Effects of BS Configuration on Channel Capacity of MIMO System in Urban Area

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1. Introduction

Many recent researches have concluded that Multiple-Input Multiple-Output (MIMO) wireless communication architecture promises an approach to achieve high bandwidth efficiencies and allow robustness against channel fading and interference over traditional single antenna systems [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 resolve the problem in traffic capacity for the future networks. However, the performance of MIMO wireless communication systems has been considered that it strongly depends on the propagation environment [3].

In this paper, the propagation characteristics such as arrival direction, intensity, and delay time between the base station and respective terminal are calculated by using ray-tracing method. This simulation technique has been employed for SDMA system in an urban area [4] and an indoor MIMO system [5]. Besides those, there is another system that promises significant to be considered; it is a MIMO system in an urban environment. The performance of this system in term of channel capacity is herein studied. Effects of configuration such as average building height, the height of base station antenna, number of antenna elements, and element spacing 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 configuration of the base station on channel capacity 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. This model is composed of 64 blocks of 50x50m. Each block is composed of 4 buildings. The road width is 20m. The buildings are assumed to be constructed of concrete which its relative dielectric constant and conductivity are 5 and 0.01S/m, respectively.

The model considered as the reference in this paper is a 4x4 MIMO system, i.e., both base station (BS) antenna and mobile terminal (MT) antenna are consisted of 4 elements with the spacing of a half-wavelength. For the BS side, an array of antennas placed at equal intervals on a straight line is employed. It is located at the top of a building on one side of the model as shown in Fig.1. To encounter a perfect reflection and diffraction environment, the MT is assumed to move on the road in the area of 280x280m around the center of the model along the broken lines in

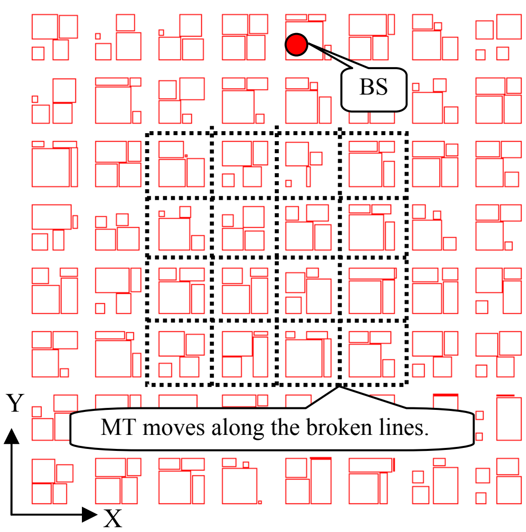

Figure 1: Urban Propagation Model

Fig.1 at the height of 1.5m. The array of the MT antenna is arranged in a squared-shape. The radiation pattern of both BS and MT antenna is omni-directional. The propagation characteristics between BS and respective MT are calculated by using 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 χ-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 Eq.(1) [4].

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

where $f(\chi^2)$ is the χ-squared distribution. The width of each building is determined from its height as Eq.(2) [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 and the maximum number of reflection is considered up to 30 times. The channel response matrix is obtained by normalizing complex received voltage matrix that is 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 adaptive control for the weight coefficients in the MIMO system can be optimized by the Minimum Mean-Squared Error (MMSE) algorithm. The channel capacity is calculated by Eq.(3) [5].

$$C = -\sum_{j=1}^{N_t} \log(1 - h_j^H (HH^H + N_t I_{N_r} / \gamma_0)^{-1} h_j \ . \tag{3}$$

Where, H is the channel response matrix, upper subscript H means Hermite-transpose, h_j is the j-th column of H matrix, I is an identify matrix, γ_0 is the average receiving signal-to-noise ratio (SNR), N_t and N_r are the number of antenna elements of BS and MT, respectively. The channel response matrix is found by tracing the ray into the propagation model mentioned in Sec. 2. The channel capacity is 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 an amount number of different urban propagation models. The channel capacity is then averaged from these values in units of bits per second per Hertz (bps/Hz).

3. Effects of BS Configuration on Channel Capacity

3.1 Effect of Building Height Distribution

To evaluate the effectiveness of the MIMO system statistically, the cumulative probability (Cumulative Density Function, CDF) of the channel capacity is calculated. Figure 2 represents an example of channel capacity distribution around the observed area along the broken lines in Fig.1 in the case of the average building height is set to 20m and the BS antenna height is set to 60m. The further distance from the BS, more deteriorated the channel capacity is.

Figure 3 represents the CDF of the channel capacity. The vertical and horizontal axis indicates the value of the CDF and the channel capacity, respectively. The average building height is a parameter varied among 20, 30 and 40m as the BS is mounted at the height of 70m. Along with the increasing of the average building height, the CDF of the channel capacity relatively increases, i.e., the effectiveness of MIMO system is deteriorated.

