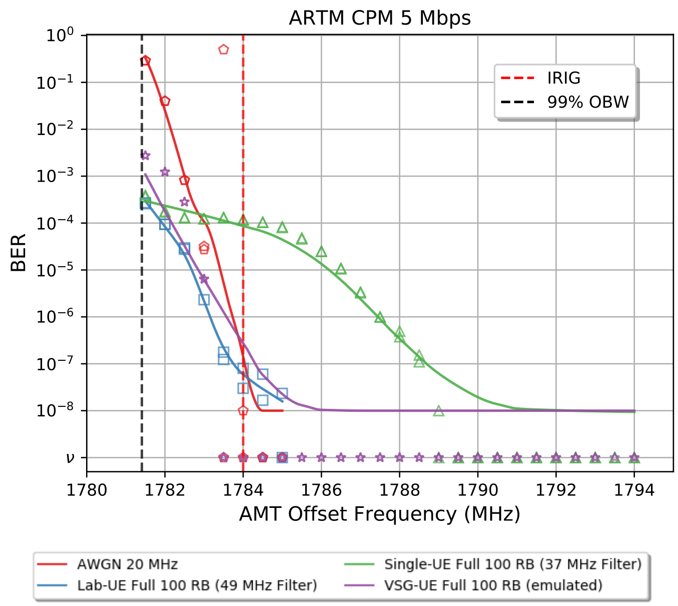

Figure 4: BER vs AMT Offset Frequency for laboratory derived ABE types: ARTM CPM 5 Mbps

CONCLUSIONS

We present additional results for consideration in the impact analysis of AMT link susceptibility to LTE spectrum neighbors. The comparison here adds information on the LTE impact on AMT link configurations when considering an emulated LTE waveform, as is typical of 3GPP emulation enabled vector signal generator (VSG)s.

We showcase the differences in impact for four select waveforms which are commonly used to represent emissions of LTE uplink. Notably, impact is not uniform and great care has to be given in the selection and recording of waveforms for the interpretation of adjacent band impacts.

REFERENCES

[1] Federal Communications Commission. Auction 97: Advanced Wireless Services (AWS-3). Last accessed: 7/2021. [Online]. Available: https://www.fcc.gov/auction/97

[2] FCC. AWS-3 Band Plans. Last accessed: 7/2021. [Online]. Available: https://www.fcc.gov/sites/default/files/wireless/services/aws/data/AWS3bandplan.pdf

[3] M. Frey, G. Sanders, J. Splett, J. Ladbury, F. Sanders, A. Kord, and R. Jacobs, "Measured Emission Spectra of Selected AWS-3 LTE Transmitters," National Institute of Standards and Technology, Tech. Rep. 1980, Dec 2017. [Online]. Available: https://doi.org/10.6028/NIST.TN.1980

[4] W. F. Young, D. A. McGillivray, A. Wunderlich, M. Krangle, J. G. Sklar, A. W. Sanders, M. K. Forsyth, M. A. Lofquist, and D. G. Kuester, "AWS-3 LTE Impacts on Aeronautical

Mobile Telemetry," National Institute of Standards and Technology, Tech. Rep. 2140, Feb 2021. [Online]. Available: https://doi.org/10.6028/NIST.TN.2140

[5] E. D. Nelson and D. A. McGillivray, "In-Situ Captures of LTE for Aeronautical Mobile Telemetry System Evaluation," National Telecommunications and Information Administration, Tech. Rep. 553, Mar 2021. [Online]. Available: https://www.its.bldrdoc.gov/publications/download/TR-21-553.pdf

[6] A. W. Sanders, M. K. Forsyth, R. D. Horansky, A. Kord, and D. A. McGillivray, "Laboratory Method for Recording AWS-3 LTE Waveforms," National Institute of Standards and Technology, Tech. Rep. 2159, May 2021. [Online]. Available: https://doi.org/10.6028/NIST.TN.2159

[7] J. G. Sklar, "Public Data Resource: AWS-3 LTE Impacts on Aeronautical Mobile Telemetry," Sept 2020. [Online]. Available: https://data.nist.gov/od/id/mds2-2279

[8] A. W. Sanders, "Public Data Resource: Uplink IQ Recordings," April 2021. [Online]. Available: https://data.nist.gov/od/id/mds2-2395

[9] K. Temple, "An initial look at adjacent band interference between aeronautical mobile telemetry and long-term evolution wireless service," in *Proc. Int. Telemetering Conf.*, Glendale, AZ, Nov. 2016. [Online]. Available: https://repository.arizona.edu/handle/10150/624192

[10] Inter-Range Instrumentation Group: Range Commanders Council Telemetry Group. IRIG 106-19: Telemetry Standards. [Online]. Available: http://www.irig106.org/docs/106-19/106-19$_{T}elemetry_{S}tandards.pdf$