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Channel Capacity Performance of Multi-band Dual Antenna in Proximity of a User

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ABSTRACT:

This paper presents an evaluation of single input single output (SISO), single input multiple output (SIMO) and multiple input multiple output (MIMO) channel capacities for a dual antenna prototype in proximity of a user. The dual antenna prototype mimics today's small mobile phone design in size and in comprising internal, compact, multi-band antennas. Four different user cases are evaluated by measuring the antenna radiation performance for each of the different interactions between a phantom user and the antenna. Measurements of a single antenna prototype with user are also performed for comparisons between the SISO case and the SIMO/MIMO cases. Depending on the user interaction case, the MIMO capacity of the prototype is between 40-90% at 850 MHz and 60-80% at 2100 MHz higher than the SISO performance of the single antenna prototype or the best antenna on the dual antenna prototype.

INTRODUCTION

Future generations of the mobile communications are inquiring into the possibilities of smart antenna solutions like diversity and multiple input multiple output (MIMO). Introducing diversity and MIMO in a handheld mobile terminal involves use of multiple antennas in a compact space. Closely spaced antennas in a terminal and their mutual interactions can lead to a severe degradation in MIMO performance. Furthermore, the antennas´ interaction with a user will have an impact on the performance. The benefits of MIMO have been shown and discussed, from theoretical point of view, in [1-3]. Diversity and MIMO in handheld terminals with user present have been mainly discussed with focus on diversity gain [4-6]. Very little work has been done on the channel capacity gain. In [7], the authors show the potential of enhancing the channel capacity by using MIMO in a mobile terminal in proximity of a user. However, their study focuses on the effects of propagation on channel capacity and limits the scope of their work to the simulations of four simple, single-band, external antennas in one user case at 2.1 GHz.

In this paper, MIMO channel capacity has been investigated for a dual antenna prototype with a size of a regular mobile terminal and two internal multi-band antennas covering WCDMA850, WCDMA1800 and UMTS frequency bands. The antennas used in the study are PIFA- and monopole-based, and are designed for a small handset. The evaluation of the capacity in proximity of a user is presented here for two frequencies: 850 MHz and 2.1 GHz. Four different user interaction cases are investigated: free space (no user interference), data mode (hand held position in front of head), talk position without the hand (head only position), and talk position with hand (head and hand position). Radiated antenna performance was measured for the user interaction cases using a state-of-the-art phantom hand and head from IndexSAR [8]. For the purpose of understanding the capacity gain in replacing one antenna in a mobile handset with two antennas, we also introduce a single antenna prototype with one internal multi-band antenna. Comparisons are made between the SISO, SIMO and MIMO capacity performance of a dual antenna prototype and the SISO capacity performance of the single antenna prototype.

THEORY

The propagation channel in this paper is assumed to have uniform 3D angular power spectrum (APS). However, the $M \times N$ channel matrix $\mathbf{H}$ used for capacity calculation, with M receive elements and N transmit elements, is calculated from the uniform 3D APS and the farfield data of each of the receiver antenna ports excited in turn while the other port is terminated in 50 ohm. The eigenvalues of the channel matrix were obtained from singular value decomposition [2] and used to calculate the MIMO capacity, with and without channel knowledge at the transmitter. Shannon capacity when there is no channel knowledge at the transmitter, i.e. the power evenly allocated over the transmitting antennas, is defined as [1]

$$C_{ep} = \sum_{i=1}^{L} \log_2\left(1 + \frac{SNR \cdot \lambda_i}{N}\right), \tag{1}$$

where L is number of SISO orthogonal channels. In this work, $L = N = M = 2$. Assuming there is channel knowledge at the transmitter side, optimum power allocation for maximum capacity performance is achieved with "water filling" [9]

$$C_{wf} = \sum_{i=1}^{N} \log_2(\lambda_i D), \tag{2}$$

and

$$D = \frac{1}{\lambda_i} + P_i, \tag{3}$$

where D is a common level for all of the eigenchannels and $P_i = SNR_1 / \lambda_i$ is input power to the i-th eigenchannel. Using the appropriate 1×1 and 2×1 channel matrices, SISO and SIMO capacities (SIMO) were also calculated [3]

$$C_{SISO,SIMO} = \log_2\left(1 + SNR \cdot \sum_{i=1}^{M} |h_i|\right) \tag{4}$$

where $M = 1$ for SISO and $M > 1$ for SIMO.

