LTE Concurrent Operations with DTV

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Abstract - *As per the 600 MHz post-auction rules, wireless LTE networks cannot be deployed with less than 5 MHz spectral separation from on-air TV channels inside their service contours. However, DTV-LTE concurrent operations within 5 MHz guard band can potentially help both the broadcasters and wireless carriers by allowing TV stations to be on-air, while the carriers commence network operations. This can provide flexibility in repacking. T-Mobile has conducted lab and field testing which demonstrates that LTE networks can be successfully deployed with as low as 0 MHz guard-band without causing harmful interference into TV receivers. Moreover, concurrent operations between channel 51 and LTE in 700MHz A block have been successfully in place for the past many years with many broadcasters in several major markets, without any complaints from TV viewers. This paper presents results of the lab and field work.*

Introduction

As a provision to protect over-the-air TV viewers from receiving harmful interference from commercial wireless communications services, FCC's post-auction rules of the 600 MHz incentive auctions require a minimum of 5 MHz guard-band with on-air TV channels for deployment of wireless communication services inside their service contours [1]. This applies to both LTE Downlink and Uplink frequencies. T-Mobile has conducted rigorous lab and field testing which demonstrate that concurrent operations with far less than 5 MHz guard-band are practically feasible in both LTE Downlink and Uplink. More over T-Mobile has successfully launched wireless services in multiple markets in 700MHz A block (formerly Channel 52) concurrently with Channel 51. These have been operational for over 3 years without any complaints from TV stations or their viewers.

This paper presents results from these lab and field testing. Field tests were conducted with two low-power and a high-power TV station.

DTV Concurrent Operations with LTE Downlink

I. Operating Frequencies

The 600 MHz LTE Downlink (DL) and Uplink (UL) frequencies as they correspond to the TV channels 38 to 51 are shown in Figure 1. LTE Downlink range covers 617-652 MHz.

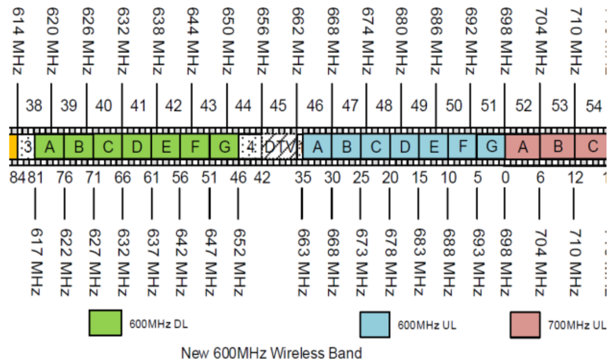

FIGURE. 1: LTE DOWNLINK, UPLINK AND CORRESPONDING TV CHANNEL FREQUENCIES.

II. Interference Mechanism and Test Cases

Interference in the downlink frequencies can potentially occur due to transmission from a base station. Figure 2 illustrates the mechanism of interference. Typical LTE base stations are three sectored with 65-degree beam width antennae. Linear inter-site distances for low-band LTE cell sites can range from approximately 0.5 miles (in dense urban areas) to over 5 miles (in rural areas). However, it should be noted that in dense urbans areas, it is not very likely that multiple sites will have line-of-sight with each other. The small separation is mostly required because the signal from one cell-site is blocked by building structures and another cell site is deployed to cover areas on the other side of the building. Hence, in practice, strong interference from multiple sites, while theoretically possible, is not practically likely. Figure 2 shows a scenario where a TV receiver potentially receives interference from three base stations. Here we consider two test cases: a) when a directional TV antenna is used outdoor, and b) when an omnidirectional antenna is used indoors. Table 1 provides signal power calculations for variations of these test cases. Radiation pattern of a typical consumer outdoor TV antenna is shown in Figure 3, which is used in the calculations.

The worst-case (although impractical) scenario assumes the TV receiver is separated by only 100 m from three LTE Base Station sectors with their maximum antenna gain pointed directly towards the TV receive antenna. When an outdoor TV antenna is used, it is assumed to be oriented towards the TV transmitter.

