Compact Eight MIMO Antennas for 5G Smartphones and Their MIMO Capacity Verification

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Abstract—The handset or smartphone antenna has evolved from the external antenna before the year 2000 to the internal antenna and casing-integrated antenna for 2G/3G/4G communications till now. For the fifth-generation (5G) communications, it is expected that the Massive MIMO system is very promising for applications and a large number of MIMO antennas will be attractive to be deployed in the smartphone to effectively increase the channel capacity. In this paper, promising compact eight MIMO antennas in the smartphone are presented. The MIMO antennas are operated in the 3.5-GHz band (3400–3600 MHz), which has been recently identified in WRC-15 for global mobile broadband services in the future. The achievable MIMO channel capacities for the proposed compact eight MIMO antennas are calculated and verified by MIMO OTA (over-the-air) testing in the open space. Results are presented and discussed.

Keywords—smartphone antennas, MIMO antennas, 5G communications, MIMO capacity

I. INTRODUCTION

2 x 2 MIMO (multiple-input multiple-output) system has been successfully applied for the fourth-generation (4G) mobile communications. For such applications, two LTE MIMO antennas are required to be embedded in the smartphone for the 2 x 2 MIMO operation in the LTE bands such as in the 698–960 and 1710–2690 MHz bands [1]. It is also predicted that for the LTE MIMO operation, the achievable channel capacity increases with the numbers of both the MIMO antennas in both the smartphone and the base stations. It has been reported that with eight MIMO antennas in the smartphone for the 8 x 8 MIMO operation, the achievable channel capacity can be about 37 bps/Hz at 20-dB signal-to-noise ratio (SNR) [2], which is close to 8 times that of a single antenna for SISO (single-input single-output) operation. With such a channel capacity and a wide frequency spectrum (for example, at least 200 MHz), the data rate can be much higher than 1 Gbps. In this regard, the MIMO antennas with at least eight antennas in the smartphone are promising for application in the fifth-generation (5G) mobile communications.

However, owing to the very limited space in the smartphone, it is very challenging to embed a large number of MIMO antennas (for example, at least eight antennas) therein with good isolation with low envelope correlation coefficients (ECCs). In addition, there are very few measured results of the achievable channel capacities for the MIMO operation with at least four MIMO antennas in the smartphone to verify the predicted channel capacities.

Recently, in Nov. 2015, the WRC-15 (World Radiocommunication Conference 2015) identified a new frequency spectrum of 3400–3600 MHz for global mobile broadband services [3]. This frequency spectrum is promising for application in 5G mobile communications. This motivates the present study to devise promising compact eight MIMO antennas for the 5G smartphone applications. The proposed MIMO antennas has a compact structure than that reported in [4] and also has a narrow width of 1 mm only, less than that reported in [2], [5]. The compact size of the proposed MIMO antennas makes it promising to be embedded in the narrow region between the casing and the large display panel along the two side edges of the smartphone.

In this study, typical Massive MIMO systems for 5G communications are described in Sec. II. The proposed compact eight MIMO antennas in the smartphone and the measured results of the MIMO OTA testing in the open space are presented in Sec. III and IV. The measured channel capacities for 8 x 4 and 4 x 4 MIMO operation have been obtained and will be discussed. Conclusion is summarized in Sec. V.

II. MASSIVE MIMO SYSTEMS FOR 5G COMMUNICATIONS

Fig. 1. Massive MIMO systems for 5G communications. (a) 3D base-station MIMO antennas for multi-users. (b) Planar base-station MIMO antennas for the smartphone with multiple MIMO antennas.

Fig. 1 shows typical Massive MIMO systems for 5G communications. In Fig. 1(a), the base station antennas are in a three-dimensional circular cylindrical array structure, and the mobile unit can have one or multiple antennas. In Fig. 1(b), the base station antennas are in a planar array structure, which makes it suitable to be mounted on the flat surfaces of the building. The smartphone antennas in Fig. 1(b) can have at
least eight MIMO antennas along two side edges of the smartphone to achieve a much higher channel capacity for the MIMO operation. It is also noted that the two short edges (top and bottom edges) of the smartphone are reserved to accommodate the 2G/3G/4G antennas.

