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저층 고밀도 건물 교외 환경에서 3 GHz 및 24GHz의 건물 인입 손실과 클러터 손실의 전파 모델 결합

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Propagation Model Combination of Building Entry Loss and Clutter Loss in Suburban Environment with Low-Rise High-Density Buildings at 3 and 24 GHz

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요 약

본 논문에서는 저층 고밀도 교외 환경에서 신호의 클러터 손실(Clutter loss)과 건물 인입 손실(Building entry loss)을 측정 후 분석했다. 선정된 환경에서 BEL, CL, BEL과 CL 결합 등 3가지 전파 모델을 측정하였다. 각 모델 측정 결과 바탕으로 BEL과 CL을 결합하였을 때의 수치를 분석했다. 각각 주파수에서 BEL과 CL 결합 측정값은 27.55dB 와 26.12dB 였으며, 계산값과 차이는 –4.19dB와 5.82dB였다. 측정이 건물 내부에서 이루어졌다는 점을 고려할 때 이러한 차이는 미미해 보인다. 따라서 BEL과 CL의 각각 측정값 합산과 결합 모델의 측정값을 비교하였을 때 –4.19dB와 5.82dB 오차를 도출하였고, 본 결과는 유사한 사례의 전파 모델 분석 시 참고 자료로 활용될 수 있을 것이다.

ABSTRACT

We measured the clutter loss (CL) and building entry loss (BEL) of signals in a low-rise high-density suburban environment. Three propagation models for BEL, CL, and a combination of BEL and CL were measured in the selected environment. We then derived the figures when the BEL was combined with the CL. At the two frequencies, the measured value of combination of BEL and CL is 27.55 dB and 26.12dB, respectively, and the differences between the measured value and the sum were –4.19 dB and 5.82 dB. Considering that the measurement was performed inside a building, such a difference seems to be small. Therefore, when BEL and CL were measured separately and summed, and then combined and summed, differences of –4.19 dB and 5.82 dB were apparent. This this result can be referenced when similar case of a propagation model was analyzed.

키워드

Building Entry Loss, Clutter Loss, Propagation Model, Satellite Communication
건물 인입 손실, 클러터 손실, 전파 모델, 위성 통신

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Ⅰ. Introduction

When satellite radio waves are delivered to ground-based receivers, the signal strength is generally extremely low, and service is often unreliable [1]. There are two sources of loss when waves are transmitted from a satellite to inside a building. One is clutter loss (CL) attributable to the outer shape of the building, and the other is entry loss caused by walls and/or windows. An International Telecommunication Union (ITU) document dealing with CL [2] and building entry loss (BEL) has been published [3]

Clutter refers to objects, such as buildings or vegetation, which are on the surface of the Earth but not actually terrain [2]. The building or vegetation can cause an additional loss compared with the free space loss [4-6]. In order to determine the receiver sensitivity, the path loss by clutter should be considered. Recently much research has been performed to find the propagation model of clutter loss. The path loss caused by the clutter effect in the VHF/UHF bands has been analyzed based on unobstructed line-of-sight (LOS) transmission between a transmitter and receiver [7]. The clutter loss was also calculated and verified using a transmission line matrix method [8]. Clutter loss in mm-wave bands a small urban environment was reported at 26 GHz [9] and 32.4 GHz [10].

Building entry loss can be measured as the difference, expressed in dB, between the signal level of a building and the signal level inside the building [11]. An out-door-to-indoor study of propagation loss in the 852-3,500-MHz band (based on the COST-231 report) in a residential building environment has appeared [12]. BEL on the slant path were studied instead of the horizontal path to the ground [13-14]. On the other hand, ITU-R has collected the measurement data in many countries [15]. In terms of mo-bile communications, BEL can be utilized for predicting the propagation loss from one indoor space to another [16]. BEL can be combined into the outdoor-to-outdoor study in order to plan the wireless cell [17-18].

