Analysis of Wi-Fi HaLow Device Interference to LTE User Equipment

Yeon-Gyu Park[1], Eun-Young Chang[1], Il-Kyoo Lee[1], and Yan-Ming Cheng[2]
[1] Department of Electricity Control Engineering, Kongju National University, Cheonan-si 31080, Korea
[2] College of Electrical & Information Engineering, Beihua University, Jilin 132013, China
Email: yeon910416@smail.kongju.ac.kr; {ceyng; leeik}@kongju.ac.kr; mycheng@beihua.edu.cn

Abstract—Recently, the interest in Internet of Things (IoT) has been increasing. Thus, it is necessary to study on the coexistence between IoT devices and other radio communication services for the efficient use of limited frequency resource. In this paper, the interference of the IoT device using Wi-Fi HaLow to the Long Term Evolution (LTE) User Equipment (UE) was studied through Minimum Coupling Loss (MCL) method and Monte Carlo (MC) method. As a result, the separation distance and the number of acceptable Wi-Fi HaLow devices based on Duty Cycle (DC) were obtained to protect the LTE UE from the interference of Wi-Fi HaLow device.

Index Terms— Interference, Wi-Fi HaLow, LTE UE, MCL, MC, separation distance, DC

I. INTRODUCTION

Due to the development of the mobile communication technology, it has been possible to communicate with each other at anywhere by mobile phone and connect the internet at any time by appearance of smart phone combined with mobile internet. Furthermore, many devices have been combining with diverse sensor networks in the form of Internet of Things (IoT). According to the latest research report of International Data Corporation (IDC), the IoT spending scale increased with 17.9% compared to last year through the increasing investment in hardware, software, service and connectivity. The various radio communication technologies are used for IoT in order to connect to network. There are Wi-Fi (Wireless Fidelity) HaLow, Narrowband-IoT (NB-IoT), Long Range (LoRa) and Z-wave as representative technologies for IoT services [1,2]. The NB-IoT using licensed bands was announced in June, 2016. The maximum throughput is 150 kbps based on 3rd Generation Partnership Project (3GPP) release 13. The LoRa was released in June, 2015 by LoRa alliance. It has an excellent coverage from 2 km to 15 km and a low power consumption under 25 mW. The Z-wave has coverage of 30 m and supports data rate of up to 100 kbps. Among them, Wi-Fi HaLow has global competitiveness through the popularization of existing Wi-Fi. Thus, it is required that radio communication services should be coexisted with IoT services. As related work, Stankevicius et al. have studied the compatibility between Long Term Evolution (LTE) User Equipment (UE) and Short Range Device (SRD) and also, the compatibility between DVB-T/T2 and LTE. Ying Liu et al. have computed packet loss experienced by 802.15.4g when 802.11ah network and 802.15.4g network coexist. They have calculated the separation distance, interference probability and data loss considering frequency, bandwidth, power, and so on [3]-[5]. As one of examples, this paper focuses on the interference of IoT device based on Wi-Fi HaLow to the most widely used LTE UE. In particular, the duty cycle was taken into account in addition to frequency, bandwidth and power. For the interference analysis, an interference scenario and system performance parameters are considered. The separation distance was obtained to protect the LTE UE from the interference of Wi-Fi HaLow device through the Minimum Coupling Loss (MCL) and Monte Carlo (MC) method based on Spectrum Engineering Advanced Monte Carlo Tool (SEAMCAT) simulation. Also, the number of acceptable Wi-Fi HaLow devices was obtained using MC method.

The structure of this paper is as follows. We explained the interference scenario to analyze the interference of Wi-Fi HaLow device to LTE UE and reviewed the system characteristics for interference analysis. We introduced the two methods for the analysis. One is the MCL which is a theoretical method and another is SEAMCAT simulation which is a statistical approach. We carried out interference analysis by considering the system performance parameters and operating scenario. Then, we presented the separation distance and interference probability for the coexistence between Wi-Fi HaLow device and LTE UE.