III. COMPACT EIGHT MIMO ANTENNAS IN THE SMARTPHONE FOR 3.5-GHZ LTE MIMO OPERATION

Fig. 2(a) shows the compact eight MIMO antennas for operating in the 3.5-GHz band (3400–3600 MHz) [3]. The quad antenna linear (QAL) array [2] is applied. The QAL array is constructed based on the open-slot antenna structure [6] and has a size of 1 x 60 mm² along the side edge of the system circuit board in the smartphone. The four antennas in the QAL array has a total length of 60 mm and a narrow width of 1 mm only. Each antenna in the QAL array has acceptable antenna efficiency better than 45%, and the ECC between two antennas thereof is less than 0.1. For the system circuit board, it has a size of 75 x 150 mm², which is reasonable for the modern smartphone.

The four dual-polarized patch antennas used as the base station antennas are also shown in Fig. 2(b). The four dual-polarized patch antennas have a size of 14.5 x 14.5 cm² and can provide up to eight isolated ports for the MIMO operation. The antenna efficiency for each port is better than 90% and the ECC between two antennas thereof are very small (close to 0). Very good isolation for the base station antennas is obtained.

IV. LTE MIMO ANTENNAS CHANNEL CAPACITY TESTING

Fig. 3 shows the 4 X 4 LTE MIMO testing arrangement. Four ports in the smartphone [Fig. 2(a)] are used as the receive antennas, and four ports in the base station antennas [Fig. 2(b)] are used as the transmit antennas. On the other hand, Fig. 4 shows the 8 X 4 LTE MIMO testing arrangement. In this case, eight ports in the smartphone are used as the receive antennas, and four ports in the base station antennas are for the transmit antennas. Also note that the R&S vector signal generator [7] is connected to the base station antennas for transmit the LTE signals. The R&S digital scope and the in-house software receiver including the MIMO detector are used in the receiver side for the MIMO testing.

Typical testing results (the SNR results at each receive antenna and the channel capacities) of the 4 X 4 and 8 X 4 MIMO operation are listed in Table I and II. The calculated capacities obtained by assuming independently and identically distributed (i.i.d) wave propagation channels with Rayleigh fading environment are shown for comparison. In addition, results with the user’s hand holding the smartphone are also shown for discussion.

It is seen that the measured capacities in general agree with the calculated results for the cases with and without the user’s hand. The results indicate that although the eight MIMO antennas are compact in size and totally has a length of 60 mm only (about 0.7 wavelength at 3.5 GHz), the obtained MIMO capabilities in general agree with the theoretical prediction. This suggests that if the ECC between two antennas can be as low as possible (for example, less than 0.1), the compact size of the MIMO antennas has very small effects on the MIMO performance.

<table>
<thead>
<tr>
<th>TABLE I. 4 X 4 MIMO capacity testing results.</th>
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<tbody>
<tr>
<td>4 X 4 MIMO</td>
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<tr>
<td>SNR1</td>
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<tr>
<td>17.9</td>
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<tr>
<td>Channel Capacity</td>
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<tr>
<td>Mea. = 18.6 bps/Hz, Cal. = 19.1 bps/Hz</td>
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TABLE II. 8 x 4 MIMO capacity testing results.

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<th>Channel Capacity</th>
<th>Channel Capacity</th>
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<tr>
<td>Mts. = 24.6 bps/Hz, Cts. = 25.8 bps/Hz</td>
<td>Mts. = 23.4 bps/Hz, Cts. = 23.5 bps/Hz</td>
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</table>

For the case of 8 x 4 MIMO with user’s hand presence, the measured capacity is 22.4 bps/Hz. In this case, the upper limit of the data transmission for a 200-MHz bandwidth can be about 4.4 Gbps. With the obtained results, it can be expected that the achievable capacity of the 8 x 8 MIMO can be larger than 30 bps/Hz. In this case, the upper limit of the data transmission can be increased to be larger than 6 Gbps with a 200-MHz bandwidth.

V. CONCLUSION

A promising design of compact eight MIMO antennas in the smartphone has been presented. The measured channel capacities for the 4 x 4 and 8 x 4 MIMO operation with and without user’s hand presence have been obtained. The measured capacities in general agree with the calculated results. The obtained results in this study suggest that the Massive MIMO operation with at least eight antennas in the smartphone is promising for 5G mobile communications to achieve the data transmission much higher than 1 Gbps.

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References