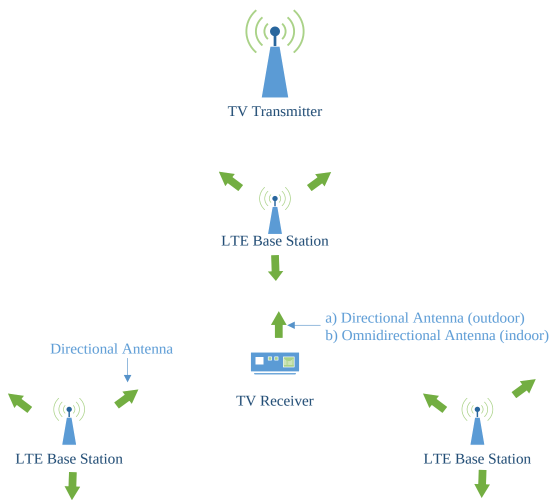

FIGURE 2: INTERFERENCE MECHANISM FOR LTE DOWNLINK.

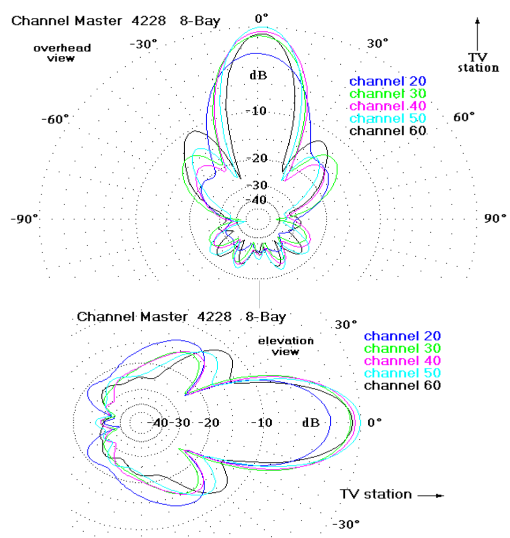

FIGURE 3: TYPICAL OUTDOOR TV ANTENNA PATTERN.

I. *Lab Testing*

Lab testing was performed with simulated DTV (8VSB) and LTE signals. Figure 4 shows the conceptual setup. The details of equipment are as follows:

Spectrum Analyzer: Anritsu BTS Master MT8220T

DTV and LTE Simulator: Rhode & Schwarz Broadcast Test Center

TV Receivers: Two commercially available TV sets were used for lab testing:

LG Model No. 24LJ4840
Insignia Model No. NS-19NDNA220NA 16-A

Aggregate Interference from 3 LTE Base Stations	
Frequency (MHz)	629
Individual transmit powers from Base Stations 1, 2 & 3 (dBm)	46
Maximum LTE Base Station antenna gain (dBi)	15
Free space path loss LTE at 100 m / 0.062 miles (dB)	68.42
Free space path loss LTE at 1km / 0.62 miles (dB)	88.42
Building penetration loss (dB)	15
Directional TV antenna gain - 0 degrees azimuth (dBi)	10
Directional TV antenna gain - 120 degrees azimuth (dBi)	-20
Directional TV antenna gain - 240 degrees azimuth (dBi)	-20
Omnidirectional TV antenna gain (dBi)	0
Calculated LTE Received power at TV Receiver (outdoors at 100m / 0.062 miles, with Directional antenna, dBm)	2.59
Calculated LTE Received power at TV Receiver (outdoors at 1km / 0.62 miles, with Directional antenna, dBm)	-17.41
Calculated LTE Received power at TV Receiver (indoors at 100m / 0.062 miles, with Omnidirectional antenna, dBm)	-17.65
Calculated LTE Received power at TV Receiver (indoors at 1km / 0.62 miles, with Omnidirectional antenna, dBm)	-37.65

TABLE 1: CALCULATIONS OF LTE POWER ARRIVING AT A TV RECEIVER.

The LG model represented higher-end of the consumer market and Insignia represented the value-end. Their receive sensitivity was measured in conducted mode with simulated DTV signal in the absence of LTE or any other interferer and is given in Table. All other tests were also performed in conducted mode. Both TVs have similar receive sensitivity however, they varied in their tolerance to LTE interference at different levels of desired DTV signal.

