Effects of Path Visibility on Urban MIMO Systems

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1. Introduction

It has been concluded in many researches that MIMO wireless communication architecture promises an approach to achieve high bandwidth efficiencies [1], [2]. MIMO wireless channels can be simply defined as a link for which both transmitting and receiving ends equipped with multiple antenna elements. This advanced communication technology has potential to improve the channel capacity for the future networks. However, the performance of MIMO wireless communication has been considered that it strongly depends on the propagation environment [3].

In outdoor wireless communication, the propagation environment becomes very complex because the antenna heights among the surrounding buildings and the building height distribution itself in each urban area are different. The signal paths, especially the Line-of-Sight (LoS) between the base station (BS) antenna and the mobile terminal (MT), yield to change according to city environments [3]. Hence, we introduce a ray-tracing simulation method (EEM-RTM), in order to evaluate the channel capacity in urban MIMO systems. This method can be used for estimation of various propagation characteristics such as complex electric field, delay and angular profiles of emission/arrival of radio waves, etc. The simulation based on this method with various sets of parameters can discriminate the effects of urban model configurations as well as the antenna configurations over the actual experiment.

Generally, the channel capacity in MIMO channel can be represented by the SNR and the spatial correlation. However, since these propagation parameters are largely affected by the antenna heights of the BS and the surrounding buildings, it was very difficult to simply explain the relationship between the channel capacity and these propagation parameters. Hence, a new parameter "path visibility" which means a measure whether the direct path can be received at the BS when considering the uplink scenario, is introduced herein. Although it is clear that there is relationship between the SNR and the path visibility in Single-Input Single-Output (SISO) channel, the MIMO channel capacity is affected by not only the SNR but also the spatial correlation.

In this study, the relationships between the SNR, the channel capacity and the spatial correlation characteristics of urban MIMO systems and the path visibility are evaluated. Analysis model for urban propagation model, distribution of building height and width and channel capacity calculation is described in Sec. 2. Effects of path visibility on the SNR, channel capacity and spatial correlation are then discussed in Sec. 3. In Sec. 4, the contribution of this paper is concluded.

2. Analysis Model

2.1 Urban Propagation Model

The urban propagation model employed in this paper is represented in Fig. 1. The entire space of the model considered throughout the study covers the area of 640m×640m. This model is composed of 64 blocks of 50m×50m. Each block is composed of 4 buildings. The

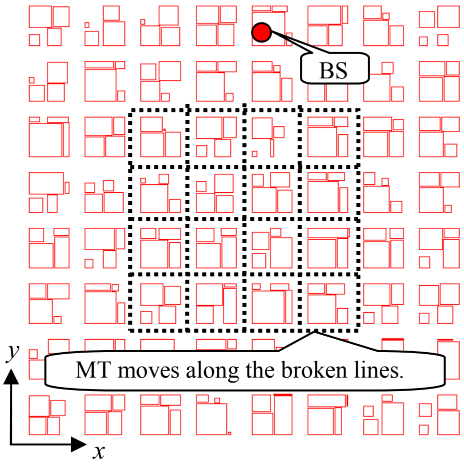


Figure 1: Urban Propagation Model

road width is 20m. The buildings are assumed to be constructed of concrete and the relative dielectric constant and conductivity are set to 5 and 0.01S/m, respectively.

The reference urban model is a 4×4 MIMO system, i.e., both BS and MT antennas are consisted of 4 elements with the element spacing of a half wavelength. For the BS antenna, a linear array is employed. It is located at the top of a building on one side of the model as shown in Fig. 1. Since an accurate reflection or diffraction cannot be obtained at the edge of analysis model in Fig. 1, the MT is assumed to move on the road in the area of 280m×280m around the center of the model along the broken lines in Fig. 1 at the height of 1.5m. The array of MT antenna is arranged at equal intervals in a squared shape. The radiation patterns of both BS and MT antenna are omni-directional. The propagation characteristics between the BS and the MT are calculated by using EEM-RTM program based on the ray-tracing method.

2.2 Mathematical Model for Distribution of Building Height and Width

The distribution of the height of the buildings is assumed following chi-squared distribution with degree of freedom (DOF) of 5 and the minimum height of these buildings is set to 4m, i.e., it can be expressed as [4]

$$h = f(\chi^2) + 4 . \tag{1}$$

Where $f(\chi^2)$ is the chi-squared distribution. The width of each building is determined from its height as [4]

$$w_m = w_0 \left\{ 1 - \alpha \times \exp\left(-\beta h\right) \right\} . \tag{2}$$

Where, w_m is the width of the building, w_0 is 55m, α is 1.1, β is -0.025 m^{-1}, and h is the height of the building.

2.3 Evaluation Method of Urban MIMO System

The carrier frequency employed in this paper is 3GHz. The numbers of reflection and diffraction considered in all simulations are 30 and 2, respectively. The channel response matrices are obtained from the complex received voltage matrices which are calculated at intervals of 14m in length along the broken lines in Fig. 1. It means that the number of calculated points is 185.

