Separation Distance for Frequency Coexistence between Unsynchronized Time Division Duplex 5G Private Networks at 4.7 GHz

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Abstract **—Frequency sharing problems may occur between neighboring networks when multiple operators build 5G private networks within a specific region. The interference between time division duplex (TDD) 5G private networks depends on various factors, such as frequency channels, synchronization, and building entry loss (BEL). In this study, we propose separation distances at which two 5G private networks in close proximity can coexist. The amount of interference according to the separation distance between the two 5G private networks was simulated by the Monte Carlo (MC) method. When the two networks operated in an outdoor environment and had different channels, there was a minimum interference effect even if the cell radii of the two networks overlap. However, the separation distance between networks using the same channel was simulated to be approximately 500 m. The TDD synchronization of two networks using the same channel reduced the separation distance to approximately 100 m. The additional radio wave attenuation by the BEL reduced the amount of interference, allowing frequency coexistence between networks even within the cell radii.**

Keywords **—interference, 5G private network, TDD, synchronization, BEL, separation distance**

I. INTRODUCTION

As the world promotes industrial intelligence, many companies are increasing their efforts to use 5G communication technology in various business fields, such as manufacturing, logistics, and medical care [1]. Companies want to own and operate local area networks (LANs) based on 5G communication technologies, which are called 5G private networks. Further, 5G private network is referred to as local 5G, 5G LAN, enterprise 5G, and non-public 5G [2]. 5G private networks have a series of challenges such as performance improvement, support quality of service (QoS), saving energy, privacy, and security [3].

The Korean government has allocated 4.7 GHz and 28 GHz as frequencies for 5G private networks to enable non-communication operators to build and operate 5G networks [4]. By separately allocating a frequency band to the 5G private network, interference with other wireless services can be avoided; however, there may be interference between 5G private networks. Compared to existing 5G mobile communication networks, where operators build nationwide networks to provide services, 5G private networks allow users to build customized 5G networks within their land area. Frequency sharing problems may occur between neighboring networks when multiple users build their 5G private networks within a specific area. A 5G private network should not interfere with other 5G private networks located nearby.

In this study, the interference is analyzed by calculating the average bit rate loss according to the separation distance between the 5G private networks. The frequency channel, TDD synchronization, and building penetration loss are interference-calculation conditions. Under each condition, the interference between the two 5G private networks is analyzed according to the separation distance.

The remaining parts of this paper are sectioned as follows. The interference scenarios between the 5G private networks are defined in Section II, and the interference conditions are summarized in Section III. Section IV summarizes the parameters for simulation, and Section V presents the analysis results of the interference according to the separation distance under the interference conditions.

II. INTERFERENCE SCENARIOS OF 5G PRIVATE NETWORKS

When two TDD 5G private networks using the same frequency band, including the co-channel or adjacent channel TDD networks, are deployed in a close area, various interference scenarios may occur. The interference scenarios between two 5G private networks are shown in Figs. 1-2.

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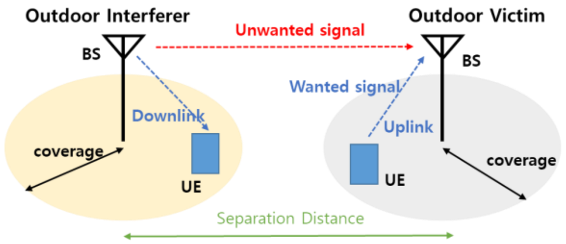

Fig 1. Interference Scenario of outdoor-outdoor 5G private networks.

It is difficult to synchronize the 5G private networks because the network operators are different. When different TDD networks are not synchronized, uplink (UL) transmission and downlink (DL) transmission may simultaneously occur, which may cause base station (BS)–BS and user equipment (UE)–UE interferences. The following section describes the synchronization between the two TDD networks.

Fig. 1 shows an interference scenario in which two 5G private networks are deployed outdoors. The interfering network is the DL transmission, and the victim network is the UL transmission. Since the two networks are not synchronized, BS–BS interference occurs, resulting in the loss of the transmission bitrate of the victim network. As the separation distance between the two networks increases, the strength of the interference signal and the bit rate loss of the victim network decrease.

