Effectiveness of a Fading Emulator in Evaluating the Performance of MIMO Systems by Comparison with a Propagation Test


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Abstract—This paper presents a MIMO spatial fading emulator, used to represent a street microcell environment. The fading emulator can reproduce a multipath radio propagation environment with either a uniform or non-uniform angular power spectrum (APS) in the horizontal plane. In this paper, we used the emulator to measure the 2-by-2 MIMO characteristics of four handset arrays with two monopoles in a multipath environment with one spatial cluster of incoming waves. From our investigation, good agreement was obtained between the results from the emulator and data measured in a radio propagation test in a street microcell. This demonstrates that the emulator is effective in evaluating the MIMO performance in a multipath propagation environment.

I. INTRODUCTION

There have been significant investigations into over the air (OTA) tests for mobile handsets with multiple input multiple output (MIMO) systems for upcoming Long Term Evolution (LTE) and IMT-Advanced cellular radios [1-3]. Some fading emulators, proposed for OTA testing, consist of a number of antenna probes for producing multipath fading in the spatial domain [4 - 6]. These emulators can reproduce MIMO radio propagation channels by waves radiated from the antenna probes in both spatial and time domains. However, there has not been much study in verifying the effectiveness of these emulators.

This paper presents a spatial fading emulator [3] suitable for MIMO OTA tests in a street microcell environment. Four handset arrays with two monopole antennas were used for the OTA test, and with these we were able to evaluate the 2-by-2 MIMO characteristics. The handset MIMO antennas tested and their radiation characteristics are shown in section II. In section III, the experimental conditions used in the propagation test and the OTA test using the emulator are described. The propagation test was conducted in a central area of the city of Aalborg in Denmark [7]. Section IV presents the measured propagation test results for the 2-by-2 MIMO and the OTA test. From a comparison between the measured results, the effectiveness of the emulator was confirmed. Finally, in section V, we conclude our study.

II. HANDSET ARRAY FOR 2-BY-2 MIMO TESTING

Fig. 1 illustrates the four handset arrays used in the MIMO radio propagation and OTA tests. Each handset has two monopole antennas and a ground plane with a size of 90 mm by 45 mm, and is operated at 2.35 GHz. Fig. 2 shows the measured impedance characteristics at 2.35 GHz. Each antenna gives good return loss characteristics of less than -9 dB, as shown in Fig. 2(a), which corresponds to a radiation power loss of only 0.6 dB. The highest mutual coupling of -2 dB is found for handset D, because the spacing between the two antennas of this handset is the smallest, as shown in Fig. 2(b). Handset C has the lowest coupling and is, therefore, predicted to exhibit good radio efficiency.

![Fig. 1 Handset arrays with two monopole elements. (a) Handset A. (b) Handset B. (c) Handset C. (d) Handset D.](image-url)
Fig. 2 Measured impedance characteristics of each handset at 2.35 GHz. (a) Return loss. (b) Mutual coupling.

Fig. 3 shows the radiation efficiencies of the handset arrays measured in an anechoic chamber. The efficiency was the average of the efficiencies of each antenna for each handset array. It is observed from Fig. 3 that handset C exhibits the highest efficiency, as estimated from the mutual couplings in Fig. 2. Moreover, the efficiency of handset D is the lowest because the mutual coupling of -2 dB of this handset is the largest, resulting in a radiation power loss of -4 dB. Thus, with respect to radiation efficiency, it is predicted that handset C will have the greatest channel gain in the radio propagation and OTA tests, and that handset D will have the lowest channel gain. This shows that mutual coupling is one of the most significant factors for a handset’s MIMO antennas because the strong coupling, caused by the closely-spaced antennas in a small handset, directly degrades the radiation efficiency.

Fig. 4 shows the spatial correlation between the two antennas of each handset at 2.35 GHz, which is calculated using the measured complex radiation patterns in the horizontal plane. The correlations were determined as the absolute values of the complex spatial correlations. From Fig. 4, handset C gives the lowest spatial correlation, whilst handset D has the highest correlation of 0.88. These results can be attributed to the distance between the two antennas comprising the MIMO array. The high correlation of handset D can deteriorate the array performance.

Figs. 3 and 4 indicate that handset C would have the best MIMO performance in the propagation and OTA tests, and that handset D would exhibit the worst MIMO reception from the point of view of both the radiation efficiency and spatial correlation. In the following sections, we compare the MIMO characteristics measured in the propagation test and the spatial fading emulator using the four handset arrays, which have different radiation efficiencies and spatial correlations.
III. EXPERIMENTAL CONDITIONS

A. Radio Propagation Test

Fig. 5 shows the site used for the MIMO propagation test [7], in an urban area of Aalborg, Denmark. As shown in Fig. 5, the test was performed along four sub routes. The base station, shown as a blue circle in Fig. 5, was set near the test route. Fig. 6 shows an illustration of the radio propagation test. The height of the base-station array was set at 14.5 m. Almost all of the buildings have a height of more than 15 m. Thus, all the sub routes were in a non-line of sight (NLOS) condition. The base station consisted of a horizontal linear array with two antenna elements at 2.35 GHz. Each array had an antenna spacing of two wavelengths and was set parallel to sub route II. The signal from each base-station antenna was vertically polarized with power of 33 dBm at 2.35 GHz.

