Influence of Reflected Waves on Communication between Floors of LOS Buildings

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***Abstract* - In order to overcome the increasing traffic problems of mobile terminals used in high-rise floors of buildings, the three-dimensional cell configuration which places small cells on various floors is considered. In order to evaluate wireless transmission technologies for the three-dimensional cell configuration, it is necessary to clarify the time-spatial characteristics of the path loss, delay profile and spatial arrival angular profile for waves travelling from one indoor space in a high-rise office to another such indoor space. In order to evaluate these time-spatial characteristics for each arrival path, our previous study introduced a ray trace system applicable to indoor-outdoor layouts. Then, to evaluate the predicted accuracy of the system, we calculated the path loss characteristic, which is the most fundamental characteristic of the time-spatial characteristics, for a simple indoor-outdoor layout of two cuboids facing each other. We confirmed that the system could reproduce the measured results except when the receiving antenna was far from the window. This paper proves that this difference in measured and calculated results was due to the omission of the waves reflected between buildings. We add the wall reflections to a simple indoor-outdoor layout and show that the calculated results well reproduce the measured results.**

***Index Terms* — Data communication traffic, 3D cell structure, Ray trace, Path loss characteristics, Reflected wave between buildings, Delay profile characteristics**

1. Introduction

Recently, data traffic is explosively growing in cellular mobile communication systems due to the prevalence of smart phones and other terminals. In order to overcome the increasing traffic loads of mobile terminals used in high-rise buildings, the three-dimensional cell configuration which sets small cells on various floors, is being considered [1]-[5]. In order to evaluate the time-spatial characteristics of the three-dimensional cell configuration, we developed a ray trace system applicable to indoor-outdoor layouts. Our simple initial indoor-outdoor layout set two cuboids facing each other. Then, to evaluate the accuracy of the system, we calculated the path loss characteristic, which is the most basic characteristic of the time-spatial characteristics. We confirmed that the calculation results could reproduce the measured results except when the receiving antenna was far from the entry window.

This paper extends our prior research by adding the waves reflected between the facing walls of the two buildings. We confirm that when the receiving antenna is far from the window, some the reflected waves yield higher received levels than the first path. An analysis of the recorded data shows that adding the wall reflections to the calculation can well reproduce the measured results for all receiving antenna distances from the window.