The signal-to-interference plus noise ratio level can be obtained by calculating the level of the wanted signal between the BSs and UEs in each network and the level of the interference signal according to the separation distance between the networks. The attenuation values of the desired signal and the interference signal can be calculated using the basic transmission loss model of the international telecommunication union–radio communication sector (ITU-R) recommendation. The model that can be applied in the urban line-of-sight environment is given by Eq. (1) [5]:

$$L_b\,(d, f) = 21.2\,log_{10}(d) + 29.2 + 21.1\,log_{10}(f) \qquad (1)$$

where d is the distance (m), and f is the operating frequency (GHz).

Companies possibly deploy 5G private networks in indoor factories. Fig. 2 shows an interference scenario where one of the two 5G private networks is deployed indoors and the other is deployed outdoors. When a network is deployed indoors, radio waves are attenuated by the BEL and propagated outdoors. Outdoor radio waves are attenuated by the BEL and propagated indoors.

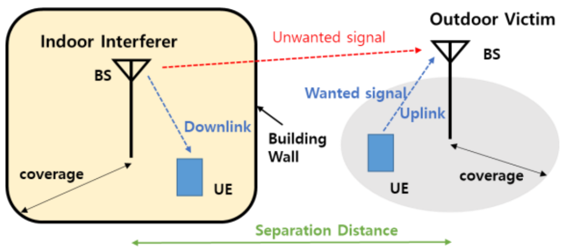

Figure. 2. Interference Scenario of outdoor-indoor 5G private networks.

Therefore, to calculate the interference signal from the 5G private network deployed indoors, the BEL should be considered with the basic transmission loss.

In addition to the interference scenario(indoor-to-outdoor) shown in Fig. 2, there is an interference scenario in which two 5G private networks are deployed inside different buildings(indoor-to-indoor). Additionally, there is an interference scenario where different operators deploy 5G private networks on different floors inside the same building(floor-to-floor).

III. Conditions for Frequency Coexistence

The interference to the victim network depends on the design conditions of the interfering network such as frequency channel, synchronization, and site location.

A. Co-channel vs. Adjacent Channel

In Korea, 4,720–4,820 MHz (bandwidth 100 MHz) is the dedicated frequency for 5G private networks. Fig. 3 shows an example of a frequency plan in which channels are divided into 40 MHz in the 4.7 GHz band. Depending on the frequency bandwidth required by the 5G private network, the 100 MHz bandwidth can be divided into 40 MHz channels. Two 5G private networks deployed in close proximity can use the co- or adjacent channel of 40 MHz.

When two 5G private networks use the adjacent channels, the adjacent channel selectivity (ACS) of the receiver and the adjacent channel leakage power ratio (ACLR) of the transmitter are considered to calculate the interference effect. The ACS is a measure of the ability of the receiver to receive a wanted signal at its assigned channel frequency with an adjacent channel signal [6]. The ACLR is the ratio of the filtered mean power centered on the assigned channel frequency to the filtered mean power centered on the adjacent channel frequency [6]. The 3rd generation partnership project (3GPP) has studied the ACS and ACLR values of a 5G system [6, 7].

B. Sync. vs. Unsync

TDD 5G private networks deployed in close proximity have more interference between networks during unsynchronous operation than during synchronous operation. Synchronization operation occurs when all DL transmissions or all UL transmissions are performed at any moment between several TDD networks. To operate in synchronization for multiple TDD networks, network operators should use a common clock reference and agree on the DL/UL ratios and frame lengths [8].

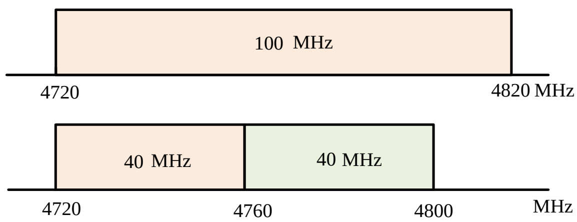

Figure. 3. 40 MHz channels in 4.7 GHz frequency band.

It is an unsynchronous operation when two TDD networks transmit UL/DL simultaneously in any one time slot. Fig. 4 shows examples of frame structures in TDD networks. Compared to reference frame structure (a) shown in Fig. 4, frame structure (b) differs only in the guard intervals and is synchronized to (a) because DL/UL are not transmitted simultaneously in any one time slot. Frame (c) has the same frame structure as (a), but different start times; thus, the time slots in which DL/UL are simultaneously transmitted are obtained. Compared to (a), frame (d) shown in Fig. 4 has the same start time but a different frame structure; thus, the time slots in which DL/UL are simultaneously transmitted are obtained. Frame (b) operates synchronously with the reference frame (a), and the frames (c) and (d) operate unsynchronously with the reference frame (a). Compared with that of the synchronous operation, the interference effect is greater in the unsynchronous operation in which DL/UL is simultaneously transmitted; thus, the separation distance between networks should be increased to reduce this effect.

