An Interference Assessment between New Unlicensed Wireless Connectivity and Outside Broadcasting Service in the 6 GHz Band

Seung-Nam Kim[1], Il-Kyoo Lee[1], and Bub-Joo Kang[2]
[1] Department of Electrical, Electronics & Control Engineering, Kongju National University, Cheonan 31080, Korea
[2] Department of Electronics, Information & Communication Engineering, Dongguk University, Gyeongju 38066, Korea
Email: kimsn1989@gmail.com; leeik@kongju.ac.kr; bjkang@dongguk.ac.kr

Abstract —New innovative technology such as unlicensed wireless connectivity has become essential to provide more beneficial and advanced services. Therefore, it is necessary to study the use of broadband available and potentials of spectrum harmonization for massive unlicensed applications, equally Wireless Fidelity (Wi-Fi) with higher frequency and wider bandwidth. This paper presents an interference assessment between unlicensed Wi-Fi service and an incumbent service such as Outside Broadcasting (OB) system in the 6 GHz band. It also includes several radio interference scenarios to analyse coexistence by Minimum Coupling Loss (MCL) and Monte Carlo (MC) methods. Consequently, this study suggests protection distance as a possible approach for the coexistence of the unlicensed Wi-Fi service and OB system in the 6 GHz band.

Index Terms—6 GHz, Wi-Fi, OB, Interference, Coexistence, MCL, MC, Protection distance

I. Introduction

The field of smart technology is an essential paradigm to develop future innovations that can undoubtedly bring more convenient lives to the public. Thus, the technology that can handle with higher data speed should be studied. From this point of view, low-power and short-range wireless link such as Wireless Fidelity (Wi-Fi) has appeared to be used as a key factor in terms of connectivity with an advanced technology. Hence, it is necessary to study the usage of Wi-Fi with wider bandwidth and higher frequency. Since a report of unlicensed use of the 6 GHz band (5925 - 7125 MHz) was released in the United State in 2020, the unlicensed Wi-Fi service in the 6 GHz band has drawn industry's attention [1]. However, the report provides only outdoor and indoor services and there is a limitation for the transportation. Additionally, it is required that the impact studies should be carried out. Subway is a popular transportation in densely populated areas. Therefore, this paper has analyzed the degree of interference between unlicensed Wi-Fi system in subway and an incumbent licensed service such as Outside Broadcasting (OB) service being used in Republic of Korea in the 6 GHz band (5925 – 7190 MHz) [2].

Sections in this paper are fivefold: a review of unlicensed Wi-Fi system based on IEEE 802.11ax, an investigation of OB system, interference scenarios, interference analysis by Minimum Coupling Loss (MCL) and Monte Carlo (MC) methods, and the results of the interference analysis. Ultimately, this study indicates a possible approach for the coexistence unlicensed Wi-Fi system and the existing OB system in the 6 GHz band.

II. Overview of Interfering and Victim Systems

A. *Unlicensed Wi-Fi System in the 6 GHz Band*

While remarkable advances, over the last a few decades, have been accomplishing in the huge wireless world, the improvement of Wi-Fi system still plays a vital role in annually growing wireless industry. Furthermore, new wireless local area network specifications which are based on IEEE 802.11ax to be used for higher spectrum efficiency have currently been set up. To be compared with previous version, key benefits are an extended range of bandwidth up to 160 MHz and OFDMA (Orthogonal Frequency Division Multiple Access) which allocates resources for multiple users.

Unlicensed Wi-Fi access point is treated as interferer for the interference assessment and a radio link between the access point and user's mobile device is an interfering link. The layout of the interfering link in subway is shown in Fig. 1 [3].

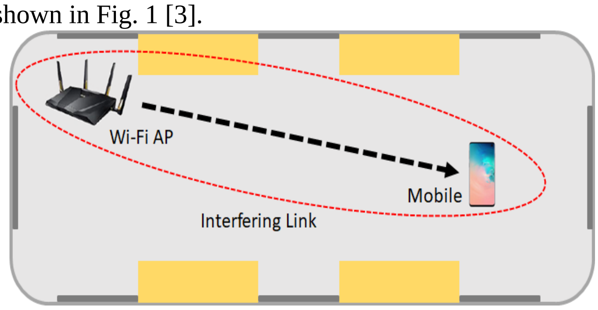

Fig. 1. The layout of the interfering link

Several key specifications of IEEE 802.11ax are described in Table I and spectrum emission mask for 160 MHz bandwidth is illustrated in Fig. 2 [4].

