Channel Capacity of a Handset MIMO Antenna Influenced by the Effects of 3D Angular Spectrum, Polarization, and Operator

*Koichi Ogawa, Hiroshi Iwai, Atsushi Yamamoto, and (1)Jun-ichi Takada
Matsushita Electric Industrial Co., Ltd. 1006, NDC, Kadoma, Osaka, 571-8501 Japan
ogawa.koichi@jp.panasonic.com

(1)Graduate School of Science and Engineering, Tokyo Institute of Technology
2-12-1-S6-4, O-okayama, Meguro-ku, Tokyo 152-8550, Japan

1. INTRODUCTION
So far, effects of MIMO on the enhancement of channel capacity have been investigated principally in the i.i.d. (independent and identically distributed) channel [1]. However, for a handset MIMO, some subjects have to be considered, such as:
(1) 3D-angular spectrum for incident waves,
(2) Polarization of both theta and phi components, i.e. XPR,
(3) Electromagnetic effects of a human operator.
This can clarify the relationship between the handset MIMO capacity, and radiation and incident wave properties.

There are some difficulties of handset MIMO antennas. The number of antenna elements is limited because of the small physical size of the handset, which leads to narrow antenna spacing. Furthermore, radiation patterns are strongly influenced by biological electromagnetic effects caused by the human operator. In this study, particular interest is how well the handset MIMO antenna works under those limitations.

The purpose of this study is to evaluate a handset MIMO antenna under practical use conditions, involving multipath radio wave propagation and the influence of the body of the user. To this end, a Monte Carlo computer simulation has been carried out to investigate the distribution of eigenvalues and channel capacity.

2. CHANNEL MODELING
Fig. 1 shows the channel modeling for $M$-by-$N$ MIMO, which is an improved version of the channel modeling for handset adaptive arrays [2]. $M$ BS antennas create a set of $M$ uncorrelated waves, each of which is made of $K_m$ scatterers surrounding around $N$ handset antennas. Thus, $M$ uncorrelated waves are subject to the i.i.d. complex Gaussian process creating a Rayleigh fading. Furthermore, correlation characteristics of BS and MS sides are independent with each other.

A handset is assumed to be surrounded by $K_m$ scatterers arranged in a 3-dimensional fashion, as shown in Fig. 2.

3. MONTE CARLO SIMULATION
Using the channel modeling, we have carried out a Monte Carlo simulation according to the procedure in the followings:

1st STEP: Generation of $K_m$-Path

The angular power spectrum is uniform in azimuth and Gaussian in elevation, as shown in Fig. 3 [2]. XPR is assumed to be an average value. Signals for a certain snapshot are generated using random numbers.

$$P_r(\theta, \phi) = \frac{XPR}{1+XPR} A_y \exp \left\{ -\frac{\left(\phi - \frac{\pi}{2} m_y\right)^2}{2\sigma_y^2} \right\}$$
4th STEP: Evaluation of Channel Capacity

The eigenvalues and eigenvectors are obtained using SVD operation as:

\[ H_s = U_s D_s V_s^H \]

\[ U_s = [e_{s1}, \ldots, e_{sh}] \]
\[ V_s = [e_{s1}, \ldots, e_{sh}] \]
\[ D_s = \text{diag}[\sqrt{\lambda_1}, \ldots, \sqrt{\lambda_L}] \]

Using the eigenvalues, the channel capacity and its average value are finally evaluated as:

\[ C_i = \sum_{m=1}^{L} \log_2 \left( 1 + \frac{\gamma \lambda_m}{M} \right) \]
\[ \overline{C} = \frac{1}{S} \sum_{s=1}^{S} C_i \quad (s = 1 \ldots S) \]

4. HANDSET MIMO ANTENNA

A 4-element array comprising monopoles and PIFAs is located close to a phantom simulating a display-viewing situation, as shown on the left-hand side of Fig. 5.

Fig. 5 also shows a model of a human phantom used for the numerical calculations. Fig. 5 represents a practical use condition with a simplified structure assuming biological human tissue parameters. The radio is inclined at angle of \( \alpha \) from the vertical and at distance \( D \) from the body. From these structural parameters, the model employs a more realistic geometrical relationship between the human body and the radio during ordinary use. The radiation and impedance characteristics are calculated by means of the moment method, in which a wire-grid is employed to accommodate the surface impedance method for the simulation of the biological parameters of human tissue [2].

5. SIMULATION RESULTS

A. Effect of XPR on Channel Capacity

Fig. 6 shows the eigenvalues as a function of XPR with the input SNR=30dB, \( m_V=m_H=0\)deg, and \( \sigma_V=\sigma_H=10\)deg. The input SNR is defined as an SNR for each incident
wave when an isotropic antenna is used for receiving the incident wave. The handset is inclined at angle of 40° from the vertical and at distance 20cm from the body.

It is found from Fig. 6 that the 1st eigenvalue increases as an XPR increases. This fact indicates that a higher-XPR environment has a merit for MRC. But, other eigenvalues have to be considered for MIMO. The 2nd-4th eigenvalues decrease with increasing an XPR. Thus, there might be a compromise between the capacity and XPR.

![Fig. 6 Effect of XPR on the Eigenvalue](image)

Table 1 shows the fading correlation between branches. The correlations are found to be relatively low, and thus have little effect on the channel capacity.

Although the results mentioned above are obtained from specific antenna structure and propagation model, this gives us a design guideline about the relationship between the
radiation patterns and propagation properties (XPR) for gaining a higher channel capacity.

Table 1 Fading Correlation Between Branches

<table>
<thead>
<tr>
<th></th>
<th>monopole#1</th>
<th>monopole#2</th>
<th>PIFA#1</th>
<th>PIFA#2</th>
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<td>0.18</td>
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<td>0.02</td>
<td>1</td>
</tr>
</tbody>
</table>

B. Capacity for Various Configurations

Fig. 9 shows the channel capacity comparison between the handset and a vertically oriented 4-element λ/2-dipole array with λ/2-spacings in free space. Using MIMO, a four times capacity can be achieved as compared with the capacity with SISO. An 80 percent capacity as compared with the dipole array is attained.

Fig. 10 shows the comparison of channel capacity as a function of the number of branches with changing the input SNR. XPR=6dB, m_v=m_H=20deg, and σ_v=σ_H=20deg. A two-element handset means that a handset has only two PIFAs, PIFA1 and PIFA2, on a radio case, shown in Fig. 5. A 4-by-4 handset MIMO can achieve as twice a capacity as a 4-by-2 handset MIMO. Furthermore, 4-by-2 and 2-by-2 MIMOs show almost the same capacity.

6. CONCLUSION

The study shows that a handset MIMO under consideration has a substantial potential to enhance the channel capacity, even in a practical use condition near an operator. An interesting relationship between the channel capacity and XPR has been shown, suggesting that a lower XPR has a merit for achieving a higher capacity for a handset MIMO considered in this paper in a cellular environment.

REFERENCES