C. *Indoors vs. Outdoors*

To calculate the amount of outdoor interference generated by the 5G private network deployed inside the building, the BEL should be considered with the basic transmission loss.

The BEL is determined by the material and shape of the building. In particular, ITU-R classifies buildings as traditional buildings and thermally efficient buildings. The BEL of thermally efficient buildings, which uses materials such as metalized glass and foil-backed panels, is generally significantly higher than that of traditional buildings without such materials [8]. To estimate the BEL, the overall character of the building is important. For example, if the body of a building uses thermally efficient materials, but the windows are made of thin glass, the building is thermally inefficient.

Fig. 5 shows the median building penetration loss values of a traditional building and a thermally efficient building according to frequency. In the 4.7 GHz band, the difference in the BEL values between the traditional building and the thermally efficient building is more than 15 dB [9]. The BEL value is doubled when calculating the interference level in an interference scenario (indoor-to-indoor) in which two 5G private networks are deployed in different buildings.

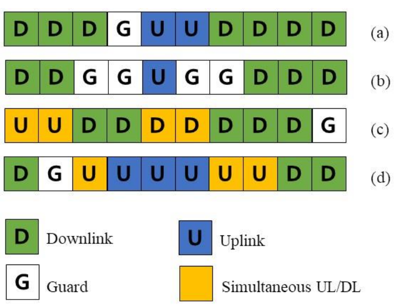

Figure. 4. Examples of UL/DL transmission in TDD networks.

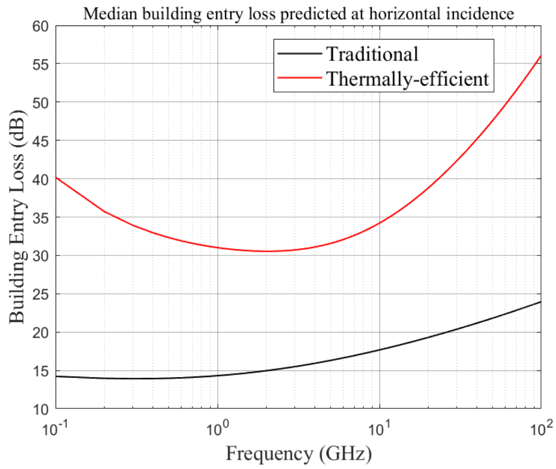

Figure. 5. Median building entry loss [9].

IV. Parameters for Monte Carlo Analysis

SEAMCAT® is used to determine the performance of the victim network according to interference conditions, such as the channel, synchronization, and BEL, of the interfering network. SEAMCAT® is a software tool based on the Monte Carlo simulation method, which was developed by the European conference of postal and telecommunication administrations [10]. The Monte Carlo method mathematically approximates the value of a function using repeated random sampling. The interference scenarios in the co- or adjacent-frequency channels can be statistically modeled using this tool.

The parameters in Table I are used to simulate the performance of the victim network according to the interference conditions of the interfering network. The bandwidth of the victim network channel is 40 MHz, and the center frequency of the channel is 4,740 MHz. The Co-channel center frequency is 4,740 MHz, and the center frequency of the adjacent channels is 4,760 MHz. The transmit power of the UE is 23 dBm, and the transmit power of the BS is 27 dBm in 40 MHz bandwidth.

TABLE I: Simulation Parameters for 5G Private Network

Parameters	Values
Frequency channel	4720 ~ 4760 MHz
Bandwidth	40 MHz
Cell radius	50 m, single cell
BS power	27 dBm/40 MHz
BS antenna height outdoor	6 m
BS antenna height indoor	3 m
BS antenna configuration	8 x 8 array
BS antenna element gain	5 dBi
BS noise figure	5 dB
UE power	23 dBm
UE antenna height	1.5 m
UE antenna type	Omni directional
UE antenna gain	-4 dBi
UE noise figure	9 dBi
Co-channel	4720 ~ 4760 MHz
Adjacent channel	4760 ~ 4800 MHz
BS ACLR	45 dB
BS ACS	37.6 dB
UE ACLR	30 dB
UE ACLR	30 dB

To compensate for the large path loss at 4.7 GHz, highly directional beamforming is required based on large antenna arrays [11]. The antenna of the BS is composed of an 8 by 8 array antenna, and the gain of each element is 5 dBi. Figs. 6-7 show the synthesized antenna patterns of an eight-element BS antenna deployed indoors. The antenna patterns are calculated according to formulas developed by ITU-R [12].