Manuscript received May 5, 2021; revised October 18, 2021.
Corresponding author email: leeik@kongju.ac.kr
doi:10.12720/jcm.16.11.479-484

TABLE I: KEY SPECIFICATIONS OF IEEE 802.11AX

Key Specifications	Description
Channel Bandwidth (MHz)	20, 40, 80, 160
Subcarrier Spacing (kHz)	78, 125
Symbol Time (us)	12.8
Cyclic prefix (us)	0.8, 1.6, 3.2
MU-MIMO	Uplink and Downlink
Modulation	OFDM
Data subcarrier modulation	BPSK, QPSK, 16QAM, 64QAM, 256QAM, 1024QAM
Coding	BCC (mandatory) LDPC (mandatory)

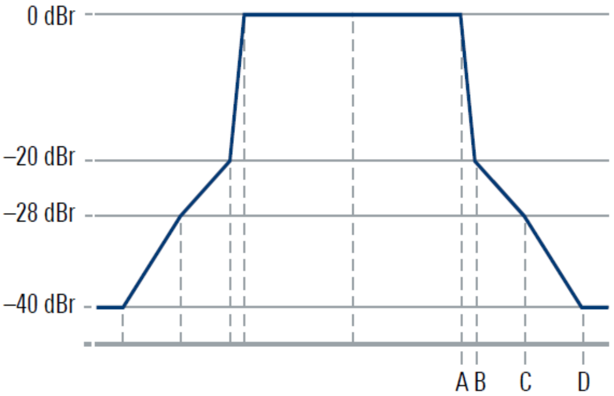

Fig. 2. Spectrum emission mask for 160 MHz bandwidth

Relative levels of the spectrum emission mask is summarized in Table II.

TABLE II: RELATIVE LEVELS OF THE SPECTRUM EMISSION MASK

Frequency Offset from Center Frequency [MHz]	Relative Level [dBr]	Reference Bandwidth [kHz]
79.5	0	1,000
80.5	-20	1,000
160	-28	1,000
240	-40	1,000

B. *Outside Broadcasting System*

OB system is a system that captures news and various events outdoor and transmits them to TV viewers by filming outdoors, not using broadcasting studios indoors. In case of frequency allocation in Republic of Korea, the OB system is operated by microwave frequency range, in 5925-7190 MHz band. It is noticed that the ranges of frequency for unlicensed Wi-Fi and OB system are overlapped. However, spectrum sharing is virtually impossible inasmuch as it must be completely free from any harmful interference to ensure the safety of video transmission. Thus, coexistence study should be taken between unlicensed Wi-Fi and OB system. The OB system is treated as a victim for the interference assessment and a radio link between video transmission from camera and receiver is a victim link. The layout of the victim link is shown in Fig. 3 [5]-[7].

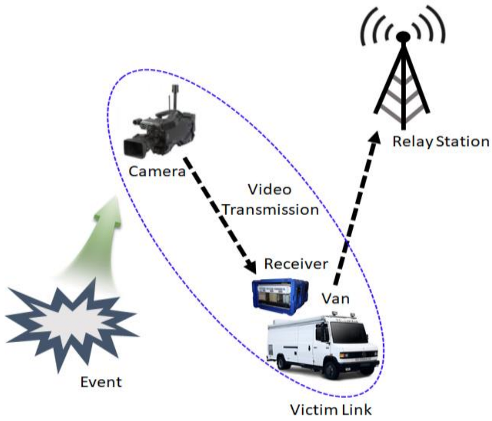

Fig. 3. The layout of the victim link

III. INTERFERENCE SCENARIO

The interference scenario of general wireless system to compute interference impact is depicted in Fig. 4 [8].