II. INTERFERENCE SCENARIO AND SYSTEM DESCRIPTIONS

A. Interference Scenario

The assumed coexistence scenario for analyzing the interference is illustrated in Fig. 1. There are a Wi-Fi HaLow device, an Access Point (AP), a LTE UE and a LTE enhanced NodeB (eNB). The Wi-Fi HaLow device uses radio communication technology based on Institute of Electrical and Electronics Engineers (IEEE) 802.11ah using frequency of 945.7 MHz. The LTE UE uses frequency of 954.3 MHz in DownLink (DL). In this

Manuscript received April 4, 2019; revised December 6, 2019.
Corresponding author email: ceyng@kongju.ac.kr.
doi:10.12720/jcm.15.1.58-64

operation, the Wi-Fi HaLow device could potentially produce interference to LTE UE. In order to analyze the interference of Wi-Fi HaLow device to LTE UE, the path between Wi-Fi HaLow device and AP is set as an interfering link, and the path between LTE UE and LTE eNB is set as a victim link. Here, dRSS is desired received signal strength and iRSS is interference received signal strength at victim receiver. To protect the LTE UE from the interference of Wi-Fi HaLow, the separation distance between Wi-Fi HaLow device and UE, the duty cycle of Wi-Fi HaLow device and the number of Wi-Fi HaLow devices are considered as main factors affecting the probability of interference.

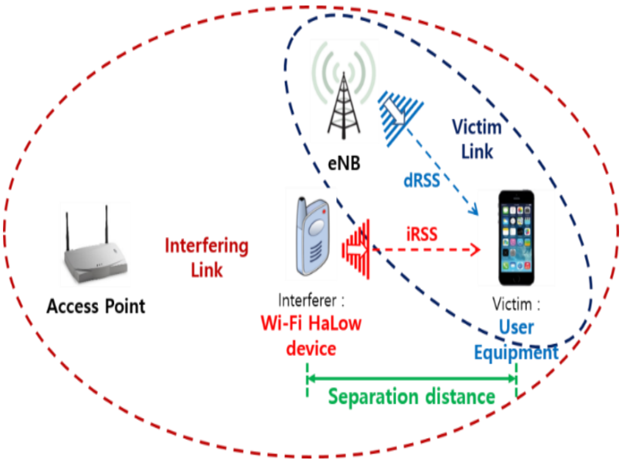

Fig. 1. Coexistence scenario between IoT and LTE UE.

B. System Characteristics

The Wi-Fi HaLow device meets IEEE 802.11ah standard which was published in 2017. It operates in sub 1 GHz and supports 1, 2, 4, 8 and 16 MHz channel bandwidth [6]. The distance between Wi-Fi HaLow device and AP is up to 1 km and the maximum number of Wi-Fi HaLow within the coverage of AP devices is 6000. There are many applications for IoT such as smart city, smart home, health care and connected car. As the interferer, the performance characteristics of Wi-Fi HaLow device are summarized in Table I. Here, the duty cycle means a period of existing signal among the operating time of the device, which is expressed as a percentage. It is one of most important factors because it mitigates the interference from numerous IoT devices and allows them to coexist with other devices or systems.

TABLE I: CHARACTERISTICS OF WI-FI HALOW DEVICE

Characteristic	Value	Unit
Center Frequency	945.7	MHz
Bandwidth	1	MHz
Transmit Power	23	dBm
Duty Cycle	0.1 ~100	%
Antenna Peak Gain	0	dBi
Antenna Height	1.5	m
Antenna Pattern	Omni-directional	-
Thermal Noise	-133.97	dBm/MHz
Propagation Model	Extended-Hata	-

The spectrum emission level of Wi-Fi HaLow device is summarized in Table II and the emission mask is depicted in Fig. 2 [7].

TABLE II: SPECTRUM EMISSION LEVEL OF WI-FI HALOW DEVICE

Frequency Offset from Center Frequency [MHz]	Attenuation [dBc]	Reference Bandwidth [kHz]
0.45	0	1,000
0.60	-20	1,000
1.00	-28	1,000
1.50	-40	1,000

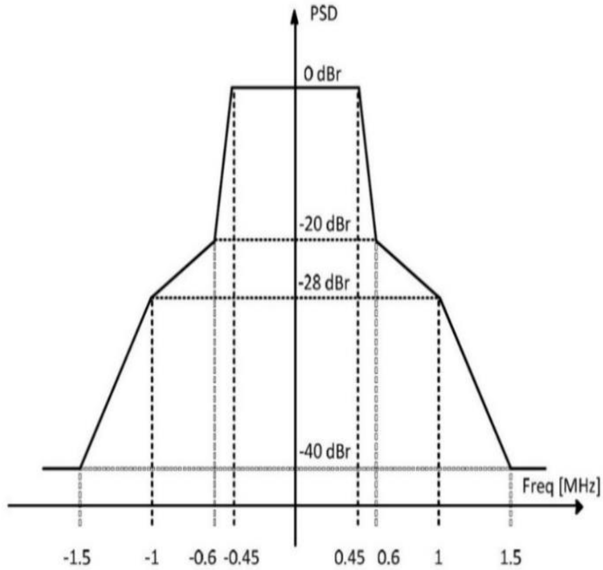

Fig. 2. Spectrum emission mask of Wi-Fi HaLow device.