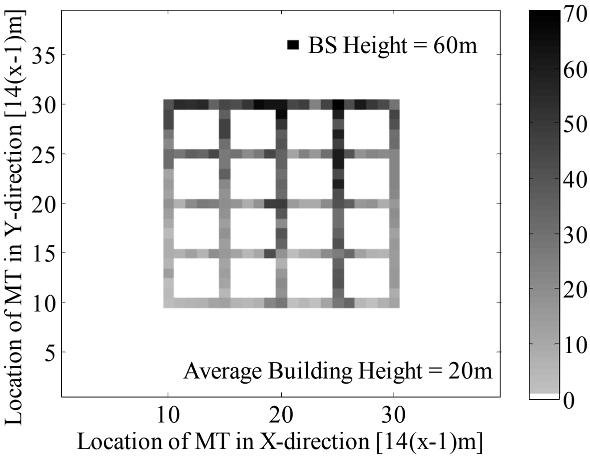

Figure 2: Example of Channel Capacity Distribution

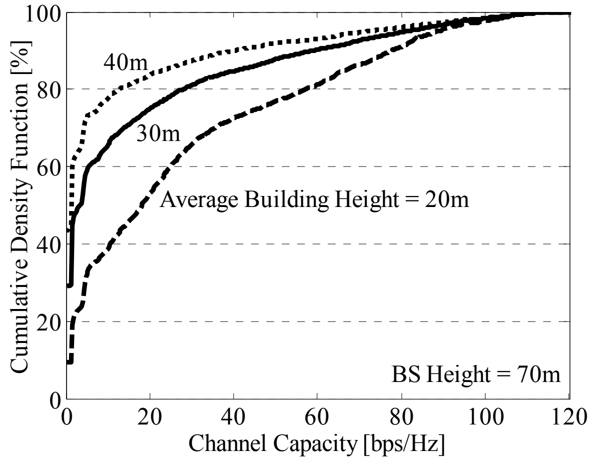

Figure 3: Effect of Building Height Distribution

3.2 Effect of BS Antenna Height

Figure 4 represents the CDF of the channel capacity. The vertical and horizontal axis indicates the value of the CDF and the channel capacity, respectively. The BS antenna height is a parameter covering the range 40-100m in steps of 10m as the average building height is set to 30m. When the BS antenna is mounted higher, the CDF of the channel capacity decreases, i.e., the effectiveness of MIMO system is improved.

Figure 5 represents the channel capacity at 50% of CDF which is indicated on the vertical axis, as the horizontal axis indicates the value of the BS height. The average building height is a parameter varied among 20, 30 and 40m. Along with the increasing of the BS antenna height, the channel capacity at 50% of CDF increases or the effectiveness of MIMO system is improved. However, as the average building height is 20m, the channel capacity at 50% of CDF does not depend on the BS height when the BS antenna is mounted higher than 80m.