TV	**Receive Sensitivity (dBm)**
LG Model No. 24LJ4840	-87
Insignia Model No. NS-19NDNA220NA 16-A	-86

TABLE 2: MEASURED RECEIVE SENSITIVITY

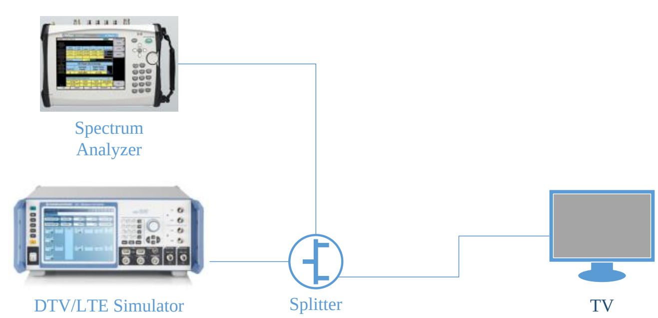

FIGURE 4: LAB TEST SETUP.

Figure 5 shows tolerable levels of adjacent-frequency LTE signal for various levels of DTV receive signals at the inputs of the TV sets. Using the calculated signal levels given in Table 1, in the worst case, an LTE signal of 2.59 dBm can be tolerated (i.e. does not cause picture degradation) when the received DTV signal is -32 dBm (101dBu) or stronger. For more practical case, an LTE interfering signal of -17.41 dBm can be tolerated in areas where the available DTV received signal is between -50 and -60 dBm (81 and 71 dBu) or stronger. Testing shows that the value-end TV (Insignia) has more tolerance to interference when the DTV signal is stronger, whereas the more expensive LG TV showed more tolerance with weaker DTV signal. Testing with 0, 1 and 2 MHz guard-band between DTV and LTE signal reveals that larger guard-band can allow deployment of LTE service in relatively weaker DTV signal. Results are shown in Figure 5.

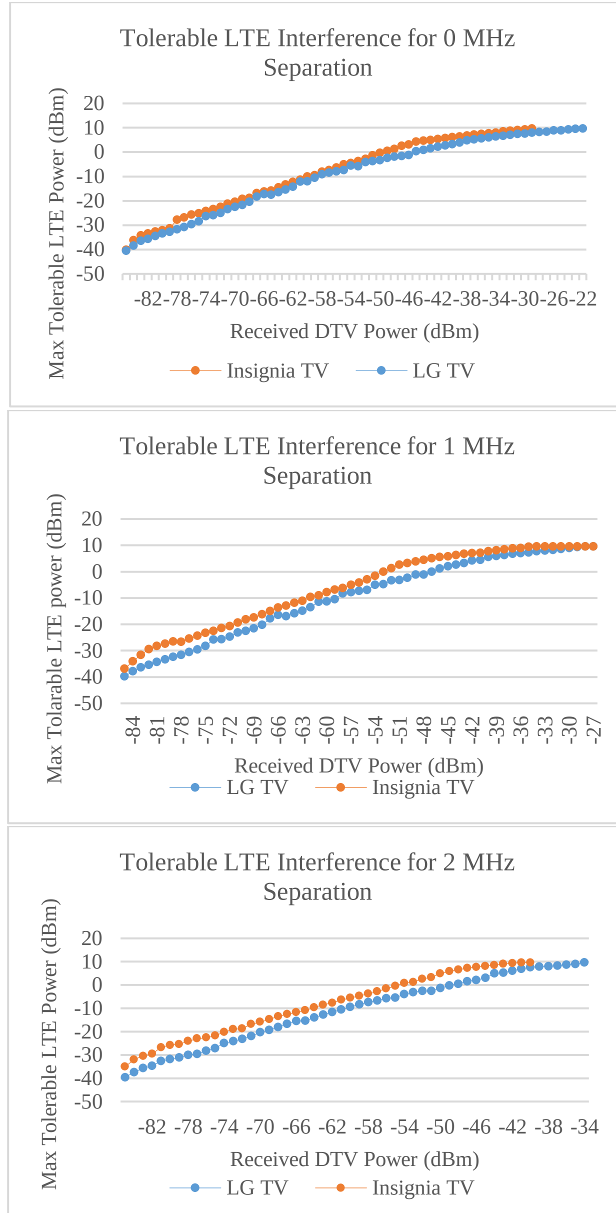

FIGURE 5: LAB MEASUREMENT RESULTS.

II. Field testing

Field testing was performed in Chicago, IL, with low power television station WESV-LD (RF channel 40), and in Liberal, KS, with KSWE-LD (RF channel 39). Similar observations were made in both cases. However only results from Chicago are presented here. RF specifications of the TV station's transmitting facility and the LTE base stations are given below.