The performance of the victim network is simulated by comparing the case where the interference network uses the co-channel and the case where the adjacent channel is used. In this simulation, the two networks are located outdoors and operate unsynchronously.

To simulate the performance of the victim network according to the synchronization condition of the interfering network, the interfering network is set to DL operation and the victim network to UL operation. Furthermore, the two networks are set to use the co-channel and are located outdoors.

The performance of the victim network according to the BEL value of the interfering network is simulated. The interfering network is set to be deployed indoors and the victim network is set to be located outdoors. The two networks are set to use co-channels and operate unsynchronously.

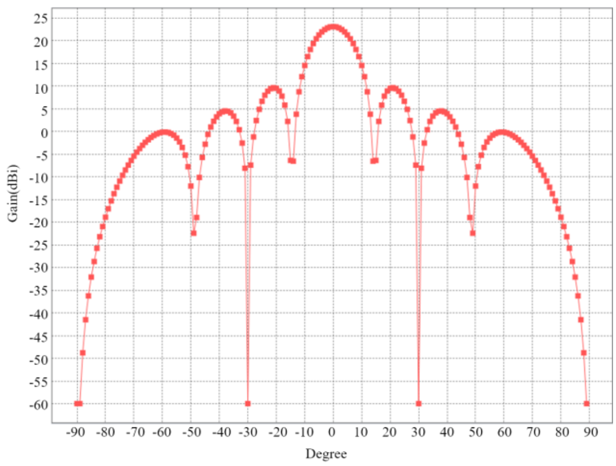

Figure. 6. Composite vertical radiation patterns of Indoor BS antenna.

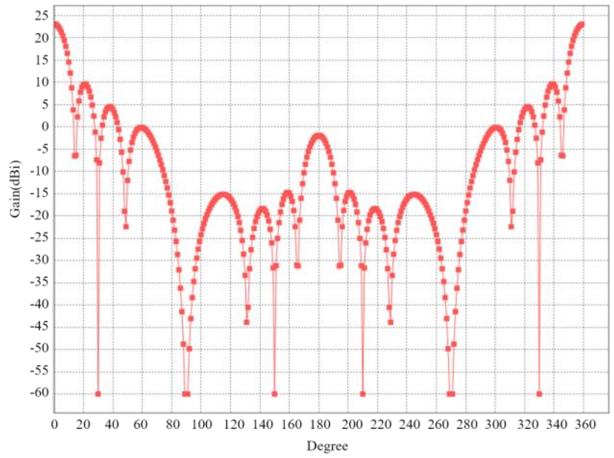

Figure. 7. Composite horizontal radiation patterns of Indoor BS antenna.

The BEL value is 16.3 dB for a traditional building and 31.5 dB for a thermally efficient building in the 4.7 GHz band [9].

V. Results

Average bit rate loss, which is one of the performance measures of the victim network, was simulated using SEMCAT® according to the interference conditions, such as channel, synchronization, and BEL, of the interfering network.

Figs. 8-10 show the performance simulation results of the victim network according to the interference conditions. As the amount of interference between the victim network and the interfering network decreased, the average bit rate loss of the victim network decreased.

Fig. 8 shows the average bit rate loss of the victim network according to the channel used by the interfering network. As shown Fig. 8, when the interfering network used a co-channel with the victim network, the average bit rate loss of the victim network became 5% as the separation distance between the two networks exceeds 550 m. When the interference network used an adjacent channel, the amount of interference was small; thus, the average bit rate loss was 0.056% at a separation distance of 100 m. Even though two 5G private networks were deployed in very close proximity in a specific area, the amount of interference between the two networks could be small if their frequency channels were different.

