The Impact of LTE UE on Audio Devices

Yongsup Shim, Ilkyoo Lee, and Seungkeun Park

In this letter, the acoustic noise due to long term evolution (LTE) user equipment (UE) is investigated with various transmitting powers of the LTE UE by using the Monte Carlo method in a practical acoustic noise experiment.

Keywords: Acoustic noise, audio device, LTE UE power, cell radius, Monte Carlo.

I. Introduction

The demands for multimedia services have dramatically increased in a digital society. The long term evolution (LTE) system providing multimedia services, which is regarded as the fourth generation (4G) for mobile communication, is spreading over many countries, and the number of users is growing rapidly.

It was reported that an acoustic noise is generated from audio devices such as speakers and headsets operating at an audio frequency band of 20 Hz to 20 kHz due to the transmit switching characteristics of LTE user equipment (UE) in a situation in which the LTE UE devices are transmitting in close proximity to the audio devices [1]. Thus, there is a need to investigate the acoustic noise of audio devices caused by the LTE UE devices.

To the best of the authors' knowledge, although the acoustic noise produced by the global system for mobile communications (GSM) based on time division multiple access (TDMA) has been studied [2]-[5], a study on acoustic noise from LTE UE has not been reported yet.

Being motivated by the possibility of coexistence between LTE UE devices and audio devices, we have examined the impact of LTE UE devices on audio devices by using the Monte Carlo method in a practical acoustic noise experiment. As a result, this letter presents the transmitting power level of LTE UE depending on the cell radius so as not to produce the acoustic noise of audio devices in the vicinity of LTE UE devices.

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II. Characteristics of LTE UE Signal

It is well known that LTE UE transmits the RF signals that are switched on and off according to the time schedule defined by 3GPP standards [6]. As shown in Fig. 1, the frame of the LTE UE signal with the amplitude (A) has the time period of 10 ms (T) with a pulse repetition frequency of 100 Hz. A frame is divided into 20 slots, each of a 0.5-ms duration. The minimum unit of scheduling is a time-frequency block corresponding to one subframe with a 1-ms (τ) duration and 12 subcarriers with a 180-kHz spectrum.

When transmitting LTE UE signals on the basis of the format illustrated in Fig. 1, the signal that has direct current and its harmonics in the frequency domain is obtained as in (1) [7]:

$$V(f) = \frac{A\tau}{T} + \frac{2A\tau}{T}\sum_{n=1}^{\infty}\left|\frac{\sin[n(\tau/T)\pi]}{n(\tau/T)\pi}\right|, \tag{1}$$

where n represents the order of harmonics oscillation and determines null frequencies at n/τ.

The spectrum of LTE UE harmonics at the frequency from 0 kHz to 5 kHz is shown in Fig. 2. The A and duty cycle (τ/T) are the parameters that affect the magnitude spectrum of harmonics of the LTE UE's transmitting signal. Figure 2 also shows a magnitude spectrum of harmonics according to the variation of A and τ/T, respectively.

In practical situations, the A and τ/T can be changed randomly on the basis of the LTE signal transmitting mechanism. It is observed in Fig. 2 that the variations of two harmonics at 100 Hz are almost the same for both Case 1 and

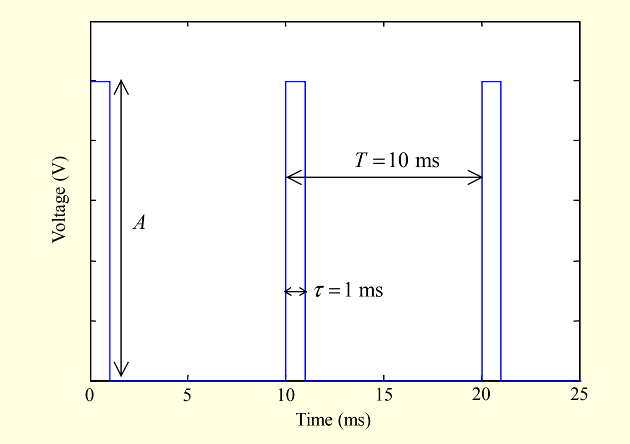

Fig. 1. LTE UE signal format in time domain.

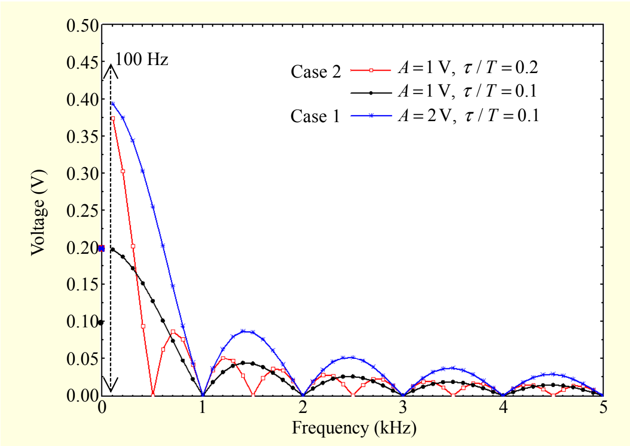

Fig. 2. Comparison of harmonics spectrum with variation of A and τ/T.