The MIMO systems employed herein is the Eigen-Mode Transmission System (EMTS) with equal power control algorithms. The channel capacity can be obtained by [1]

$$C = \sum_{j=1}^{N_t} \log(\lambda_j \gamma_0 / N_t + 1) . \tag{3}$$

Where λ_j is the eigenvalue of the diagonal column of the channel response matrix, γ_0 is the average receiving signal-to-noise ratio (SNR), N_t and N_r are the number of antenna elements of the BS and MT, respectively. The channel response matrix is determined from the matrix of amplitude and phase of the signal received at each MT antenna element from each BS antenna elements, which found by tracing the ray into the propagation model mentioned above. The channel capacity is then obtained by setting up the average SNR. Here, the transmission power is determined so that the SNR becomes 20dB at 400m apart from a transmitter in free space.

To obtain reliable results, the propagation characteristics between BS and respective MT are simulated in 20 different urban propagation models for each setting. The channel capacity is then averaged from these values in units of bit per second per Hertz (bps/Hz).

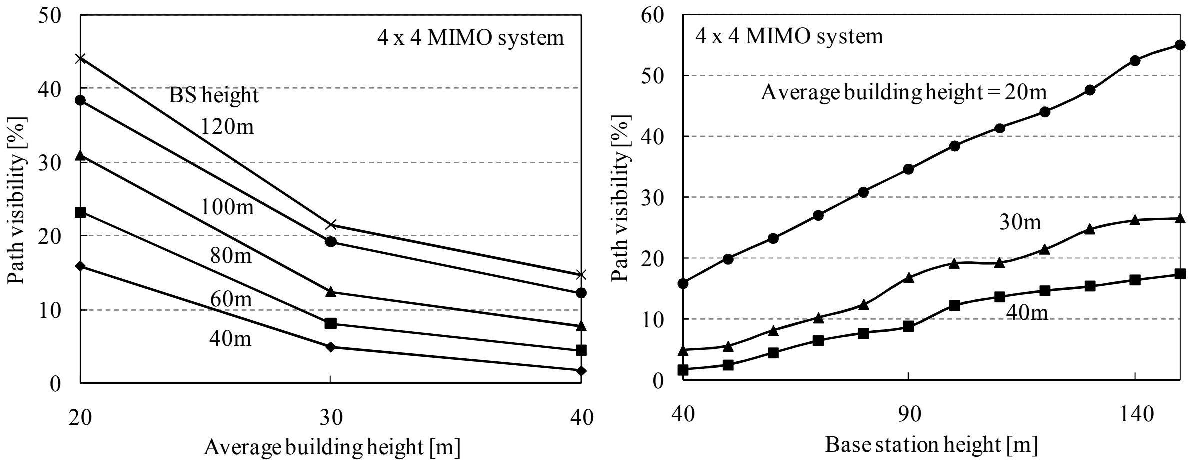
3. Effects of Path Visibility

3.1 Effects of Urban Model Configurations on Path Visibility

Before discussing about the effects of the path visibility in this section, the definition of path visibility has to be clearly described. The word “path visibility” introduced herein is defined as the probability that the direct wave can be received at the MT antenna or the Line-of-Sight (LoS) exists. When considering the uplink scenario, it is a measure whether the direct path can be received at the BS antenna. Additionally, it is clarified that the path visibility around the observed area is quite influenced by the signal obstacles, in this case the surrounding buildings, as well as the BS antenna height.

Figures 2(a) and 2(b) represent the effects of the building height distribution and the BS antenna height on the path visibility, respectively. In Fig. 2(a), the BS antenna height is a parameter varied from 40m to 120m in steps of 20m. It is clarified that, at any BS antenna heights, the path visibility reasonably decreases when the average height of surrounding buildings is higher. Furthermore, when the average building height is 40m, the path visibility changes in only a small range or about only 12 percent even the BS antenna is mounted higher at the 3-time height (120m).

In Fig. 2(b), the average height of surrounding buildings is a parameter varied among 20m, 30m and 40m. It is clarified that, at any average heights of surrounding buildings, the path visibility reasonably increases when the BS antenna is mounted higher. Moreover, they all seem to be ably and roughly approximated as the linear functions, i.e., the relationship between the path visibility and the BS antenna height looks linearly with a constant slope for each average building height.



(a) Effect of Building Height Distribution (b) Effect of BS Antenna Height

Figure 2: Effects of Urban Model Configurations on Path Visibility

3.2 Effects of Path Visibility on SNR, Channel Capacity and Spatial Correlation

Since the influence of the spatial correlation on the MIMO-EMTS is not too large, the path visibility becomes a key parameter in the urban MIMO channels. In this section, the effects of the path visibility on the SNR, the channel capacity and the spatial correlation characteristics are respectively represented in Fig. 3(a), 3(b) and 3(c).