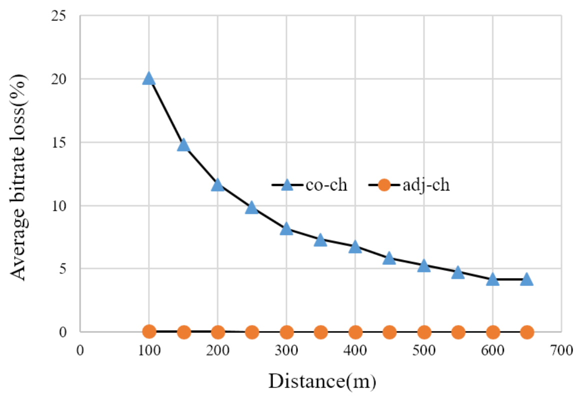

Figure. 8. Average bitrate loss of the victim network according to the channel frequency of the interferer.

Fig. 9 shows the average bit rate loss of the victim network when the interfering network using the co channel is unsynchronous with the victim network. For the synchronous operation, the separation distance at which the average bit rate loss of the victim network was 5% was approximately 110 m. Conversely, for the unsynchronous operation, the separation distance was 550 m, which was approximately five times higher than that of the synchronous operation. When 5G private networks are deployed in close proximity and use the same channel, interference can be reduced by synchronous operation.

Fig. 10 shows the average bit rate loss of the victim network according to the BEL value when the interfering network that uses co-channel unsynchronous operation is deployed indoors and the victim network is deployed outdoors. The effect of attenuating the interference signal by the BEL was observed. In particular, if the building in which the interference network was deployed was thermally efficient building, the effect of interference was less than that of a traditional building. It was observed that the interfering network could be deployed within the cell radius of the victim network because of low interference.

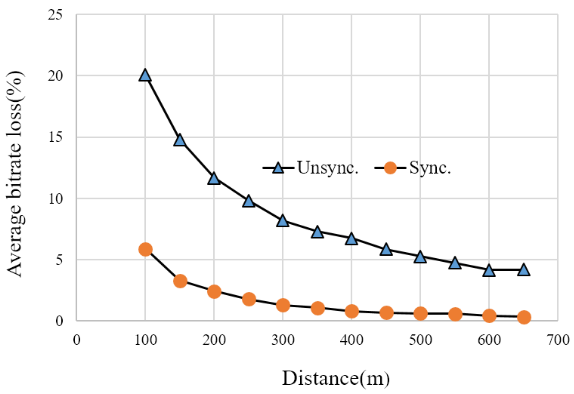

Figure. 9. Average bitrate loss of the victim network according to the frame structure of the interferer.

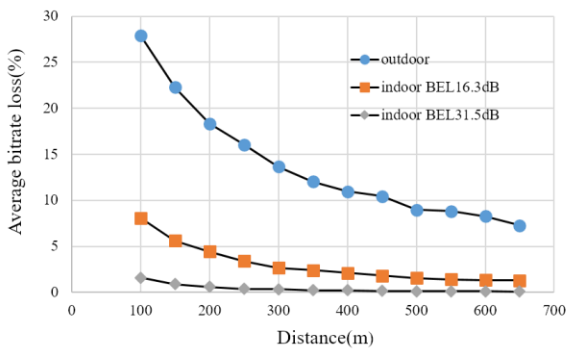

Figure. 10. Average bitrate loss of the victim network according to the BEL of the interferer site.

VI. CONCLUSIONS

In this study, we simulated the average bit rate loss of the victim network according to the interference amount of the interfering network. When the frequency channels used by the two networks were different, the average bit rate loss of the victim network was less than 5%, even at a separation distance within the cell radius. The separation distance that satisfied the average bit rate loss of 5% of the victim network using the same frequency channel as that of the neighboring network was simulated to be approximately 500 m. The separation distance between two networks that used the same channel and operated synchronously was reduced to approximately 100 m. Additionally, when networks were deployed indoors, the amount of interference to and from other networks was small because of the building entry loss; thus, they can be operated in close proximity.

When 5G private networks using different channels are synchronized and deployed indoors, they can be operated in close proximity without interference. The interference conditions and the separation distance values of this study will be helpful to operators who want to deploy 5G private networks to share frequencies with nearby 5G private networks.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Hyuk-Je Kim analyzed the raw-data and wrote the original draft; Il-Kyoo Lee conducted the pre-investigation and edited the paper; all authors had approved the final version.

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