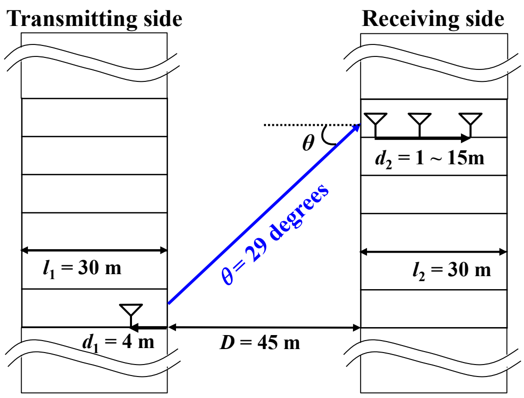


Figure 1. 3D cell structure

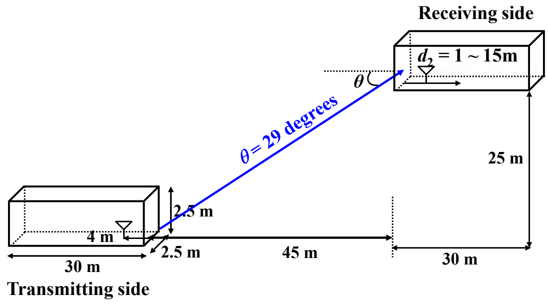


Figure 2. Indoor-outdoor layout without building wall

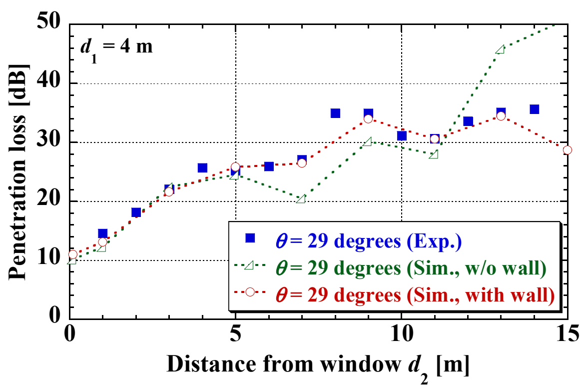


Figure 3. Characteristics of path loss

2. Comparison of ray trace calculation and radio propagation measurement results

Figure 1 provides a major example of the three-dimensional cell configuration. The indoor spaces face each other. We measured the path loss characteristics between different buildings [6], see Figure 1. Figure 2 shows the simple indoor-outdoor layout, two cuboids face each other, that we calculated in previous works. Figure 3 plots the measured penetration loss values for θ = 29 degrees. The distance from the transmitting antenna to departure window, d_1, was 4 m. Figure 3 also plots the calculated penetration loss values for θ = 29 degrees for the simple indoor-outdoor layout. It is found that the system could reproduce the characteristics only if d_2 was 11 m or less [6].

3. Influence of waves reflected between buildings

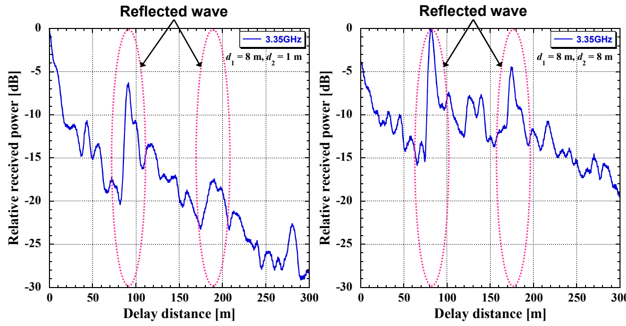
We also measured the delay profile characteristics in the measurement environment [7], see Figure 1. Figure 4 plots the measured delay profile values for d_1 = 8 m and θ = 29 degrees. Fig. 4 (a), (b) shows the result for the distance from window to receiving antenna, d_2, was 1 m and 8 m, respectively. In Fig. 4 (a) and (b), there are the 90 m and 180 m long delay paths. These delay paths include 2 and 4 reflections between the buildings because the distance between buildings, D, is 45 m. The received power of reflected wave is higher than that of first wave, when d_2 is a long distance from the window, see Fig. 4 (b). We found that the some of reflected waves between buildings have an impact on the path loss characteristics, when d_2 is a long distance from the window.

4. Development of calculation model in consideration of a reflected wave between buildings

In response to the measurement results of the delay profile characteristics, we make amendment to the simple indoor-outdoor layout applicable to the reflected wave between buildings as shown in Fig. 5. The ray trace system can calculate the reflected wave between buildings, due to, building walls are added to the respective cuboids. The reflection and the diffraction numbers are 6 and 2 times, respectively. Figure 3 also plots the simulated penetration loss values for θ = 29 degrees for the indoor-outdoor layout with building walls. It is found that the system could reproduce the characteristics, for the distance from window to receiving antenna, d_2, was 12 m or more. Under considering the influence of a reflected wave between buildings, this result basically matches the measured result, which confirms that the developed system could reproduce the characteristics of the measurement results.

5. Conclusion

We analyzed the difference of measured and calculated results by using measured results of delay characteristic. Then we confirmed that there are reflected waves on the building wall and that some of the waves received level are larger than first path in the range where the distance from window to received antenna is long. Therefore we added the building wall to simple indoor-outdoor layout in order to consider the reflected waves on building walls and showed that the results of the layout calculated with building walls can reproduce the measured results.



(a) d_1 = 8 m, d_2 = 1 m (b) d_1 = 8 m, d_2 = 8 m

Figure 4. Characteristics of delay profile

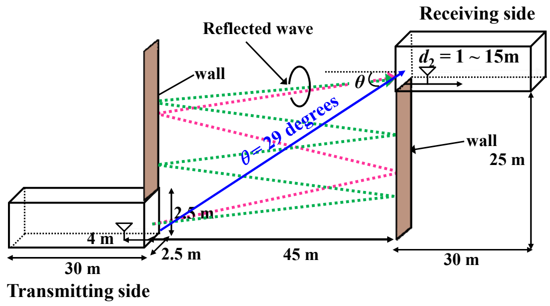


Figure 5. Indoor-outdoor layout with building wall

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