The LTE developed by the 3GPP is a technology that meets International Mobile Telecommunications (IMT)-2000. This technology uses Orthogonal Frequency Division Multiple Access (OFDMA) which transfers data on several subcarriers, and supports 1.4, 3, 5, 10, 15 and 20 MHz bandwidth. It also has Frequency Division Duplex (FDD) and Time Division Duplex (TDD). As the victim, the performance characteristics of LTE eNB and UE are indicated in Table III and Table IV, respectively, and the blocking mask of LTE UE is depicted in Fig. 3.

TABLE III: CHARACTERISTICS OF LTE ENB

Characteristic	Value	Unit
Center Frequency	954.3	MHz
Bandwidth	10	MHz
Transmit Power	43	dBm
Coverage	0.43	km
Antenna Peak Gain	15	dBi
Antenna Height	15	m
Antenna Pattern	3-sector antenna	-
Propagation Model	Extended-Hata	-

TABLE IV: CHARACTERISTICS OF LTE UE

Characteristic	Value	Unit
Center Frequency	954.3	MHz
Bandwidth	10	MHz

Sensitivity	-94	dBm
Protection Radio (C/I)	12	dB
Thermal Noise	-113.97	dBm/MHz
Antenna Peak Gain	0	dBi
Antenna Height	1.5	m
Antenna Pattern	Omni-directional	-
Propagation Model	Extended-Hata	-

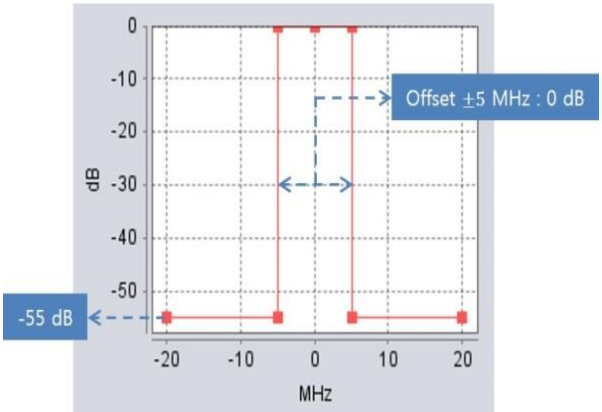

Fig. 3. Spectrum blocking mask of LTE UE.

III. Interference Analysis Method

A. *Minimum Coupling Loss Analysis*

Coupling loss is the attenuation of signal strength due to distance and medium when a signal is transferred from a transmitter to a receiver. That is, the MCL refers to the least coupling loss considering the worst-case scenario in theory. Therefore, the free space channel model with minimum coupling loss is used for MCL analysis. The MCL analysis calculates the separation distance between a victim and an interferer in order to protect the victim receiver from interfering signal [8]. The allowable maximum strength of interfering signal at a victim receiver can be calculated as in (1).

$$I_{max} = T_P - C_I \tag{1}$$

where, the I_{max} is the strength of allowable maximum interfering signal. T_P is the target of protection which could be the receiving sensitivity level or the noise floor level. The C_I is the criterion evaluating interference whether there is interference at victim and it could be C/I (Carrier signal to Interfering signal ratio) or I/N (Interfering signal to Noise ratio). Then the MCL is calculated as in (2).

$$MCL = P_{INT} + Corr - I_{Max} \tag{2}$$

Here, the P_{INT} is the power of interfering signal, the Corr is the bandwidth correction factor and is indicated in (3).

$$Corr = 10\log\frac{BW_{VIC}}{BW_{INT}} \tag{3}$$

where, BW_{VIC} is the bandwidth of victim and BW_{INT} is the bandwidth of interferer. The MCL is converted into the required propagation loss as in (4).

$$L_P = MCL + G_{A\_INT} + G_{A\_VIC} \tag{4}$$

Here, L_P is the required propagation loss, G_{A_INT} and G_{A_VIC} are the antenna gain of a victim and an interferer, respectively. The separation distance can be obtained through Free Space Path Loss (FSPL) model with (5) explained in [9].

$$FSPL = \left(\frac{4\pi f d}{c}\right)^2 \tag{5}$$

where, π is circular constant, f is the frequency of interferer, c is the light velocity and d is the separation distance between a victim and an interferer. Then the d is calculated as in (6).

$$d = \frac{c}{4\pi f} \times 10^{\left(\frac{L_P}{20}\right)} \tag{6}$$

B. *SEAMCAT Simulation*

SEAMCAT is a radio interference analysis simulation distributed by European Communications Office (ECO), the affiliated organization of the European Conference of Postal and Telecommunications Administrations (CEPT). It is based on MC method which computes the probabilistic distribution of the wanted value through repeatable experimentations. Here, the wanted value is the interfering signal strength to evaluate the performance of a victim or an interferer [10], [11]. This method is used for the sharing of co-channel and the compatibility of adjacent channel between radio communication systems. SEAMCAT can define numerous system parameters required for simulation as a probability distribution function, so that an interference scenario between diverse radio communication systems can be analyzed similar to actual environment. Basic interference scenario in the SEAMCAT is depicted in Fig. 4 [12].

