Frequency correlation characteristics for broadband MIMO systems in indoor NLOS propagation environment

Nobuhiko TACHIKAWA, Kentaro NISHIMORI, Yasushi TAKATORI, and Kouichi TSUNEKAWA
NTT Network Innovation Laboratories, NTT Corporation
1-1 Hikari-no-oka, Yokosuka, Kanagawa, 239-0847
E-mail: tachikawa.nobuhiko@lab.ntt.co.jp

1. INTRODUCTION
Due to the recent popularity of mobile phones and broadband wireless LANs, broadband wireless systems employing Orthogonal Frequency Division Multiplexing (OFDM) signals were introduced to combat the effects of multi-path fading in indoor wireless LAN systems. Moreover, Multiple Input Multiple Output (MIMO) is incorporated into these broadband wireless systems using OFDM signals to achieve higher transmission speeds without expanding the frequency band [1].

Since the channel capacity of a MIMO channel greatly depends on the fading environment between the transmission and reception antennas, the difference in radio frequency also affects the capacity of the broadband MIMO channels. The channel capacity of MIMO channels based on the antenna arrangements and the element spacing in an actual non-line-of-sight (NLOS) indoor environment was investigated to clarify the relationship between the antenna configuration and the propagation channels in MIMO systems [2]. Although it is well known that the frequency correlation characteristics can be used to judge the transmission quality in conventional broadband propagation channels [3], no research has been done regarding the effect of the capacity of broadband MIMO channels.

This paper investigates the frequency correlation characteristics of the channel capacity for broadband MIMO channels in NLOS indoor environments. Particularly, we focus on the dependency of the element spacing on the frequency correlation characteristics. Based on simulation and measurement results in NLOS indoor environments, we show that the calculation results agree well with the measured results.

2. FREQUENCY CORRELATION OF BROADBAND MIMO CHANNEL IN INDOOR NLOS ENVIRONMENT
2.1 Analysis Model
Figure 1 shows the propagation model considered in this paper. The height of this room is 3 m. We assume that the walls, partitions, ceiling, and floor are all constructed of metal. We used the ray-tracing method to analyze the propagation channels, and the numbers of reflections and diffractions are set to 20 and 2, respectively. As shown in Fig. 1, a transmission antenna is placed at Location X (x = 14 m, y = 2 m), at the height of 0.7 m and a reception antenna is placed inside the partitions. The number of receiving points is 100. We employ four transmission and four reception antennas. The element spacing of the array is changed from 0.1 to 1.5 wavelengths. The carrier frequency, fc, is 5,200 MHz, and we use the frequencies fc+0.5×α (α = 1 to 10) to calculate the frequency correlation of the channel capacity in the MIMO channels.

In this paper, the frequency correlation is obtained by using the channel capacity in the MIMO channels [4]. The channel capacity, C(p), and frequency correlation of ρ(p) at a certain number of receiving points, p, is
where $C_{f_1}$ and $C_{f_2}$ represent the channel capacity of $f_1$ and $f_2$, respectively. Term $H$ is the $4 \times 4$ channel matrix for the propagation channel, $I$ represents the $4 \times 4$ identity matrix, and S/N denotes the Signal to Noise power Ratio (SNR). The input SNR was 30 dB in this simulation.

2.2 Frequency Correlation Characteristics of Channel Capacity

Figure 2 shows the relationship of the channel capacity between frequency $f_1$ and $f_2$ when the element spacing is set to 0.1, 0.5, and 1.0 wavelength, respectively. The antenna arrangement is horizontal. Frequencies $f_1$ and $f_2$ represent 5.2 and 5.2+$\alpha$ GHz, respectively. The results of $\alpha = 0.5$ and 5 MHz are shown in Figs. 2(a) and 2(b), respectively. These results are obtained using the channel capacity for the 100 points for each element spacing given above. Figure 2 shows that the channel capacity increases when the element spacing becomes wide regardless of the difference in the carrier frequency. Also, by comparing the results in Fig. 2(a) to those in Fig. 2(b), we confirm that the distribution between $f_1$ and $f_2$ at $\alpha = 5$ MHz is wider than at $\alpha = 0.5$ MHz.