The handset was set at a height of 1.5 m above the ground and was inclined at 40 degrees from the vertical, as shown in Fig. 7. In the propagation test, the handset was moved on a car trailer at a speed of about 20 kilometers per hour. The sampling frequency was 100 Hz, and the number of the snapshots was 4300 for each sub route.

B. MIMO OTA Test Using the Emulator

Fig. 8 shows a photograph of the spatial fading emulator [3] with a radius of 1.5 m in an anechoic chamber. The emulator contains 31 scattering units that are composed of two half-wavelength dipoles crossing at right angles in order to represent a cross polarization power ratio (XPR), as shown in Fig. 9.

In the radio propagation experiment, the waves radiating from the base-station antennas were modelled by one spatial cluster, as mentioned in section A. In this study, the angular power spectrum (APS) of the incoming waves in the horizontal plane was modelled by a Laplacian distribution with a standard deviation, $\sigma$, of 35 degrees, according to the spatial channel model (SCM) of 3GPP [8].

$$\Omega_\phi(\phi) = \frac{1}{2\sigma} \exp \left( -\frac{\phi - \mu_\phi}{\sigma} \right) .$$

$\mu_\phi$ was set at 0 because the incoming waves in the propagation test came mainly from the forward direction of the handset.

For a 2-by-2 MIMO evaluation, the waves transmitted from the scattering units have a different set of initial phases for different incoming waves transmitted from different base-station antennas so that correlation between the transmitted signals is almost 0. The XPR was set at 9 dB [7] and the radio frequency was 2.35 GHz. The Doppler and sampling frequencies were 25 Hz and 500 Hz, respectively. The distance moved by the handset was 1600 wavelengths of the radio frequency so that the number of snapshots was 32,000.

The theoretical open-loop Shannon capacity, $C_s$, of an M-by-M MIMO system of the s-th snapshot is given by the following [9]:

$$C_s = \log_2 \left( \det \left( I_m + \frac{SNR}{M} H H^H \right) \right) \text{ [bits/sec./Hz]},$$

where $|A|$ denotes the determinant of $A$, $H$ is a channel matrix that is an $M \times M$ complex matrix, and $I_m$ indicates the identity matrix of dimension $M \times M$. The average channel capacity is given by the following equation:

$$\bar{C} = \frac{1}{S} \sum_{s=1}^{S} C_s \text{ [bits/sec./Hz]},$$

where $S$ is the number of snapshots.
IV. COMPARISON BETWEEN MEASURED RESULTS

Fig. 10 shows the average channel gains of the handset arrays in the propagation test and the OTA test using the emulator. The channel gains are normalized to a mean value for the four handsets. As can be seen in Fig. 10, the channel gain of handset C was the highest in both the propagation test and the OTA test, and handset D gave the smallest channel gain of all the handsets, the same as the radiation efficiencies described in section II. From this, we can estimate the channel gain of the MIMO array using the antenna efficiency measured in an anechoic chamber. Moreover, it is observed from Fig. 10 that the channel gains of the OTA test are in good agreement with those of the propagation test.

Fig. 11 shows the fading correlations between signals received by the handset arrays in both the propagation and the OTA tests. The correlations were calculated as the absolute values of the complex fading correlation. Comparing the spatial correlations in Fig. 4 and the fading correlations in Fig. 11, the fading correlations of the four handsets, which were measured in a multipath propagation environment, agree well with the spatial correlations obtained in an anechoic chamber. From the above investigations, the radio propagation characteristics of the handset arrays can be predicted from their complex radiation patterns, with respect to the channel gain and fading correlation. Furthermore, it is found that the correlations measured by the emulator agree well with those obtained in the propagation test.

Fig. 12 shows the 2-by-2 MIMO channel capacities of the handset arrays. The average input signal to noise power ratio (SNR) is defined as the ratio of the average signal power received by all four handset antennas to the noise power for each measurement. In this investigation, the input SNR was set at 30 dB. It is found from Fig. 12 that handset C exhibits the largest MIMO channel capacity and that handset D gives the lowest one, as estimated in section II.

As shown in Fig. 12, the agreement between the MIMO channel capacities measured by the emulator and in the propagation test is very good. It is concluded from this that the spatial fading emulator is effective in evaluating MIMO characteristics in a multipath radio propagation environment with one spatial cluster in a street microcell of a cellular radio.
Fig. 12 2-by-2 MIMO channel capacities of the handsets in the propagation test and the OTA test using the emulator at 2.35 GHz.

V. CONCLUSIONS

Comparison between 2-by-2 MIMO performance in a radio propagation test and an OTA test using a spatial fading emulator was presented. Evaluation of the handsets’ MIMO antennas at 2.35 GHz was conducted under a multipath environment with one cluster. Four handsets with MIMO antennas with two monopoles were used for each measurement. From the agreement between the MIMO characteristics in each case, the emulator was shown to be effective in evaluating the MIMO arrays of handsets for the case of a multipath fading environment with one cluster.

REFERENCES