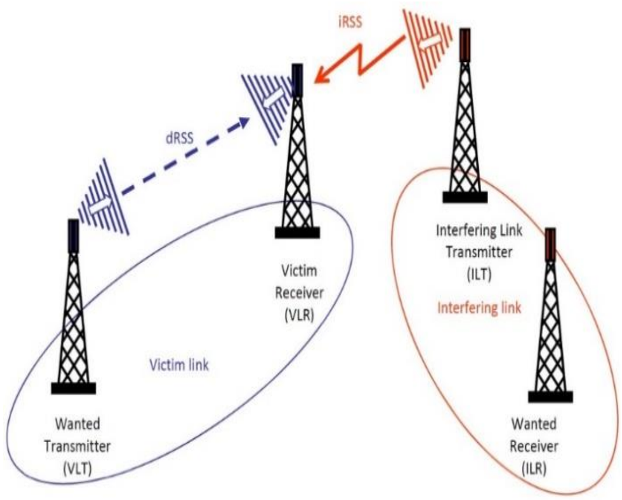

Fig. 4. Basic interference scenario.

From Fig. 4, the desired Received Signal Strength (dRSS) is the strength of the desired signal that the Victim Link Receiver (VLR) receives from Victim Link wanted transmitter(VLT), and the interfering Received Signal Strength (iRSS) is the strength of the interfering signal received at the VLR from Interference Link Transmitter(ILT). The main structure of SEAMCAT is described in Fig. 5.

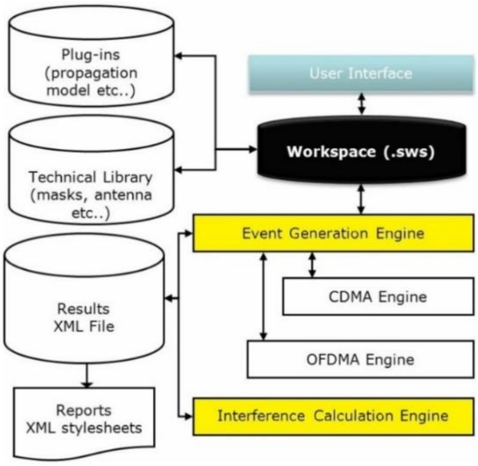

Fig. 5. Main structural elements of SEAMCAT.

The Event Generation Engine (EGE) generates random values for the scenario parameters using the distributions defined in scenario and computes the dRSS and iRSS. The Interference Calculation Engine (ICE) compares the dRSS and the iRSS generated by the EGE with respect to interference criterion such as C/I, C/(I+N) and I/N. In each event, the way to evaluate the interference is depicted in Fig. 6.

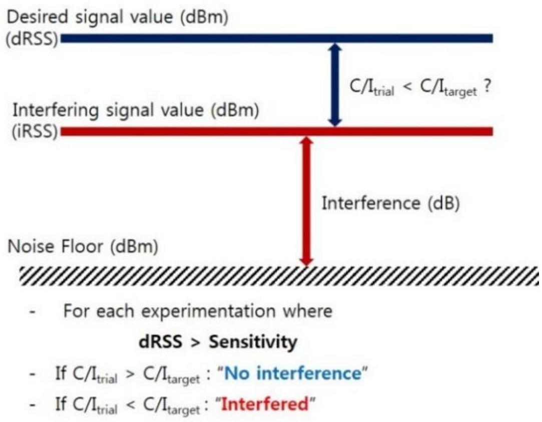

Fig. 6. Criterion of interference.