TV Station Specifications (WESV-LD):
Transmit Power = 0.34 kW / 55.3 dBm
Antenna gain = 12.47 dB
Maximum ERP = 6 kW /67.8 dBm
RF Channel = 40
Transmit frequencies = 626 – 632 MHz

LTE Base Station Specifications:
Transmit Power = 40 W/ +46 dBm
Maximum antenna gain = 15 dBi
Maximum EIRP = 1.26 kW / 61 dBm
Maximum ERP = 0.77 kW / 58.85 dBm
Antenna beam width: 65-degree Azimuth, 10-degree Elevation
LTE Block = D
Transmit frequencies = 632 – 637 MHz
Normal antenna down tilt = 3 degrees

Two TV sets (Vizio and LG brand) were selected to represent low and high end of consumer market. A test van with an extendible mast (up to 30 ft) with an outdoor TV antenna mounted on top was used as shown in Figure 8. Equipment setup inside the van is depicted in the Figure 6. First, a test location was selected where normal TV reception was of high quality (pixilation-free) in the *absence* of a LTE signal. The TV antenna (outdoor or indoor) was rotated/adjusted to receive the highest possible DTV signal strength, as a TV viewer would normally do. The signal strength indicator on one of the TV set's menus as well as on our spectrum analyzer was used to monitor the DTV signal strength while the receive antenna was adjusted. The indoor antenna has a pre-amplifier that can be turned on/off. Tests were performed with and without amplification.

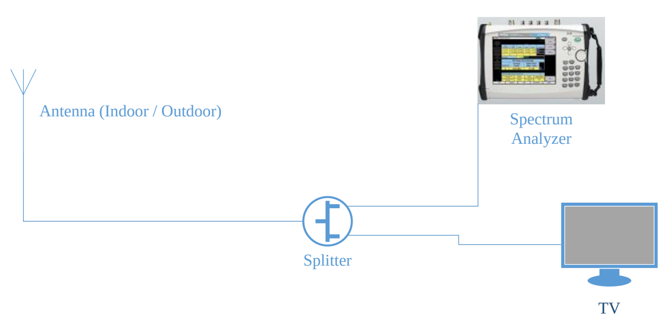

FIGURE 6: FIELD MEASUREMENT SETUP.

Once the antenna was properly oriented, the LTE base station was turned on. Two test phones were used simultaneously and OOKLA speed test was executed on both phones This test pushes the Base Station and UE to their maximum data throughput. This ensured maximum utilization of Physical Resource Blocks (PRBs) on the downlink and uplink and that the base station was transmitting near full power. Figure 7 shows locations of test sites and LTE base stations. Figure 8 shows measurement set up at location 3 – the base station antennas can be seen very close (approx. 90 m) to the TV antenna.

Test Location	Received DTV Power	Received LTE Power	Interference Observed on TVs	Antenna Configuration
1	-41.2 dBm	(LTE off-air)	No	Outdoor at 30ft, directed towards TV transmitter.
1	-41.2 dBm	-47 dBm	No	Outdoor at 30ft, directed towards TV transmitter.
1	-54 dBm	-48 dBm	No	Outdoor at 30ft, directed away from TV transmitter.
1	-55 dBm	-58 dBm	No	Indoor antenna inside vehicle. Amplifier off.
1	-38 dBm	-43 dBm	No	Indoor antenna inside vehicle. Amplifier on.
2	-59.4 dBm	(LTE off-air)	No	Outdoor antenna at 30ft height, directed towards TV transmitter
2	-60 dBm	-40 dBm	No	Outdoor at 30ft, directed towards TV transmitter
3	-57 dBm	(LTE off-air)	No	Outdoor antenna at 30ft height, directed towards TV transmitter
3	-57 dBm	-33.5 dBm	No	Outdoor at 30ft, directed towards TV transmitter. LTE antenna down-tilted to 3 degrees.
3	-57 dBm	-26 dBm	No	Outdoor at 30ft, directed towards TV transmitter. LTE antenna down-tilted to 8 degrees.