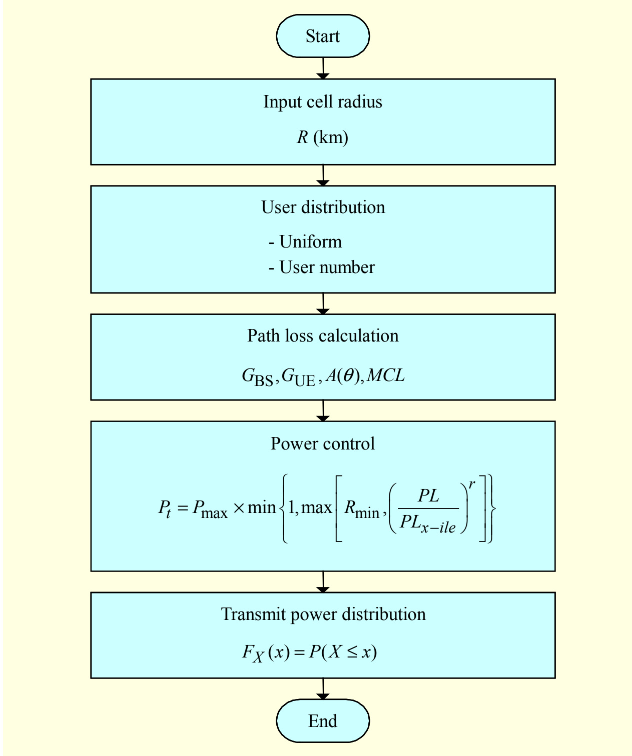

Fig. 3. Simulation flowchart for calculation of transmitting power.

Case 2; however, the variations of Case 1 are higher than those of Case 2 at 100 Hz and above. Thus, the variations of harmonics depend more on the A than on the τ/T.

Therefore, the transmitting power level of LTE UE in accordance with only the variation of A should be considered to analyze the impact of the audible harmonics of the LTE UE on audio devices.

III. Monte Carlo Simulation of LTE UE Transmitting Power

In this section, we investigate the relation between the LTE UE transmitting power and the cell radius of the LTE radio network through Monte Carlo simulation.

As presented in the previous section, the levels of audible harmonics are determined by the LTE UE's transmitting power that is obtained from A. Thus, it is necessary to analyze the statistical behaviors of the transmitting power based on the cell radius. The Monte Carlo simulation is carried out under the power control mechanism of 3GPP standards. A simulation flowchart is shown in Fig. 3.

The transmitting power of LTE UE is determined by using power control to compensate for the path loss between a base station (BS) and a UE device. Also, the LTE UE is distributed randomly within the cell radius. The power control process is used to realize the transmitting power distribution of the LTE UE according to the variation of the cell radius as follows [8], [9]:

$$P_t = P_{max} \times \min\left\{1, \max\left[R_{min}, \left(\frac{PL}{PL_{x-ile}}\right)^{\gamma}\right]\right\}, \qquad (2)$$

where P_{max} is the maximum transmitting power, R_{min} is the minimum power reduction ratio (P_{max}/P_{min}, P_{min} is the minimum transmitting power), PL is the path loss between the BS and UE, γ ($0<\gamma\le1$) is the balancing factor representing the channel status, and $PL_{x\text{-}ile}$ is the limit value of x percent in the cumulative distribution function (CDF). The UE corresponding to $1-x$ percent has a larger value than $PL_{x\text{-}ile}$ and transmits the maximum power.

For simulation, it is assumed that the UE antenna radiation pattern is omnidirectional and that the BS antenna radiation pattern has three-sector cell sites. The urban propagation model is selected at 2 GHz and the BS antenna height of 15 m is chosen. The simulation parameters, including a balancing

Table 1. Simulation parameters.