Here, C/I_{trial} is obtained as the ratio of dRSS to iRSS from each experimentations, C/I_{target} is the target ratio of dRSS to iRSS in order to protect the dRSS. The interference probability (P_I) is calculated as in (7).

$$P_I = 1 - P_{NI} \tag{7}$$

where, P_{NI} is the probability of no interference in a victim. In Fig. 6, the ratio of C/I_{target} is chosen as the protection criteria. Therefore, P_{NI} is defined as in (8).

$$P_{NI} = P(C/I_{trial} > C/I_{target} | dRSS \geq Sensitivity) \tag{8}$$

By definition of $P(A|B)=P(A\cap B)/P(B)$, P_{NI} becomes as in (9).

$$P_{NI} = \frac{P(C/Itrial > C/Itarget, dRSS \geq Sensitivity)}{P(dRSS \geq Sensitivity)} \tag{9}$$

IV. Results of Interference Analysis

A. Results of Interference Analysis

As shown in Fig. 7, the interference of Wi-Fi HaLow device to LTE UE was analyzed by MCL method.

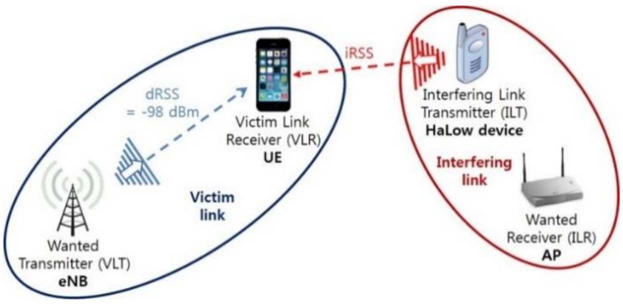

Fig. 7. Worst case of interference scenario.

When the target of protection level was selected as -94 dBm of sensitivity of LTE UE and criterion of interference was selected as 12 dB of C/I of LTE UE, the strength of allowable maximum interfering signal (Imax) was calculated as -106 dBm using (1). The attenuation value at 954.3 MHz is depicted in Fig.8.

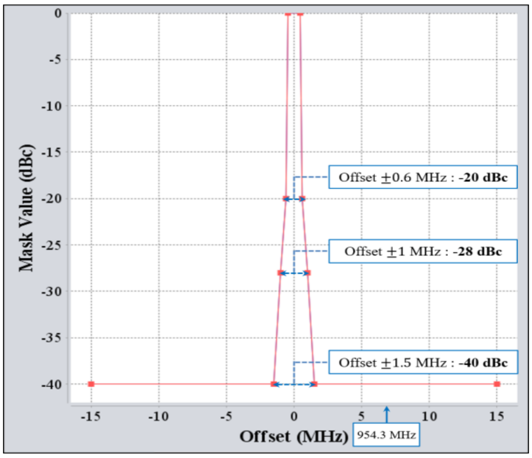

Fig. 8. Attenuation value at 954.3 MHz.

In considering the spectrum emission mask in Fig. 8 and Table I, the main power was 23 dBm and the attenuation level at frequency of 1.5 MHz above from the center frequency was -40 dBc. Therefore, the power of interferer at 954.3 MHz was -17 dBm. It is not necessary to consider the Corr because the bandwidth of victim was larger than that of an interferer. Thus, MCL was calculated as 89 dB using (2). The MCL was converted to the required propagation loss (L_P) including the antenna gains of LTE UE and Wi-Fi HaLow device. The L_P was 89 dB because antenna gain was 0 dBi for both LTE UE and Wi-Fi HaLow device.

As the communication environment was assumed as free space model, the separation distance was calculated as in (10) applying the system parameters into the (6) in log format.

$$d = \frac{3\times10^8}{4\times3.14\times945.7\times10^6} \times 10^{\left(\frac{89}{20}\right)} = 711.83\text{ m} \quad (10)$$

The separation distance of 711.83 m at least was required to protect a LTE UE from the interference of a Wi-Fi HaLow device. In view of the practical operation characteristics of interferer, not only transmitting power but also transmitting time of an interferer should be considered. Therefore, the duty cycle was included to reflect the transmitting time in calculating separation distance. The change in the interference power can be converted into a duty cycle. In order to meet the allowable maximum interference power as a protection requirement, the separation distance was calculated according to the variation of duty cycle. The results were summarized in Table V.

TABLE V: THE DUTY CYCLE VS. SEPARATION DISTANCE

Duty cycle [%]	Separation distance [m]
100	711.83
90	675.30
80	636.68
70	595.56
60	551.38
50	503.34
40	450.20
30	389.89
20	318.34
10	225.10

B. *Results of SEAMCAT Simulation*

Firstly, simulation scenario for the Wi-Fi HaLow device interfering with LTE UE is illustrated in Fig. 9. The Link length of 430 m for victim link is taken in consideration of cell radius of LTE eNB.