TABLE 3: FIELD TESTING RESULTS WITH LTE DOWNLINK

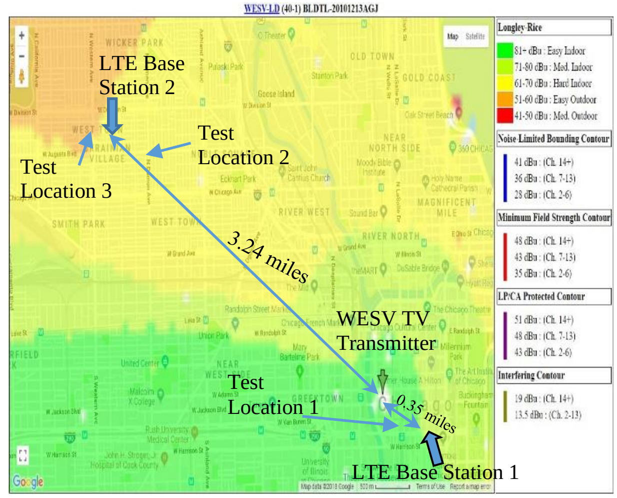

FIGURE 7: FIELD TEST LOCATIONS FOR LTE DOWNLINK.

FIGURE 8: TEST SETUP AT LOCATION 3.

No picture degradation was observed on either TVs even though Ch 40 was significantly weaker than the LTE signal in several cases, as can be seen in the spectrum scan taken at location 2 (see Figure 9). The scan shows that both channel 39 and LTE are present with 0 MHz guard-band with channel 40. Results from field testing at various locations are summarized in Table 3.

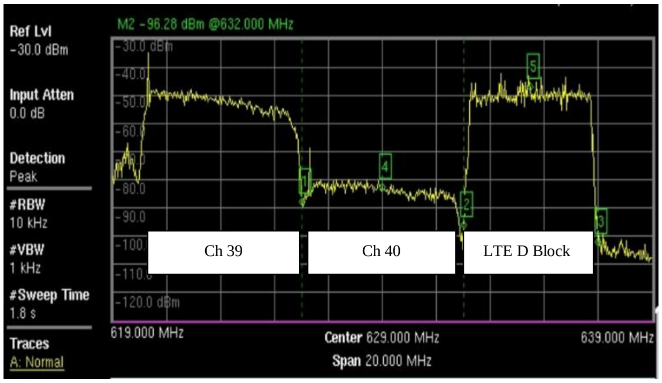

FIGURE 9: MEASUREMENT AT FIELD LOCATION 2

DTV CONCURRENT OPERATIONS WITH LTE UPLINK

I. Operating Frequencies

The LTE Downlink and Uplink frequencies as they correspond to the TV channels are shown in Figure 1. The testing described in this section was performed with TV Channel 51 and 700 MHz A-block (formerly Ch 52). The results fundamentally apply to the rest of the 600 MHz uplink band.

II. Interference Mechanism and Test Cases

Potential interference from LTE Uplink can occur from the LTE user equipment (UE), typically a mobile phone. Practical considerations were applied in deriving the worst-case test scenarios of interest.

3GPP standards [2] limit the maximum output RF power of most UE classes to +23 dBm, before the antenna. In the sub 1000 MHz frequencies, typical antenna gains are -5 dBi, which brings the maximum effective radiated isotropic power (EIRP) to +18 dm. Uplink power control is implemented in LTE networks which allows for optimization of UE battery power consumption and containing self-interference. From practical deployments, it has been determined that most (90th percentile) UE's operate at 0 dBm EIRP or lower, hence this value is used for calculations. For the test cases where an indoor TV antenna is used for reception, a practical physical separation of 2 m between the UE and the indoor TV receiver antenna is assumed, which adds a free space path loss of 30 dB. Hence the total power arriving at the indoor TV antenna is assumed to be -30 dBm.

Measurements of received signal power were conducted within the service contour of WHLV-TV, which operates on RF channel 51. The measurements correspond well to the Longley-Rice predicted values. An outdoor roof-top-level average signal strength of -26.9 dBm was measured in the core area whereas down to -85 dBm was measured in the fringe areas. For testing purposes, we divided the service area into core, moderate and fringe. It was assumed that indoor TV antennas are prevalent in the core areas, while moderate and fringe areas will require outdoor antennas. 20 dB building penetration loss was assumed. Hence for indoor cases it results in -46.9 dBm total power arriving at the indoor TV antenna. For outdoor case a 5 m separation between UE and the antenna is assumed, which adds 43 dB free-space path loss in addition to the antenna discrimination factor of -10 dB (see Figure 3). Hence from a TV viewer present indoors watching TV and using the mobile phone on adjacent channel frequencies a total power of -73 dBm will arrive at the outdoor TV antenna.