Currently, the two loss factors are commonly studied separately. However, given that wireless terminals are commonly located inside buildings, a more accurate propagation model is needed; reference [19-21] adopted such an approach when evaluating sparsely placed buildings. Here, we evaluated satellite propagation in a suburban

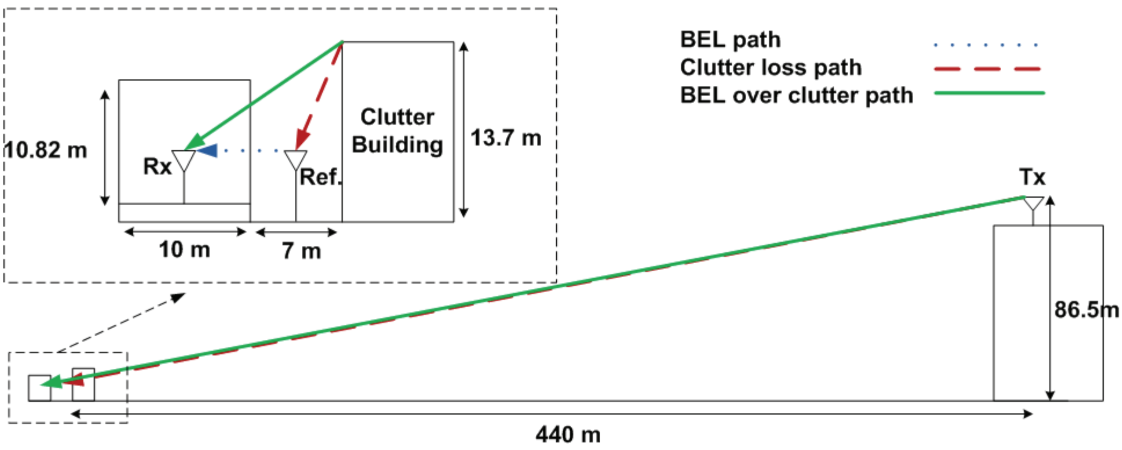


Fig. 1 Side view showing the path for BEL, CL, and the combination (BEL over clutter)

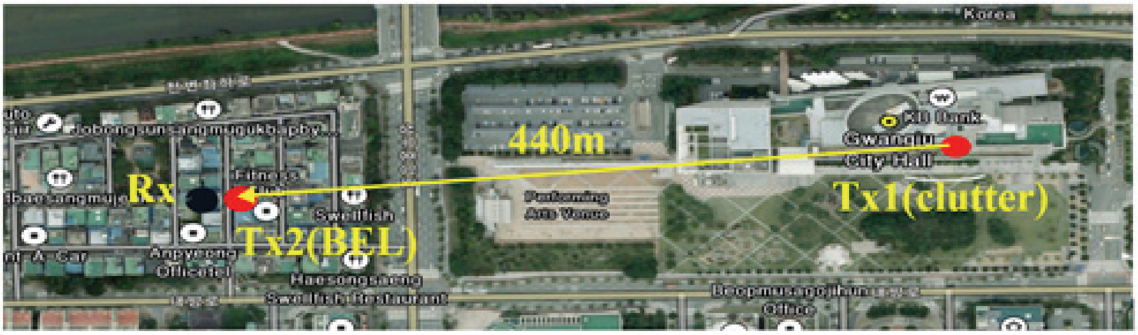


Fig. 2 Aerial photograph of the experimental environment [22]

Fig. 3 A photograph of the buildings

environment; we evaluated CL and BEL separately and together; the three figures were compared to the calculated values.

In this study, a measurement campaign for BEL, CL, and combination of BEL and CL is explained in Section 2, and the measured results is discussed in Section 3, followed by concluding remarks in Section 4.

Ⅱ. Measurement campaign

2.1 Measurement environment and system configuration

The measurement area was selected by reference to a satellite propagation model [2]. As real satellite radio waves cannot be used, we set a transmitter (Tx) at a height similar to that employed when modeling radio waves and placed a receiver (Rx) in a building. Figure 1 shows a side view of the measurement scenario. A Tx was installed on the roof of a building, 86.5 m in height, in Gwangju Metropolitan City. The distance between the Tx and Rx was about 440 m. Figure 1 shows the BEL path (blue dotted line), the CL path (red dotted line), and the two superimposed paths so called the BEL over clutter path (green solid line). We explored whether the combined loss was equal to the sum of the CL outside the building and the BEL; we measured the received powers of each path. Figure 2 is an aerial photograph showing the

Tx and Rx positions and the measurement environment [22][1)]. Figure 3 shows the buildings. The measurement site was surrounded by building clutter.