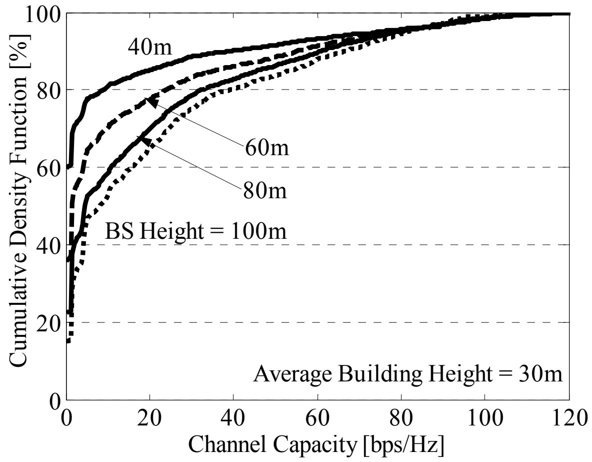

Figure 4: Effect of BS Antenna Height

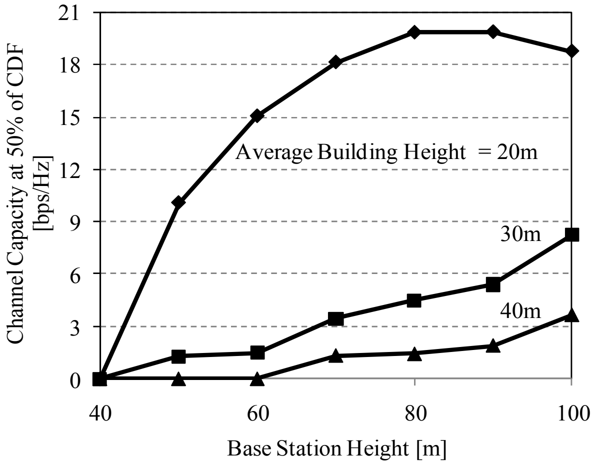

Figure 5: Effect of Building Height Distribution and BS Antenna Height

3.3 Effect of Element Spacing

Figure 6 represents the channel capacity at 50% of CDF which is indicated on the vertical axis, as the horizontal axis indicates the value of the BS height. In this section, the spacing between each BS antenna element is a parameter varied among λ/2, 1λ, 2λ and 3λ where one wavelength (λ) is 10cm. When the BS antenna is mounted higher than 60m, along with the increasing of the BS element spacing, the channel capacity at 50% of CDF relatively increases, i.e., the effectiveness of MIMO system is improved. However, the channel capacity at 50% of CDF does not depend on the element spacing when the BS antenna is mounted lower than 50m.

3.4 Effect of Number of Element

Figure 7 represents the channel capacity at 50% of CDF which is indicated on the vertical axis, as the horizontal axis indicates the value of the BS height. In this section, the number of MT antenna element is a parameter varied among 2, 3 and 4, i.e., the MIMO systems are 4x2, 4x3 and 4x4, respectively. The array of MT antenna is parallel arranged with the spacing of a half-wavelength (λ/2) in a symmetrical shape depending on its number of elements, such as a triangular shape when number of antenna element is equal to 3. When the BS antenna is mounted higher than the height of 50m, along with the increasing of the number of the MT antenna elements, the channel capacity at 50% of CDF relatively increases, i.e., the effectiveness of MIMO system is improved. Moreover, when the BS height is mounted higher than the height of 70m, more Line-of-Sight (LoS) exists, the channel capacity at 50% of CDF of 4x4 MIMO system increases greatly compared to the 4x3 and the 4x2 ones.

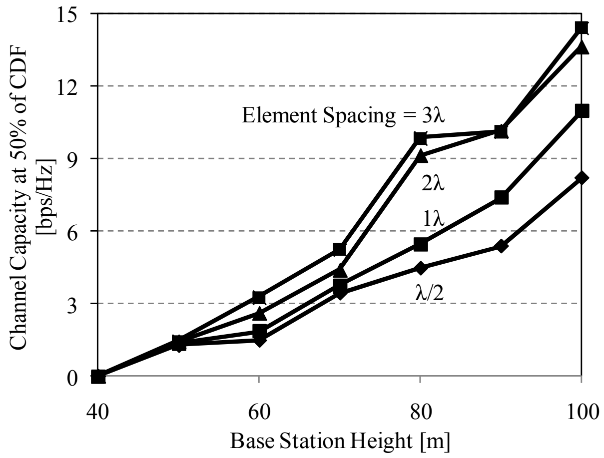

Figure 6: Effect of Element Spacing at BS

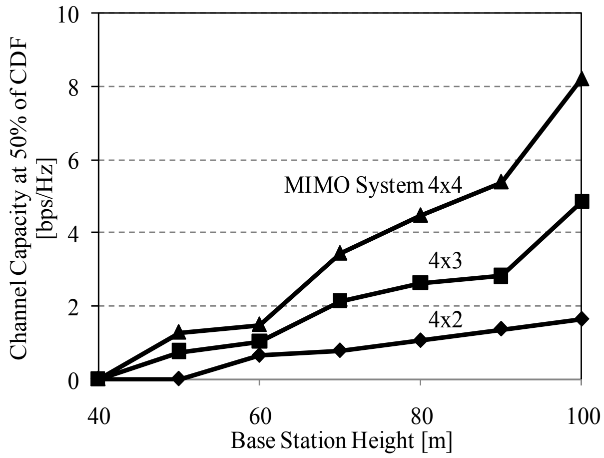

Figure 7: Effect of Number of Antenna Element

4. Conclusions

Effects of BS configuration on channel capacity of MIMO system in urban area are evaluated. As the result, it was clarified that MIMO communication system was possible to be employed in an urban environment. When the average height of the buildings increased, the effectiveness of MIMO system was deteriorated. On the other hand, when the BS antenna was mounted higher, or the spacing between each BS antenna element was wider, or the number of element was added to the MT antenna (but in practice, not more than the number of BS antenna), the effectiveness of MIMO system could be improved.

Considering the results mentioned above, to obtain a satisfied MIMO communication, it was indicated that the BS antenna should be mounted twice higher than of the average height of the buildings and the number of antenna elements employed at the BS and MT should be equalized.

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