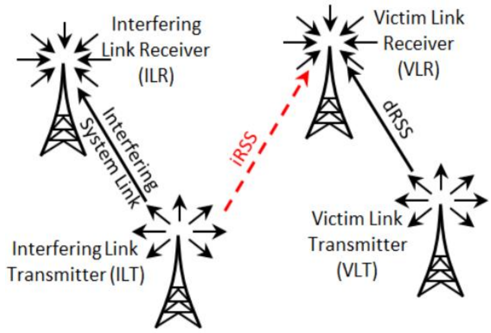

Fig. 4. The interference scenario of general wireless system

Here, there are two radio links which are a victim and an interfering link, respectively. Each link has transmission signals called dRSS (desired Received Signal Strength) from VLT (Victim Link Transmitter) and iRSS (interfering Received Signal Strength) from ILT (Interfering Link Transmitter). The degree of interference is assessed by the ratio of iRSS and dRSS. To evaluate system safety and compatibility for the victim link, C/I (Carrier to Interference) is used as interference criteria [9], [10].

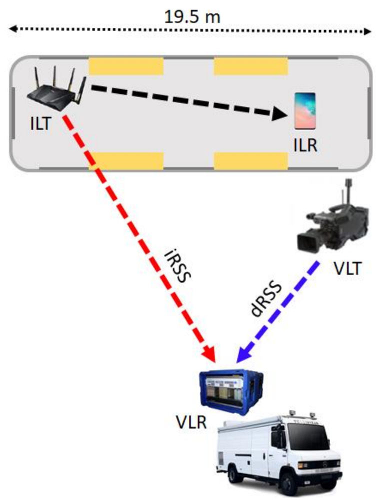

Fig. 5. The interference scenario for the interference assessment

In case of unlicensed Wi-Fi system in subway, every single Wi-Fi access point is placed in each section of subway. The greatest number of sections of subway is 10 which means that the number of ILT can increase up to 10 and the length of each one is 19.5 m. The interference scenario for the interference assessment is depicted in Fig. 5.

IV. Interference Analysis

A. *Minimum Coupling Loss Method*

MCL method is aimed at a worst-case analysis based on minimum victim receiver sensitivity. In addition, it is considered to only use a single interferer transmitting fixed maximum power and a single propagation model. This method is well known as a simple approach, relatively straight forward and unnecessary to elaborately compute. The result is converted into a separation distance that guards a victim receiver when path loss formula is appropriate.

As the sensitivity of a victim receiver is absolutely involved in MCL method, path loss between an interferer and a victim can be described as isolation in dB (decibel). Then, isolation requirement as protection distance is given by (1) [11].

$$Isolation = P_t - (P_r - C/I) + dB_{BW} + OOB \quad (1)$$

Here, P_t is transmitted power of an interferer (dBm), P_r is the sensitivity of a victim receiver (dBm), dB_{BW} is bandwidth conversion factor between an interferer and a victim (dB) and can be calculated by (2).

$$dB_{BW} = 10log\frac{BW_{victim}}{BW_{interferer}} \quad (2)$$

Continuously, OOB (Out-of-Band) is the relative levels according to the spectrum emission mask and the $Isolation$ includes propagation model considered as free space. The propagation model is indicated in (3).

$$20log4\pi\frac{10}{3} + 20log(d) + 20log(f) \quad (3)$$

where, d is a separation distance (km) and f is frequency of a victim (MHz). Free space channel model is often used in MCL method for simple calculation and worst-case scenario.

The characteristics of the interferer and victim link to analyze the degree of interference by MCL method are summarized in Table III.

TABLE III: THE CHARACTERISTICS OF THE INTERFERER AND VICTIM FOR MCL METHOD

Parameter	Value	Unit
Center frequency of the interferer	6345	MHz
Center frequency of the victim	6345	MHz
Power Spectral Density of the interferer	2	dBm/MHz
Sensitivity of the victim	-92	dBm
Interference criteria (C/I)	10	dB
Bandwidth of the interferer	160	MHz
Bandwidth of the victim	8	MHz
dB_{BW}	-13	dB
Wall loss (measured)	14	dB
Propagation Model	Free Space	
OOB	0 -20 -28 -40	dBr

B. *Monte Carlo Method*

MC provides a numerically accurate and statistically valid method to calculate the interference probability from the perspective of various wireless systems to address spectrum sharing and compatibility issues. In order to calculate with an accurate algorithm, the interference scenario which is similar to the real environment must be numerically explained and approached. Since it is repeatedly performed, the more times it is performed to calculate whether any harmful interference exist. This method is also used in the development of frequency spectrum masks around the world, and in particular, it contributes to the development of new wireless systems and the analysis that propose and evaluate unwanted system parameters. It is, moreover, possible to even create complex models by comparatively simple elementary functions handling with broadcasting (terrestrial and satellite), mobile (terrestrial and satellite), point-to-point, point-to-multipoint. Therefore, MC gives flexible analyses insights and mechanism depending on how the system parameters are set up [12].