Figure 4 shows the configurations and surroundings of the Tx and Rx. The (elevated) Tx featured a biconical antenna and a signal generator. The Rx featured a biconical antenna, a low-noise amplifier (LNA), a filter, a spectrum analyzer, and a PC for data acquisition. The metallic body such as a car around Tx antenna as shown in Figure 4a for BEL measurements could affect the flatness of the radiation field but the object placement was tried not to be changed compared with the configuration as shown in Figure 4b and 4c, the measurement of clutter loss and combined loss.

Table 1 lists the Rx and Tx parameters used to compensate for the CL and BEL of the received power. The model of the signal generator is R&S SMB 100A, which has a fre-quency range of 100 kHz to 40 GHz and a maximum output power of +16 dBm. The model of the spectrum analyzer is KEYSIGHT N9020B, which has a frequency range of 10 Hz to 50 GHz and a typical average noise level of – 152dBm and -145 dBm at 3 and 24 GHz, respectively.

Table 1. Tx and Rx parameters

Parameter		3 GHz	24 GHz
Tx	Output power	5 dBm	0 dBm
	Antenna gain	−1.65 dBi	5.16 dBi
	Cable loss	1.34 dB	3.89 dB
Rx	Antenna gain	−2.02 dBi	5.15 dBi
	Cable loss	1.94 dB	7.19 dB
	Filter insertion loss	1.54 dB	0.43 dB
	LNA gain	68.23 dB	51.96 dB

2.2 Loss extraction

Figure 4 (a) shows the Tx and Rx environment for BEL measurement. The Tx (BEL) of Figure 2 was set up in front of the building (Figure 1). The Rx of Figure 2 was located inside Building 1. The BEL is calculated by Eq. (1):

$$BEL = P_{rcv,ref} - P_{rcv,in} \quad dB \tag{1}$$

where $P_{rcv,ref}$ is the received power at the reference point in front of the building and $P_{rcv,in}$ the received

(a) BEL

(b) CL

(c) the combination (BEL over clutter).

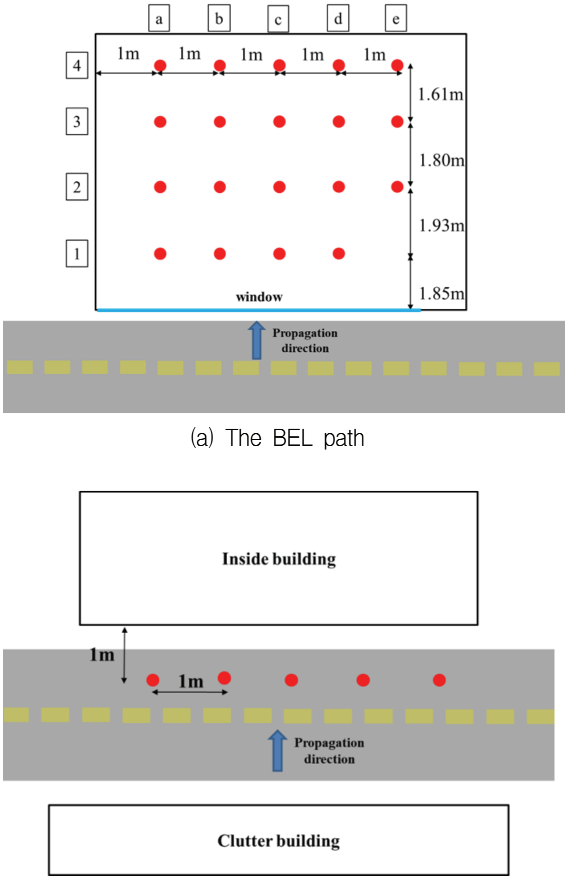
Fig. 4 System configuration and the experimental environment of the Tx and Rx used to derive

1) *https://map.kakao.com*

power from Tx2 inside the building. The receiving points are shown in Figure 5(a). Figure 4 (b) shows the Tx/Rx environment for CL measurement. Transmitter Tx1 (clutter) of Figure 2 was placed on the roof of the high-rise building of Figure 4(b). The re-ceiver was positioned on the left of the clutter building [Figs. 2 and 4(b)]. The antenna symbol at the end of the red dotted line indicates the position of the Rx for CL measurements. CL is given by Eq. (2):

$$CL = P_t - P_r + G_t + G_r + G_{LNA} - L_{cable} - L_{free}\ dB \quad (2)$$

where Pt is the output power and Pt the received power. Gt, Gr, and GLNA are the gains of the Tx and Rx antennae and the LNA respectively. Lcable and Lfree are the losses of the cable and free space over the (straight) distance between the clutter Tx and Rx. The receiving points are plotted in Figure 5(b); they form a series on a road.