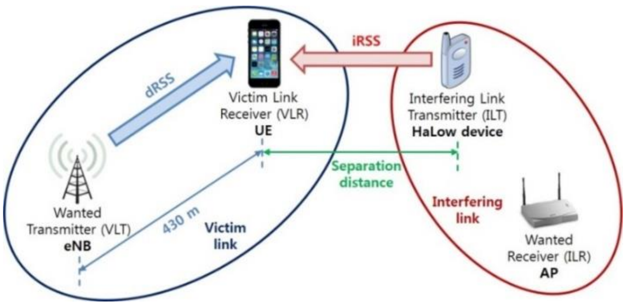

Fig. 9. The scenario according to separation distance.

The required parameters are selected for simulation analysis in accordance with the characteristics of LTE UE and Wi-Fi HaLow device. The separation distance was selected as from 5 m to 65 m. The relationship between separation distance and the interference probability is illustrated in Table VI and depicted in Fig. 10. Here, it is assumed that the duty cycle is not considered and Wi-Fi HaLow device is kept operating. The path loss of Extended Hata model is classified depending on a distance between transmitter (Tx) and receiver (Rx). If a distance is less than 0.04 km, it is applied to (11) and at a distance from 0.04 km to 0.1 km, it is applied to (12). For this reason, there is a drastic change in the curve direction at the separation distance of 40 m in Fig. 10. Where f is the frequency (MHz), d is a distance (km) between Tx and Rx, H_b is the lower antenna height among Tx and Rx, and H_m is the higher antenna height among Tx and Rx. In order to satisfy the interference probability of 5 % below, the separation distance of 53 m is required.

$$L_1(\mathrm{d}) = 32.4 + 20\log(f) + 10\log\left[d^2 + \frac{(H_b+H_m)^2}{10^6}\right] \quad (11)$$

$$L_2(d) = L_1(0.04) + \frac{[\log(d)-\log(0.04)]}{[\log(0.1)-\log(0.04)]} \times [L_1(0.1) - L_1(0.04)] \quad (12)$$

TABLE VI: THE INTERFERENCE PROBABILITY VS. SEPARATION DISTANCE

Separation Distance [m]	Interference probability [%]	Separation Distance [m]	Interference probability [%]
5	92.06	45.0	19.30
10	80.80	47.5	13.03
15	70.64	50.0	8.32
20	62.14	52.5	5.14
25	55.52	53.0	4.90
30	49.25	55.0	3.24
35	44.34	57.5	2.09
37.5	42.58	60.0	1.46
40.0	40.39	62.5	0.95
42.5	28.53	65.0	0.60

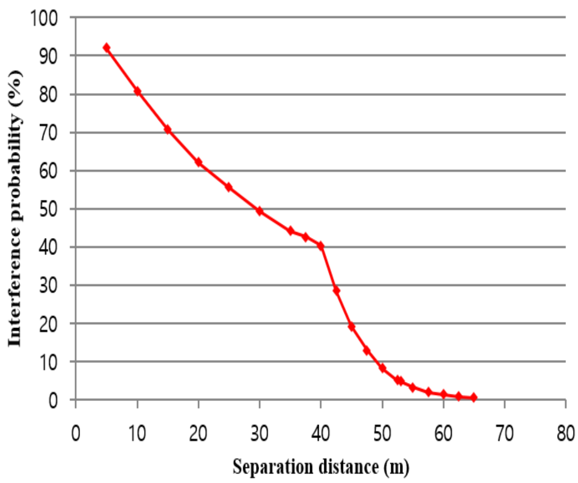

Fig. 10. The interference probability vs. the separation distance.

Secondly, the relationship between the duty cycle and the separation distance to meet interference probability of 5 % below is illustrated in Table VII and depicted in Fig. 11. Here, the duty cycle of Wi-Fi HaLow device is considered from 1 % to 100 %. In the duty cycle of 5 % below, the separation distance to meet the interference probability of 5 % below was computed as 4 m.

Lastly, from the analysis results of the single interferer case in TableVII, the minimum separation distance of 4 m was taken as simulation radius. The number of acceptable Wi-Fi HaLow devices was computed with the interference scenario as in Fig. 11. The relationship between the number of acceptable interferers and the duty cycle is illustrated in Table VIII and depicted in Fig. 12.