A simulation called SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool) is used for MC method in this study. SEAMCAT is based on MC formula and can lead to assessing potential interference among various radio communication systems and environments. SEAMCAT can also be of a great help to generate random events that users design to see the interference probability. This software is freely available and developed by CEPT administrations and ETSI (European Telecommunications Standards Institute) [13].

Fig. 6 is one of examples of design on how the interference appears when the victim is surrounded by active or inactive interferers.

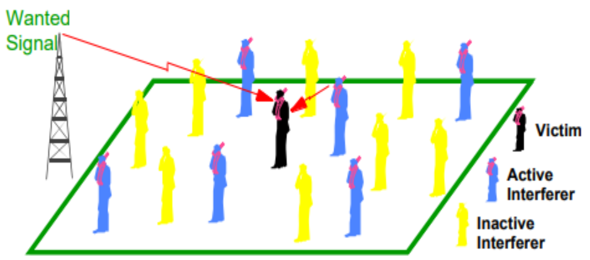

Fig. 6. An example of design for interference environment

In order to determine the degree of interference, dRSS (C) generated from repeated performances corresponds to iRSS (I) because the victim receiver receives a signal that is less than the minimum interference tolerance including protection ratio. After comparing the interference signal, the degree of interference is defined. In this part, four interference criteria are considered: C/I, C/(I+N), (N+I)/N and I/N. Signal levels to determine the occurrence of interference are illustrated in Fig. 7.

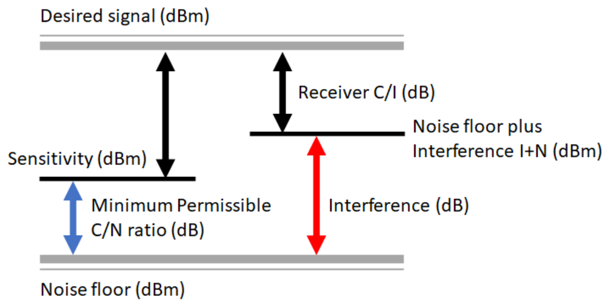

Fig. 7. Signal levels to determine the occurrence of interference

The occurrence of interference by co-channel and adjacent channel is involved in several interference mechanisms. Spurious emissions and out-of-band emissions of the transmitted signal cause the level of interference. The unwanted emissions also can be affected by the bandwidth of victim receiver and it is expressed by Fig. 8.

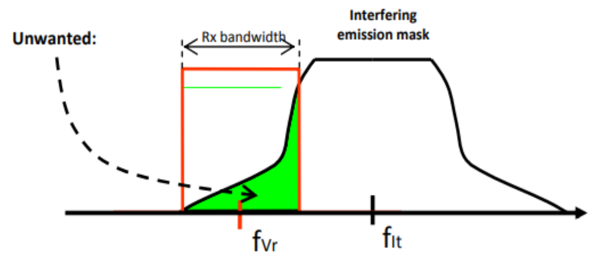

Fig. 8. The unwanted emission mask

Then, the probability of non-interference (P_{NI}) when interference criteria is C/I is defined as in (4).

$$P_{NI} = \frac{P_{\frac{dRSS}{iRSS_{comp}} > \frac{C}{I}, dRSS > Sensitivity}}{P(dRSS > Sensitivity)} \tag{4}$$

Where, $iRSS_{comp}$ is composite interfering received signal strength. Finally, the probability of Interference (P_I) is obtained by (5).

$$P_I = 1 - P_{NI} \tag{5}$$

The characteristics of the interferer and victim link to analyze the degree of interference by MC method are summarized in Table IV.