Figure 3(a) indicates that the SNR of urban MIMO systems is able to be approximated from the path visibility without necessary to figure out from the propagation model configuration, neither the building height distribution nor the BS antenna height. Fig. 3(b) indicates that the channel capacity of the MIMO systems is also able to be approximated from the path visibility. Considering the intersection between the curves and the vertical dash line in Fig. 3(b) or when the path visibility is about 30 percent, it is noticed that the average channel capacity of 4×4 urban MIMO systems becomes highest. On the right-hand side of this vertical dash line, even the path visibility increases, the average channel capacity not only cannot be improved but also gradually degrades.

In such cases which the BS antenna looks too high mounted, even the path visibility increases, the influence of the spatial correlation which still gradually increases, as shown in Fig. 3(c), becomes affecting to the average channel capacity. At such high BS antenna, the systems seem to be unable to obtain the fully benefit from higher path visibility and the reflection and diffraction of radio waves among the urban propagation models. That is to say, employing the EMTS for the MIMO transmission of 4×4 MIMO wireless communication in any urban area seems satisfied.

When considering on the cost as well as the performance point-of-views, it is adequate to mount the BS antenna at the height so as the path visibility becomes 30 percent.

4. Conclusions

In this paper, the channel capacity in urban MIMO systems was evaluated by using the ray-tracing method.

The effects of the urban model configurations on the path visibility were evaluated. It was clarified that the path visibility reasonably increased when either the average height of surrounding buildings was lower or the BS antenna was mounted higher.

The effects of the path visibility on the SNR, the channel capacity and the spatial correlation characteristics were then evaluated. Considering the above results, it was clarified that the SNR and the channel capacity characteristics of urban MIMO systems could be figured out from the path visibility between the BS and respective MT antennas. Furthermore, it also gave the guidance that the BS antenna should be mounted at the height so as the path visibility became 30 percent which the best performance of urban 4×4 MIMO wireless communication systems could be obtained.

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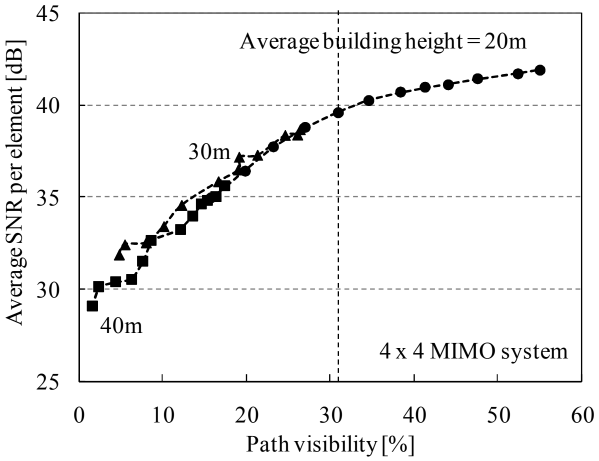
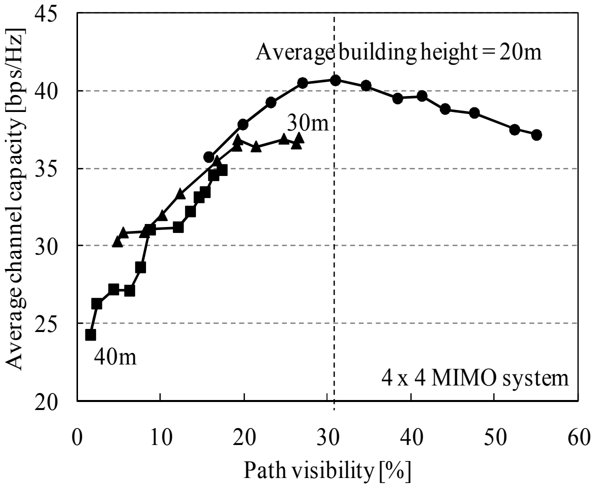
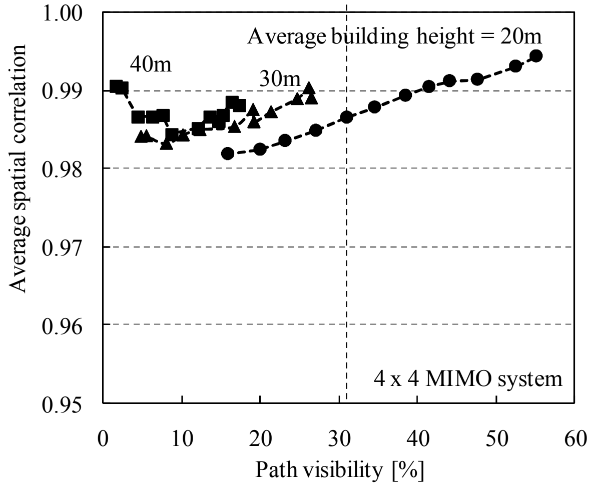


(a) Effect on SNR Characteristics



(b) Effect on Channel Capacity Characteristics



(c) Effect on Spatial Correlation Characteristics

Figure 3: Effects of Path Visibility