TABLE VII: THE DUTY CYCLE VS. SEPARATION DISTANCE TO MEET INTERFERENCE PROBABILITY OF 5% BELOW

Duty cycle [%]	Separation distance [m]	Interference probability [%]
100	53.0	4.90
90	52.5	4.94
80	51.5	4.95
70	50.8	4.96
60	50.0	4.92
50	49.0	4.99
40	47.7	4.95
30	46.0	4.95
20	43.5	4.90
10	29.5	4.91
9	25.0	4.94
8	20.0	4.90
7	14.0	4.99
6	10.0	4.94
5	4.0	4.91
4	0	3.89
3	0	2.92
2	0	2.04
1	0	0.99

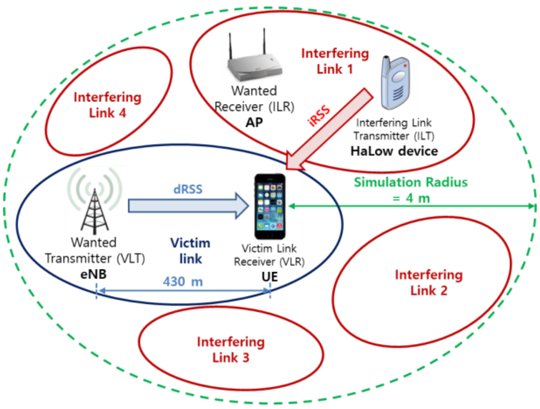

Fig. 11. The scenario according to the number of Wi-Fi HaLow device.

TABLE VIII: THE DUTY CYCLE VS. THE NUMBER OF ACCEPTABLE INTERFERERS TO MEET INTERFERENCE PROBABILITY OF 5% BELOW

Duty cycle [%]	The number of acceptable interferers	Interference probability [%]
5.0	1	4.91
4.5	1	4.47
4.0	1	3.90
3.5	1	3.35
3.0	1	2.85
2.5	2	4.84
2.0	2	3.75
1.5	3	4.13
1.0	5	4.95
0.9	5	4.29
0.8	6	4.55
0.7	7	4.76
0.6	8	4.50
0.5	10	4.81
0.4	13	4.90
0.3	18	4.95
0.2	26	4.95
0.1	54	4.95

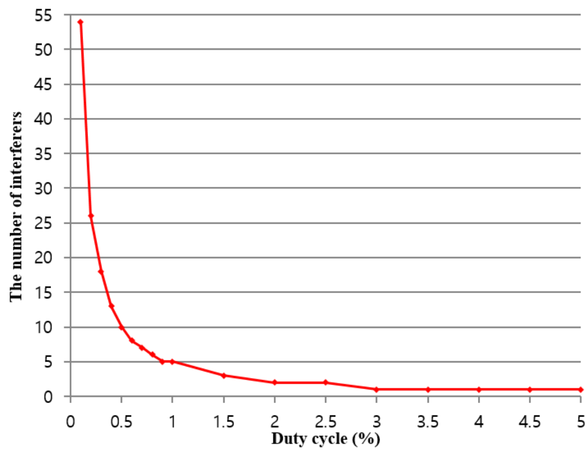

Fig. 12. The duty cycle vs. The number of interferers to meet the interference probability of 5% below.

As a result, in case that the duty cycle of interferer is not considered, at least the separation distance of 53 m was required to meet interference probability of 5% below [13]. If the duty cycle is considered, for example, the separation distance was calculated as 4 m in the duty cycle of 5 % and when the duty cycle is 4 % below, the separation distance is 0 m. Finally, in order to meet interference probability of 5 % below in simulation radius of 4 m, the number of acceptable interferers is 54 at duty cycle of 0.1%.

V. CONCLUSIONS

This paper analyzes the interference of Wi-Fi HaLow device to LTE UE by using MCL and MC method based on SEAMCAT simulation by considering practical performance parameters, and presents the separation distance and the number of allowable Wi-Fi HaLow device to meet the protection criteria. In the worst - case scenario, the separation distance of 711.83 m was obtained to protect LTE UE from interference of Wi-Fi HaLow device through MCL method. When the duty cycle is not considered, the separation distance to protect LTE UE from interference of Wi-Fi HaLow device was calculated as 53 m through SEAMCAT simulation. When the duty cycle is considered, the separation distance of 4 m is required at duty cycle of 5 % to meet interference probability of 5% below. In order to meet interference probability of 5 % below in simulation radius of 4 m, the number of acceptable interferers is 5 at duty cycle of 1 %, 10 at duty cycle of 0.5 %, 54 at duty cycle of 0.1%, respectively. The analysis approach and the results in this paper will be useful as a guideline to contrive the coexistence plan of IoT device and LTE systems in practice. In the future, it is necessary to analyze the bitrate loss of LTE UE due to Wi-Fi HaLow device and compare this with the 2 Mbps data rate required to seamlessly watch 720p quality streaming video.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Yeon-Gyu Park analyzed the raw-data and wrote the original draft; Eun-Young Chang conducted the pre-investigation; Il-Kyoo Lee edited the paper; Yan-Ming Cheng drew the figure; all authors had approved the final version.