TABLE IV: THE CHARACTERISTICS OF INTERFERER AND VICTIM FOR MC METHOD

Parameter	Value	Unit
Center frequency of the interferer	6345	MHz
Bandwidth of the interferer	160	MHz
Transmitted power of the interferer	24	dBm
Local environment of the interferer	Indoor	
The number of the interferers	1~10	
Center frequency of the victim	6345	MHz
Bandwidth of the victim	8	MHz
Noise figure of the victim	3	dB
Sensitivity of the victim	-92	dBm
Interference criteria (C/I)	10	dB
Local environment of the victim	Outdoor	
dB_{BW}	-13	dB
Wall loss (measured)	15 (10%) 21 (90%)	dB
Variation	1	dB
Propagation Model	Free Space	
OOB	0 -20 -28 -40	dBr

V. THE RESULTS OF INTERFERENCE ANALYSIS

A. The Results of MCL Method

Since the MCL method is basically aimed at a worst-case, this analysis begins by considering the sensitivity of the victim link as the minimum value which is -92 dBm and co-channel with the interferer. As OB system must be impeccably free from any harmful interference, protection distance to guard VLR from ILT was analyzed by increasing dRSS between VLT and VLR. The parameters given for MCL method and the equation (1) to obtain isolation requirement were used to derive protection distance. As a result, protection distances by dRSS and co-channel with the interferer are listed in Table V.

TABLE V: THE PROTECTION DISTANCES BY DRSS IN MCL METHOD

dRSS [dBm]	Protection distance [m]
-92	335
-82	105
-72	33
-62	10

Next, the occurrence of interference was analyzed by out-of-band emissions of the transmitted signal. The sensitivity of victim receiver was fixed as the minimum value and the spectrum emission level of the emission mask was considered to compute protection distances. The results are indicated in Table VI.

TABLE VI: THE PROTECTION DISTANCES BY OUT-OF-BAND EMISSIONS IN MCL METHOD

dRSS [dBm]	Shifted frequency [MHz]	Attenuation [dBr]	Protection distance [m]
-92	6425	-20	33
-92	6505	-28	13
-92	6585	-40	3

It can be seen from the results of MCL method that the protection distances obtained noticeably were individually reduced to 10 m at -62 dBm of dRSS and 3 m at -40 dBr of the attenuation when dRSS was increased and the out-of-band emissions were considered.

B. The Results of MC Method

There are four analyses by using the SEAMCAT for MC method to compute protection distance concerning the coexistence between ILT and VLR. The received signal must reach or exceed 95 % in order to maintain the reception performance from interference [14]. Therefore, the percentage of the interference permission is below 5 %.

First of all, the distances that satisfy the interference permission of less than 5 % when iRSS is received from a single ILT were derived by increasing dRSS. The results are summarized in Table VII.

TABLE VII: THE PROTECTION DISTANCES FROM A SINGLE ILT BY INCREASING DRSS IN MC METHOD

dRSS [dBm]	iRSS [dBm]	Protection distance [m]	Interference Probability [%]
-92	-107.93	301	4.7
-82	-97.91	95	4.8
-72	-87.88	30	4.8
-62	-78.35	10	3.1

In the second place, the distances that satisfy the interference permission of less than 5 % received from a single ILT were derived by considering out-of-band emissions of the transmitted signal. The results are summarized in Table VIII.

TABLE VIII: THE PROTECTION DISTANCES FROM A SINGLE ILT BY OUT-OF-BAND EMISSIONS IN MC METHOD

dRSS [dBm]	Shifted frequency [MHz]	iRSS [dBm]	Protection distance [m]	Interference Probability [%]
-92	6425	-107.95	34	4.4
-92	6505	-107.92	6	4.6
-92	6585	-116.16	1	0

Thirdly, the distances that satisfy the interference permission of less than 5 % when iRSS is received from 10 multiple ILT were derived by considering increasing dRSS. The results are summarized in Table IX.

TABLE IX: THE PROTECTION DISTANCES FROM 10 MULTIPLE ILT BY DRSS IN MC METHOD

dRSS [dBm]	iRSS [dBm]	Protection distance [m]	Interference Probability [%]
-92	-103.74	655	5
-82	-93.72	200	5
-72	-84.1	50	4.7
-62	-76.43	11	3.3

Finally, the distances that satisfy the interference permission of less than 5 % when iRSS is received from 10 multiple ILT were derived by considering out-of-band emissions of the transmitted signal. The results are summarized in Table X.