(a) The BEL path

(b) The CL path
Fig. 5 Measurement points

Figure 4 (c) shows the Tx and Rx environment for the BEL/CL combination. The Tx point is the same as that for the clutter path. The receiving point is the same as that for the BEL. The BEL/Cl combination is calculated as Eq. 3, which is similar to Eq. (1), but the transmitter position differs.

$$BEL \text{ and } CL\ combination = P_{rcv,rev} - P_{rcv,in}\, dB \quad (3)$$

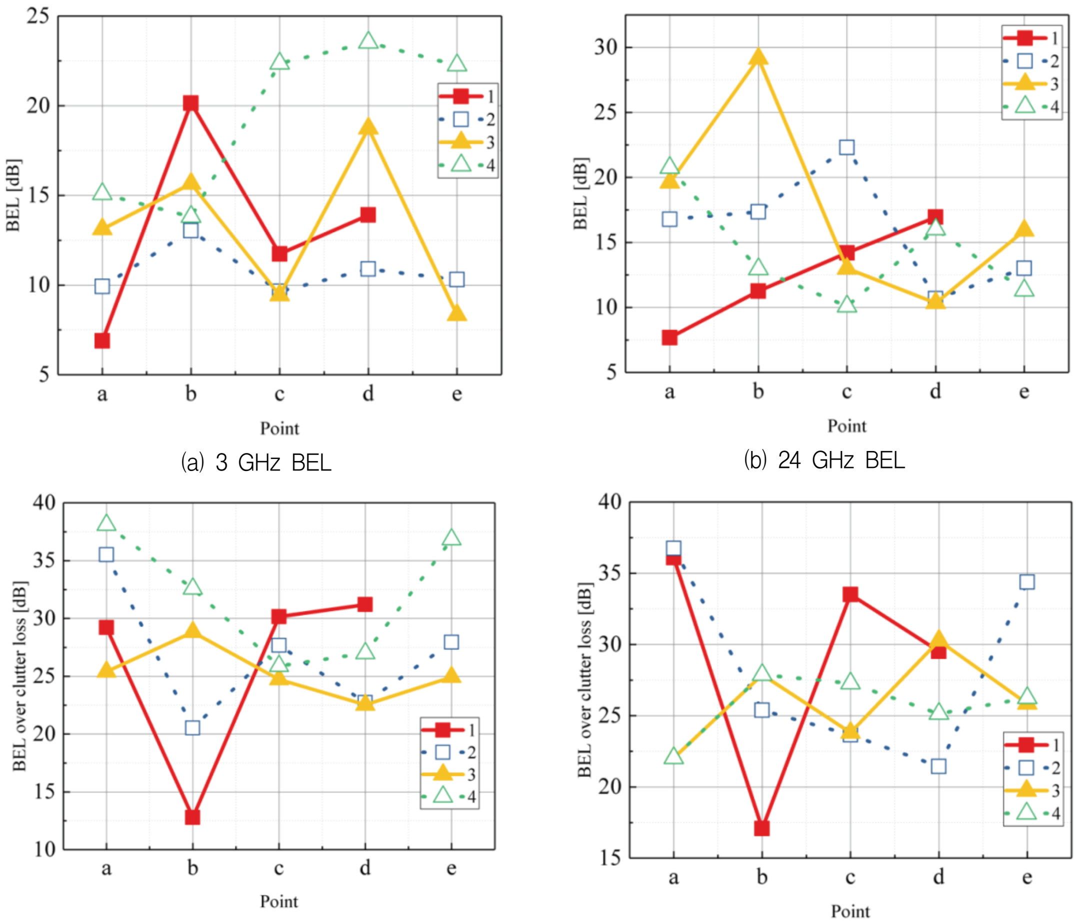
III. Measurement results

The received powers were recorded as the Rx moved by about 1 m, over 5 minutes. The representative value was the median of the recorded values of more than 300 samples. Figure 6 is analyzed data at points within Figure 5. The numbers of 1, 2, 3, and 4 are distant level from propagation direction. Figure 6 (a) and (b) show that the median BELs were 13.12 dB at 3 GHz and 14.2 dB at 24 GHz. Figure 6 (c) and (d) show the combined BEL/CL values inside the building. At 3 and 24 GHz, these were 27.79 and 26.36 dB respectively.