ACKNOWLEDGMENT

This work was supported by the research grant of the Kongju National University in 2018.

REFERENCES

[1] N. Poursafar, M. E. E. Alahi, and S. Mukhopadhyay, "Long-range wireless technologies for iot application: A review," in *Proc. 11th International Conf. on Sensing Technology*, Australia, 2017, pp. 1-6.

[2] M. I. Hossain, L. Lin, and J. Markendahl, "A comparative study of iot-communication systems cost structure: Initial findings of radio access networks cost," presented at the 11th CMI International Conference, Copenhagen, November 29-30, 2018.

[3] E. Stankevivius and A. Medeisis, "LTE 800 MHz vs. Short range devices: Adjacent band compatibility around band edge of 863 MHz," in *Proc. 55th International Symposium ELMAR-2013*, Croatia, 2013, pp. 299-302.

[4] G. Ancans, E. Stankevicius, and V. Bobrovs, "Investigation of electromagnetic compatibility between DVB-T/T2 and LTE 700 for co-channel case," in *Proc. PIERS-FALL*, Singapore, 2017, pp. 875-878.

[5] Y. Liu, P. Orlik, Y. N. K. Watanabe, and T. Sumi, "Coexistence of 802.11ah and 802.15.4g networks," presented at the IEEE Wireless Communications and Networking Conference, Barcelona, April 15-18, 2018.

[6] M. Park, "IEEE 802.11ah: Sub-1-GHz license-exempt operation for the internet of things," *IEEE Communications Magazine*, vol. 53, no. 9, pp. 145-151, Sep. 2015.

[7] ETSI Technical report 103 245, "Technical characteristics and spectrum requirements of wideband SRDs with advanced spectrum sharing capability for operation in the UHF 870-876MHz and 915-921MHz frequency bands," European Telecommunications Standards Institute, 2014.

[8] ERC Report 101, "A Comparison of the Minimum Coupling Loss method, Enhanced Minimum Coupling Loss method, and the Monte Carlo simulation," European Conference of Postal and Telecommunications Administrations, May, 1999.

[9] K. Chang, *RF and Microwave Wireless Systems*, 1st ed. New York, U.K.: Wiley, 2000, ch. 8, pp. 244-246.

[10] Y. M. Cheng, Y. Wang, I. K. Lee, and Z. X. Zhou, "Applying beamforming to LTE base station for reducing interference impact and saving frequency," *IJMUE*, vol. 11, no. 6, pp. 361-368, 2016.

[11] ERC Report 68, "Monte-carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems," European Conference of Postal and Telecommunications Administrations, 2000.

[12] *SEAMCAT Handbook*, 2nd ed., European Conference of Postal and Telecommunications Administrations, 2016, pp. 62-81.

[13] E. Stankevicius, A. Medeisis, S. Paulikas, and A. Anskaitis, "Electromagnetic compatibility problems in LTE mobile networks 800 MHz frequency band," *Elektronika IR Elektrotechnika*, vol. 21, no. 6, pp. 86-89, 2015.

Yeon-Gyu Park received the M.S. degree in Electrical and Electronic Control Engineering from Kongju National University, Korea in 2018. He is currently under the course of doctor's degree at Kongju National University. His major research interests include radio wave interference, spectrum engineering and RF system.

Eun-Young Chang received the Ph.D. degrees from Korea Aerospace University, Gyeonggi-do, Korea in 1993. Since 1991 he has been a Professor in the Department of Electrical and Electronic Control Engineering, Kongju National University. His research interests include RF system and wireless communication system.

Il-Kyoo Lee received the B.E. and M.E. degrees from Chungnam National University, Daejeon, Korea in 1992 and 1994. He had worked for Electronics & Telecommunication Research Institute (ETRI) where he was a Senior Member of the research staff of the Radio Technology Department from 1994 to 2004. Since 2004 he has been a Professor in the Department of Electrical and Electronic Control Engineering, Kongju National University, he was exchange Professor in Georgia Institute of Technology, United States of America in 2007 and 2012. His research interests include RF system, spectrum engineering and radio policy.

Yan-Ming Cheng received his Ph.D. degree in Information and Communication Engineering from Kongju National University in Korea. He is currently an associate professor of the College of Electrical & Information Engineering, Beihua University, China. He was part-time researcher in the mobile RF team in Electronics & Telecommunication Research Institute (ETRI) in Korea in 2010. His areas of research interest are compatibility between wireless communications systems, smart Antenna technology, Simulation & modeling and Internet of things.