Figure 3 shows the frequency correlation of the channel capacity versus the carrier spacing when the element spacing is set to 0.1, 0.5, and 1.0 wavelength, respectively. In Fig. 3, the carrier spacing with 0.5-MHz increments is represented on the x axis. Figure 3 shows that the frequency correlation decreases when the carrier spacing increases. For example, if we consider the correlation value of 0.5, which is defined as a correlation bandwidth frequency, the values at the element spacing of 0.1$\lambda$ and 1.0$\lambda$ indicate 2.3 MHz and 1.6 MHz, respectively.

If the element spacing of the array antenna becomes wide, it is well known that the fading correlation between the array antennas becomes small and the channel capacity becomes large in MIMO channels [4]. There is also a general relationship between the delay spread and the frequency correlation in conventional Single Input Single Output (SISO) systems. On the other hand, we find that the fading correlation between the array antennas significantly affects the frequency correlation in NLOS propagation environments when we use a MIMO configuration.

3. MEASUREMENT RESULTS OF FREQUENCY CORRELATION

3.1 Measurement Environment

To confirm the results described in Section 2, measurements are performed in an actual NLOS indoor environment. Figure 5 shows the measurement environment. To compare the calculated and measured results under the same conditions, we use the same size room and partition locations. To establish a NLOS environment in this measurement, six 2-m high partitions constructed of metal are placed in the room. The transmission antenna is located at the X in Fig. 5. Reception antennas are located at the seven points labeled A to G in the NLOS environment.
Figure 5(a) shows the antenna arrangement and Fig. 5(b) is a photograph of the antenna and the holding apparatus used to fix the location of the antenna. Sleeve antennas are used for both the transmission and reception antennas. We simulate an array antenna by moving the location of one antenna across the room horizontally, as indicated in Fig. 5(a). The sleeve antenna is fixed in the holding apparatus, as shown in Fig. 5(b). This holding apparatus is powered by an electric motor and can move the antenna with an accuracy of 10 µm. The transmission and reception antennas are located at the height of 0.7 m.

A linear array is used in the horizontal plane with both the transmitter and receiver in this measurement. This measurement is carried out in a static environment. The complex amplitude is obtained at an interval of 0.5 MHz by connecting the network analyzer to the transmission and reception antennas. After this, the channel capacity and its frequency correlations are obtained off-line for each measured spacing of the carrier frequency.

3.2 Frequency Correlation Measurement Results

Figure 6 shows the frequency correlation of the channel capacity versus the carrier spacing when the element spacing is set to 0.1, 0.5, and 1.0 wavelength. In Fig. 6, the carrier spacing with 0.5-MHz increments is represented on the x axis. The figure shows that when comparing the results of Fig. 3 to those of Fig. 6, there is good agreement in the dependency on the element spacing of the array versus the frequency correlation of the channel capacity.

4. CONCLUSION

This paper investigated the frequency correlation characteristics of the channel capacity on broadband MIMO systems in indoor NLOS environments. As a result, not only the delay spread, but also the fading correlation was shown to affect the correlation bandwidth of the channel capacity because the value of the frequency correlation decreases if the array antenna with a wide element spacing is used in an NLOS propagation environment when employing the MIMO configuration. Moreover, based on the measurement results in an actual NLOS indoor environment, the calculated and measured results show good agreement regarding the dependency on the element spacing of the array versus the frequency correlation of the channel capacity.

ACKNOWLEDGEMENT

The authors thank Dr. Masahiro Umehira of Nippon Telegraph and Telephone Corporation (NTT) for his constant encouragement.

REFERENCES

Fig. 1
Analysis model

Fig. 2
Difference in channel capacity due to frequency differences

Fig. 3
Frequency correlation of channel capacity (Dependency on element spacing)

Fig. 4
Measurement environment

Fig. 5
Antenna arrangement and photograph of antenna

Fig. 6
Frequency correlation characteristics of channel capacity