Figure 7 shows the cumulative distribution functions (CDFs) for all paths at 3 and 24 GHz. The BEL probabilities of 0.5 were 13.12 and 14.2 dB at 3 and 24 GHz respectively; the BEL probabilities by the CP loss were 27.6 and 26.13 dB at either frequency. The CL probabilities of 0.5 were 10.25 and 17.75 dB at either frequency.

Table 2 shows the measured BEL, CL, and BEL/CL at 3 and 24 GHz. The summed BEL and CL were 23.36 and 31.94 dB at 3 and 24 GHz.

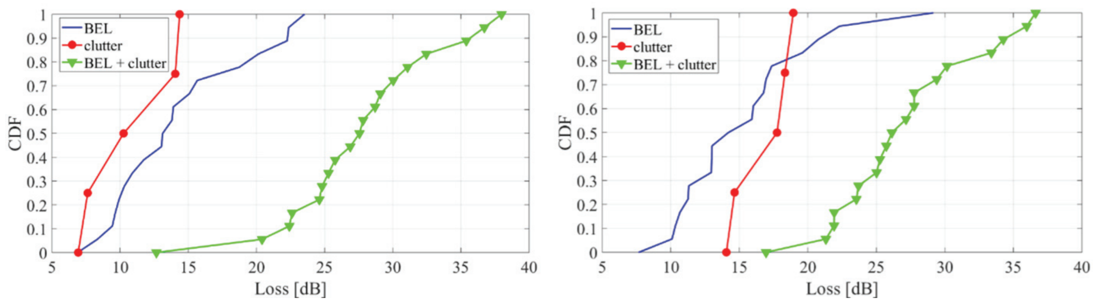
Compared to the combined BEL/CL, the difference at 3 GHz was -4.19 dB and that at 24



(a) 3 GHz BEL (b) 24 GHz BEL

(c) 3 GHz BEL/CL (d) 24 GHz BEL/CL

Fig. 6 CL and BEL data



(a) 3 GHz (b) 24 GHz

Fig. 7 Cumulative distribution function (CDF) results for BEL, CL, and BEL/CL losses

GHz, 5.82 dB (Table 2). One might think that these values are large. However, given the effects of multi-path fading and antenna alignment they are, in fact, small [4]. Especially, considering that the power receiving was performed inside a low-rise high-density building, such a difference seems to be obvious. One should note that Rx antenna has the vertical linear polarization, which is weak to the change of the polarization due to the ground and neighboring buildings. A better receiving can be achieved if a two or three-dimensional probe is utilized instead of a biconical antenna.

Table 2. The calculated and measured BEL/CL losses

Parameter		3 GHz	24 GHz
(1)	BEL	13.12	14.2
(2)	CL	10.24	17.74
(1)+(2)	Calculated summed BEL and CL	23.36	31.94
(3)	Measured BEL and CL	27.55	26.12
(1)+(2)-(3)	Difference	−4.19	5.82

Ⅳ. Conclusion

We explored whether the sums of separately calculated BEL and CL equaled those of combined BEL/CL. All tests were performed (at 3 and 24 GHz) in a suburban environment with low-rise high-density buildings. The measured BELs were 13.12 and 14.2 dB and the measured CLs 10.25 dB and 17.75 dB at 3 and 24 GHz, respectively. The measured BEL/CLs were 27.6 and 26.13 dB, respectively. The differences were -4.19 and 5.82 dB at 3 and 24 GHz, respectively.

Considering that the measurement was performed inside a building, such a difference seems to be small. A better agreement can be achieved if a three-dimensional probe is utilized instead of a bi-conical antenna with vertical linear polarization. From the measurement results introduced in this paper, The BEL/CL can be predicted by the sum of the separately measured BEL and CL. Therefore, the BEL and CL propagation models of the ITU-R can predict the path losses from a satellite to a terminal inside a building in a suburban environment.

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