ANTENNA PROTOTYPES AND MEASUREMENTS

Capacity evaluation was performed for two prototypes, *dual antenna prototype* and *single antenna prototype* (see Fig. 1). The two prototypes have the same ground plane size of 100×40×2 mm^3 and a monopole based, multi-band antenna placed at the bottom. The dual antenna prototype has an additional antenna at the top, a multi-band PIFA. The monopole based antenna in the single antenna prototype is slightly retuned to have similar performance as the monopole based antenna in the dual antenna configuration. Both of the antenna types used in this evaluation are compact antennas that cover receive bands of WCDMA850, WCDMA1800 and UMTS. The antennas' and the prototype's design, size and placement were chosen to resemble practical and implementable antenna solutions in a mobile phone. Design details on the antennas and the dual antenna prototype can be found in [10].

SISO, SIMO and MIMO capacity analyses were performed in a Matlab environment where a uniform 3D APS channel was created and combined with radiation performance of the antennas on the prototypes in the proximity of an IndexSar [8] phantom head and hand. The antenna radiation performance was measured in Satimo Stargate 64 [11] for each of the two prototypes with four different user interaction scenarios: free space (no user interference), hand held position (data mode), head only position (talk position without the hand), and head and hand position (talk position with a hand present). Radiation patterns for three frequencies per the three operating bands, were measured. The results for the WCDMA1800 band are similar to the (nearby) UMTS band, and thus omitted in our discussions. For comparison, antenna patterns have also been simulated. They give similar results.

Fig. 2 and Tab. I are showing the measured radiation performance of the prototypes, and the measured correlation performance of the dual antenna prototype, respectively.

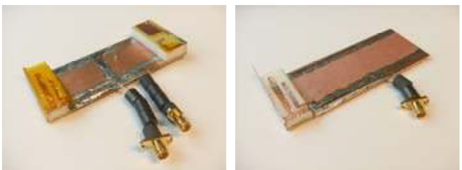

Fig. 1. Dual antenna prototype (left) and single antenna prototype (right)

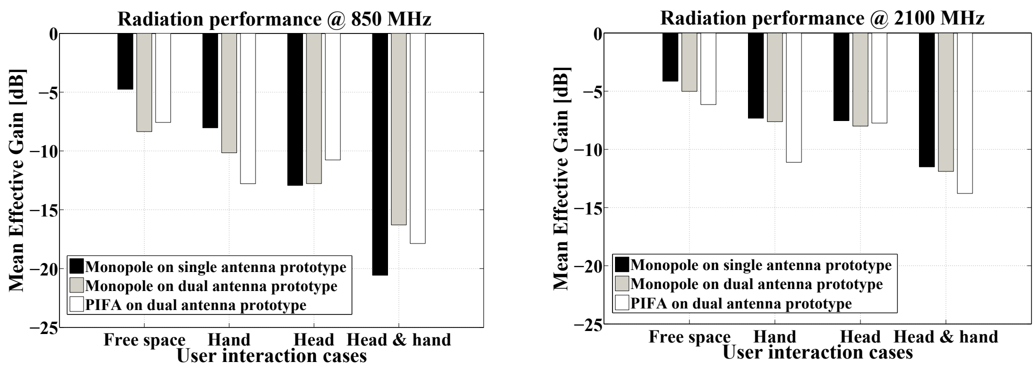

Fig. 2. Measured radiation performance of the antennas in the single and the dual antenna prototype for different user interaction cases and uniform 3D APS.

Table I. Average measured envelope correlation for two frequency bands and different user interaction cases in uniform 3D APS

	Average envelope correlation			
Frequency band [MHz]	**FREE SPACE**	**HAND**	**HEAD**	**HEAD & HAND**
850	**0.51**	**0.33**	**0.012**	**0.39**
2100	**0.006**	**0.007**	**0.004**	**0.05**