For each of the core, moderate and fringe DTV coverage conditions, LTE coverage was sub-divided into two categories: favorable and unfavorable. Under favorable RF conditions (such as line-of-sight with the base station and physically very close to it) a UE transmits at low power, while under unfavorable conditions (such as non-line of sight, indoors, far away from the base station), it is forced to transmit at high power.

III. Lab Testing

Similar equipment setup as for downlink concurrent operations testing (shown in Figure 4) was used. Measured receive sensitivity of the TV sets and set top receivers used in the testing are given in Table 4.

DTV Receiver	Receive Sensitivity
Sony XBR49X850B, 46" DTV	-88.0 dBm
Samsung UN32H5203, 32" DTV	-90.0 dBm
Vizio E280L-B1, 28" DTV	-88.0 dBm
Apex DT502, set top receiver	-82.5 dBm
Apex DT250, set top receiver	-83.1 dBm

TABLE 4: MEASURED RECEIVE SENSITIVITY WITHOUT ANY ADJACENT LTE SIGNAL

Lab test results are summarized in Tables 5 and 6. It is clear that high quality TV reception without picture degradation can be maintained despite a very weak DTV signal in the presence of a relatively strong LTE signal. In order to cause noticeable degradation, the LTE UE has to be inconveniently and impractically close to the TV receiver antenna.

DTV Receiver	Min. required DTV signal with LTE UE present (0 dBm @ 2 m from DTV receiver = -30 dBm)
Sony XBR49X850B, 46" DTV	-80.0 dBm
Samsung UN32H5203, 32" DTV	-89.2 dBm
Vizio E280L-B1, 28" DTV	-88.2 dBm
Apex DT502, set top receiver	-76.9 dBm
Apex DT250, set top receiver	-70.9 dBm

TABLE 5: MEASURED DTV SIGNAL REQUIRED FOR INTERFERENCE-FREE PICTURE WITH LTE SIGNAL IN ADJACENT CHANNEL

DTV Receiver (w/ -46.9 dBm DTV signal)	Max. tolerable LTE signal before picture gets pixelated	Equivalent distance of LTE UE (@ 0 dBm EIRP) from TV antenna	Equivalent distance of LTE UE (max output @ +18 dBm EIRP) from TV antenna
Sony XBR49X850B, 46" DTV	-3.0 dBm	0.05 m	0.38 m
Samsung UN32H5203, 32" DTV	-7.0 dBm	0.08 m	0.61 m
Vizio E280L-B1, 28" DTV	-5.0 dBm	0.06 m	0.48 m
Apex DT502, set top receiver	-6.5 dBm	0.07 m	0.57 m
Apex DT250, set top receiver	-11.9 dBm	0.13 m	1.01 m

TABLE 6: MEASURED ADJACENT CHANNEL LTE SIGNAL REQUIRED TO CAUSE INTERFERENCE IN INDOOR SCENARIO

IV. *Field Testing*

Field testing was performed in Orlando, FL, with WHLV-TV, with a 1 MHz guard-band between DTV and LTE. RF Specifications of the TV station and the LTE UE are as follows:

TV Station Specifications (WHLV-TV):
Transmit Power = 28.3 kW / 74.52 dBm
Antenna gain = 15.47 dB
Maximum ERP = 1000 kW / 90 dBm
RF Channel = 51
Transmit frequencies = 692 – 698 MHz

LTE UE Specifications:
Maximum Transmit Power = 200 mW/ +23 dBm
Maximum antenna gain = -5 dBi
Maximum EIRP = 63 mW / +18 dBm
Maximum ERP = 38.4 mW / +15.85 dBm
Antenna pattern: Omnidirectional
LTE Block = A (Band 12)
Transmit frequencies = 699 – 704 MHz

Test locations that captured the various cases described above were selected. UE transmit power was measured during each test. Sample measurements of UE transmit power are shown in Figure 10. During each test, a voice-over-LTE call and a video chat (Hangouts) session was established to create maximum utilization of physical resource blocks (PRBs) and force the UE to transmit at high power.