Parameter	Value
Cell radius (km)	1, 1.5, 2, 3
User distribution	Uniform
Propagation model	PL=128.1+37.6log(d [km])
Maximum UE power	250 mW
BS antenna gain	15 dBi
UE antenna gain	0 dBi
BS antenna pattern	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ $-180\le\theta\le180$, θ_{3dB}=65°, A_m=20 dB
MCL	70 dB
Balancing factor	0.8
$PL_{x\text{-}ile}$	133 dB

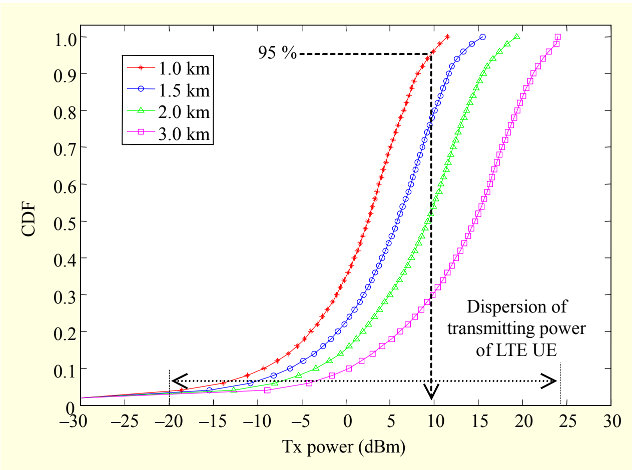

Fig. 4. Distribution of transmitting power of LTE UE.

factor, minimum coupling loss (MCL), and $PL_{x\text{-}ile}$, are summarized in Table 1 [10]-[12].

The CDF of transmitting power obtained from the simulation is shown in Fig. 4.

The simulation result shows that the cell radius is reduced to cover the increasing number of LTE UE devices per unit area. Also, the reduction of the cell radius leads to a decrease in the transmitting power of the LTE UE through the power control mechanism. A transmitting power of 10 dBm with a cell radius of 1 km is required to meet a CDF of 95%.

To validate the Monte Carlo simulation results, the field measurement of the LTE UE transmitting power is carried out in five different areas (apartment complexes A and B, highway, shopping mall, and downtown streets) in a city in the Republic of Korea. Figure 5 illustrates the dispersions of the measured

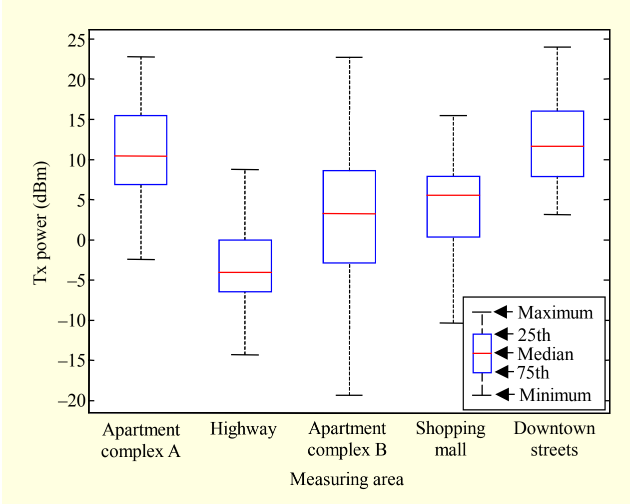

Fig. 5. Practical measurement of LTE UE transmitting power.

transmitting power.

For the practical test, 100 UE devices are placed in each of the five areas. It is observed that 34% (170 spots) have 10 dBm or above and 2.6% (13 spots) have 22 dBm or above.

IV. Experiment of Acoustic Noise

An experiment associated with acoustic noise is carried out to examine the compatibility between audio devices and LTE UE devices. As shown in Fig. 6, to investigate the acoustic noise level according to the transmitting power level of the LTE UE, we measure the sound pressure level (SPL) using an audio level meter and evaluate the acoustic noise level according to the response of our subject.

The experiment is performed in a semi-anechoic chamber to prevent interference from external noises. Three models (A, B, and C) of the LTE UE are selected and linked with the LTE BS emulator for uplink transmission, respectively. The LTE UE is spatially separated with the speaker at a distance of 5 cm. Such components as the amplifier and the coils inside the speaker are influenced by interfering signals generated by the LTE UE.

The separation distance of each is selected for the worst case scenario in the practical situation, as in Fig. 6. Three levels of acoustic noise, that is, “inaudible,” “slight,” and “loud,” are evaluated by five participants using the mean opinion score test method [13]. As expected, the sound pressure level and the acoustic noise level increase as the LTE transmitting power increases, which is shown in Table 2.

The background noise level is measured as 42.2 dBA when the LTE UE does not operate, and this is used as a reference level. The acoustic noise level in a busy traffic area is 70 dBA, and it is 40 dBA in the residential area at night [14].