TABLE X: THE PROTECTION DISTANCES FROM 10 MULTIPLE ILT BY OUT-OF-BAND EMISSIONS IN MC METHOD

dRSS [dBm]	Shifted frequency [MHz]	iRSS [dBm]	Protection distance [m]	Interference Probability [%]
-92	6425	-107.95	34	4.4
-92	6505	-107.92	6	4.6
-92	6585	-116.16	1	0

It is clear that the results analyzed from a single ILT and 10 multiple ILT by MC method seem are similar to the results of MCL method providing below 10 m of the protection distance excluding the third analysis of MC method which shows 11 m of protection distance at -62 dBm of the dRSS.

VI. CONCLUSIONS

This paper has analyzed the degree of interference between unlicensed Wi-Fi system in the 6 GHz band and an incumbent service which is OB system by using MCL method and MC method based on SEAMCAT simulation for coexistence. Thus, the protection distance has been reviewed as a feasible approach to deal with the interference issue. Basically, in MCL method, worst-case between the two targeted systems and only single ILT were considered and in MC method, a single and 10 multiple ILT were taken in order to examine the protection distance by increasing dRSS from minimum dRSS and shifting frequency from the exact overlapped spectrum. As a result, there was a similar trend in MCL and MC results that noticeably improved the protection distances. The separation was calculated as below 10 m at -62 dBm of dRSS and -40 dBr of attenuation in each analysis of both methods. In case of the third analysis by MC method, 11 m of separation distance was required when a victim receiver had -62 dBm of dRSS and 10 multiple ILT were situated. In consequence, this paper proposes a feasible solution by the protection distance for the coexistence between unlicensed Wi-Fi system and OB system in the 6 GHz band.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Seung-Nam Kim analyzed the raw-data, drew the figures and wrote the original draft; Il-Kyoo Lee conducted the pre-investigation; Bub-Joo Kang edited the paper; all authors had approved the final version.

REFERENCES

[1] ET Docket No. 18-295, “Unlicensed Use of the 6 GHz Band,” Federal Communications Comission, Apr. 2020.

[2] 2020-111, The Frequency Allocation Table of Republic of Korea, Ministry of Science and ICT in Republic of Korea, Oct. 2020.

[3] A. Zignani, “Wireless connectivity,” ABI research for visionaries, Oct. 2019.
[4] L. Ward, “IEEE 802.11ax technology introduction,” Rohde & Schwarz, Apr, 2020.
[5] HD Production, Technical Specification Outside Broadcasting van HD 03.
[6] Vislink, MDR-Series Portable Diversity Receiver System Datasheet.
[7] Vislink, L1700 Camera Transmitter Datasheet.
[8] ECC Report 252, “SEAMCAT Handbook Edition 2,” European Communications Office, Apr, 2016.
[9] Ganesh Ganeswaran and Ian Gair, “ACMA’s Proposed New 2 GHz ENG Bands,” Kordia, Apr, 2012.
[10] ECC Report 201, “Compatibility study between MBANS operating in the 2400 – 2483.5 MHz and 2483.5 – 2500 MHz bands and other systems in the same bands or in adjacent bands,” Electronic Communications Committee, Sept. 2013.
[11] ECC Report 101, “A comparison of the minimum coupling loss method, enhanced minimum coupling loss method, and the monte-carlo simulation,” Electronic Radiocommunications Committee, May, 1999.
[12] P. Yeon-gyu and L. Il-kyoo, “Impact of 5G NR downlink signal on fixed satellite service earth station,” *Journal of Information and Communication Convergence Engineering (JICCE)*, Mar, 2018.
[13] Report ITU-R SM.2028, “Monte Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems,” ITU Radiocommunication Sector, 2001.
[14] Report ITU-R BT.2265-1, “Guidelines for the assessment of interference into the broadcasting service,” ITU Radiocommunication Sector, Nov, 2014.

Seung-Nam Kim received the M.S. degree in Information & Communication Engineering from Kongju National University, Korea in 2016. 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.

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.

Bub-Joo Kang received the B.S degree in Electronic Engineering from Kyunghee University, Seoul, Korea in 1983, and the M.S and Ph.D. degrees in Electronic Engineering from Yonsei University, Seoul, Korea in 1985 and 1996, respectively. From 1988 to 2001, he worked for ETRI as a principal member of engineering staff at the Modem Technology Department. He is currently a professor in department of information and communication engineering, Dongguk University, Korea. His current research interests include modulator/demodulator design, mobile communications and wireless LAN, etc.