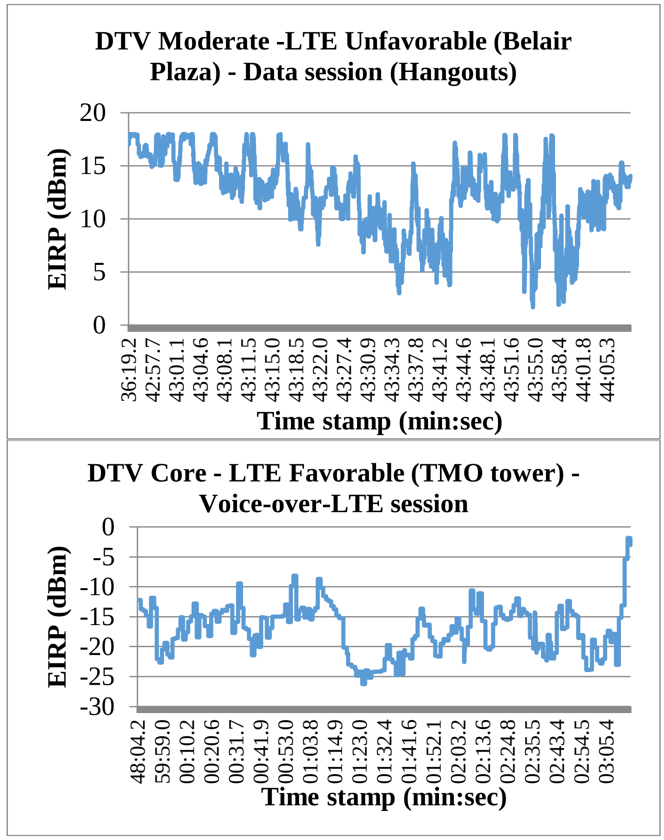

FIGURE 10: TRANSMIT POWER MEASUREMENTS FROM UE

Table 7 summarizes the results of field tests. No interference was noticed despite low DTV signal and high LTE UE signal at several locations.

Test Case	Distance from TV transmitter (miles)	Received DTV Power (dBm)	Average LTE UE Transmit EIRP (dBm)	UE Separation from DTV Antenna	Interference Observed on TVs
DTV Core – LTE Favorable (location 1, location 2)	20.4, 17.3	-51.8, -60.6	-16	2 m (indoor antenna)	No
DTV Core – LTE Unfavorable (location 1, location 2)	20.6, 18	-55.8, -55.7	-4.1	2 m (indoor antenna)	No
DTV Moderate – LTE Favorable (location 1, location 2)	51.3, 48.5	-56.2, -62	-15.9	5 m (outdoor antenna)	No
DTV Moderate – LTE Unfavorable (location 1, location 2)	50.2, 46.5	-60.9, -56.8	11.9	5 m (outdoor antenna)	No
DTV Fringe – LTE Favorable (location 1, location 2)	66.2, 68.7	-85.7, -77.8	-9.3	5 m (outdoor antenna)	No
DTV Fringe – LTE Unfavorable (location 1, location 2)	68, 71	-81.5, -88	14.6	5 m (outdoor antenna)	No

TABLE 7: FIELD TESTING RESULTS WITH LTE UPLINK

V. Field Deployment

Since 2015, T-Mobile has deployed its LTE wireless services in Band 12 A-block concurrently with 12 Channel 51 stations in major metropolitan areas, covering a population of 79 million. No complaint of interference has been received from respective TV stations or any of their viewers.

CONCLUSIONS

Lab and field testing shows that concurrent operations between DTV and LTE Downlink and Uplink with significantly less than 5 MHz guard band are practically feasible. Concurrent operations with LTE Uplink with 1 MHz guard-band have been in operation for a significant enough time, while operations with LTE Downlink with 0 MHz guard-band have been proven rigorously with lab and field testing. Such arrangement between broadcasters and wireless carriers can allow tremendous flexibility in repacking of TV stations and deployment of wireless communication services, and prove to be win-win for both.

REFERENCES

[1] FCC 15-141 Third Report & Order and First Order on Reconsideration, October 26, 2015

[2] 3GPP TS 36.101 Release 14 and above