As shown in Table 2, the SPL becomes the background noise

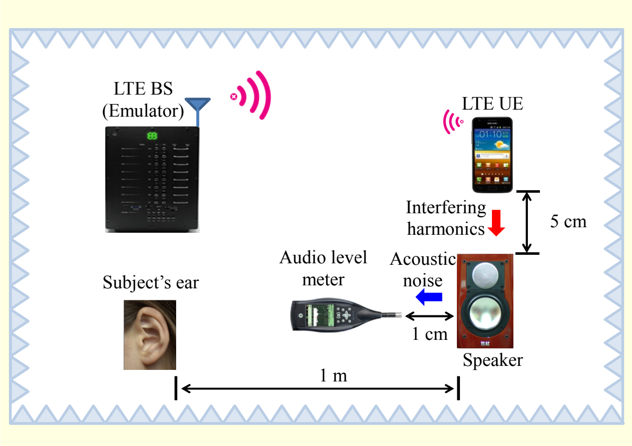

Fig. 6. Configuration of experiment.

Table 2. Maximum SPL and noise level at various LTE UE transmitting power levels.

	LTE model	LTE UE power level (dBm)			
		0	10	15	22
SPL (dBA)	A	42.2	42.3	48.1	67.0
	B	42.2	44.7	49.7	70.8
	C	42.2	44.3	47.7	62.4
	Mean	42.2	43.8	48.5	66.7
Noise level (evaluated by five subjects)		Inaudible	Inaudible	Slight	Loud

level when the transmitting power of the LTE UE is 0 dBm. Also, according to our experiments, the subject cannot recognize the acoustic noise when the LTE UE operates at or below10 dBm.

Therefore, it is recognized that 10 dBm of LTE UE transmitting power is the critical threshold to identify the acoustic noise generated by the LTE UE from the viewpoint of human hearing sensitivity.

Considering the results shown in Fig. 4 and Table 2, it is clear that a transmitting power of 10 dBm or below with a cell radius of 1 km is required to meet a CDF of 95%. Under such conditions, the acoustic noise on audio devices does not register in terms of human hearing.

V. Conclusion

This letter presented the impact of LTE UE transmitting power on audio devices. The characteristics of the LTE UE signal and the generation of acoustic noise were reviewed. The transmitting power of the LTE UE, cell radius, and acoustic noise were analyzed through both simulation and practical experiment to ensure the compatibility between the LTE UE devices and the audio devices. In conclusion, we found that acoustic noise is not perceived when the LTE UE transmitting power is 10 dBm or below with a cell radius of 1 km on the LTE radio network.

References

[1] Munhwa Broadcasting Corporation, Dec. 2011. http://imnews.imbc.com/replay/nwdesk/article/2976815_5780.html

[2] R.E. Schlegel and F.H. Grant, “Modeling the Electromagnetic Response of Hearing Aids to Digital Wireless Phones,” *IEEE Trans. Electromagn. Compat*., vol. 42, no. 4, Nov. 2000, pp. 347-357.

[3] I. Claesson and A. Rossholm, “Notch Filtering of Humming GSM Mobile Telephone Noise,” *Proc. IEEE-ICICS*, 2005, pp. 1320-2323.

[4] M. Skopec, “Hearing Aid Electromagnetic Interference from Digital Wireless Telephones,” *IEEE Trans. Rehab. Eng*., vol. 6, no. 2, June 1998, pp. 235-239.

[5] H.B Liang et al., “The Effect and Solution of EMI Caused by 217 Hz TDMA Switching from Compact Size GSM Security System,” *Proc. IEEE-iWEM*, 2011, pp. 186-190.

[6] 3GPP Std. TS 36.211 V.10.3.0, *Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation*, 2011.

[7] C.R. Paul, *Introduction to Electromagnetic Compatibility*, Hoboken, NJ: John Wiley & Sons, Inc., 2006.

[8] 3GPP Std. TR 36.942 V10.2.0, *Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) System Scenarios*, 2010.

[9] M.H. Na et al., “Coexistence Studies for 3GPP LTE with Other Mobile Systems,” *IEEE Commun. Mag*., Apr. 2009, pp. 60-65.

[10] W. Jing et al., “Interference Analysis and Coexistence Studies between E-UTRA and UTRA Systems,” *Proc. IEEE-VCT — Spring*, 2010, pp. 1-6.

[11] European Communications Office, *Spectrum Engineering Advanced Monte Carlo Analysis Tool* (*SEAMCAT*) *Handbook*, CEPT, 2010.

[12] X. Chen et al., “Coexistence Analysis Involving 3GPP Long Term Evolution,” *Proc. IEEE-VTC*, Fall 2007, pp. 225-229.

[13] ITU-T Std. P.800, *Telephone Transmission Quality*, 1996.

[14] A.D. Pierce, *Acoustics: An Introduction to Its Physical Principles and Applications*, Melville, NY: Acoustical Society of America, 1989.