RESULTS AND DISCUSSIONS

Figs. 3 and 4 feature the SISO, SIMO and MIMO capacity results for the 850 MHz and 2100 MHz frequency bands, respectively, for each of the four user cases. In general, the capacity performance is higher at the higher band because the antennas in both single and dual antenna prototypes are performing better and interacting less with each other and with the user than at 850 MHz (see Fig. 2). For the evaluated frequency bands, and for all the user interactions, the capacity gain using MIMO with or without knowledge of the channel at the transmitter, gives between 40-90% higher capacity performance than the SISO case, with single antenna prototype or the best antenna on the dual antenna prototype. In all cases, the MIMO capacity is also much higher than the SIMO capacity. Using the best antenna on the prototype is a common reference when showing the (receive) diversity gain of SIMO systems [5-6]. However in this work, we also employ a single antenna prototype as a further reference case. This is because comparing the SIMO/MIMO capacity performance gain with the best antenna in a dual antenna system does not quantify the actual benefits of replacing a one antenna prototype with a two antenna prototype. As the results show (see Figs. 3 and 4), depending on the interaction between the antennas the estimated gain may be either too optimistic or pessimistic when using (the best antenna on) the dual antenna prototype as a reference. We also plot, as a reference, the 2×2 MIMO capacity for the case of i.i.d. Rayleigh and uniform power distribution at the reference SNR of 20 dB in Fig. 3 and 4.

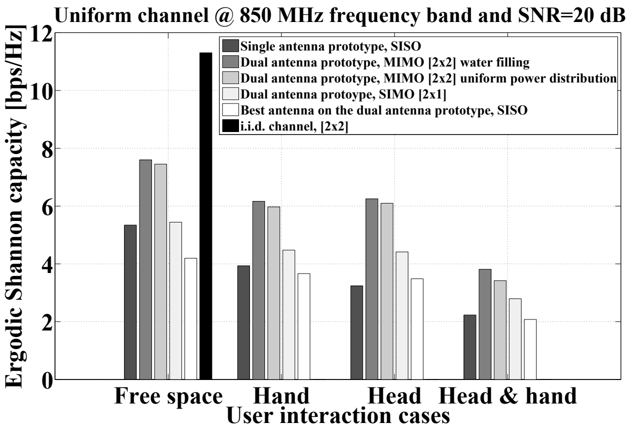

Fig. 3. Capacity results for uniform channel at 850 MHz

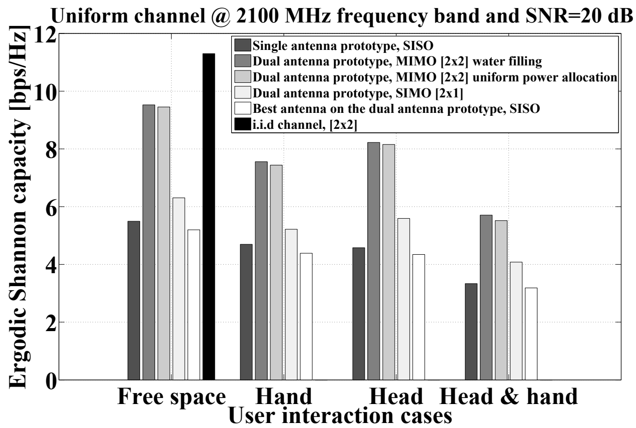

Fig. 4. Capacity results for uniform channel at 2100 MHz

At 850 MHz, a drop of 20 % in capacity for the MIMO case is caused by the user hand in data mode. The same effect on capacity is demonstrated by the head in the talk position without the hand. In both cases, there is a similar gain difference in the antenna performance but one of the cases, the data mode, has higher correlation coefficient. However, even though the correlation for the data mode is higher, it is not high enough (> 0.7 [12]) to cause any significant effects on the capacity. Thus, both cases have similar capacity performance.

An almost 50% capacity drop is seen for the MIMO cases at 850MHz when the prototype is in the talk position with hand present. As mentioned earlier, the drop is only around 20% for the other two user cases. The channel eigenvalues, Fig. 5, for the different user interaction cases reveal more details on this behavior. In Fig. 5 we also plot eigenvalues for 2×2 MIMO case of i.i.d. Rayleigh. In the data mode and the talk position without the hand, the larger eigenvalue degrades more than the other eigenvalue, which can be explained by the drop in the correlation value relative to the free space case (see Tab. 1). In the talk position with the hand, both of the SISO channels are degraded significantly and more evenly, which implies the dominating influence of body shadowing over the change in correlation. Note that despite the 50% capacity degradation relative to the free space case, the capacity of the talk position with the hand case is 71% higher than the capacity achieved with a single antenna prototype. This is the second highest increase. The highest is seen in the head only position, 90%, and the lowest MIMO capacity increase is seen in the free space case, 42 %.

At 2100 MHz band for the two cases of the data mode and the talk position without the hand, the SISO channels are affected similarly and evenly for both of the channels (see Fig. 6). The higher band has better channel responses for the

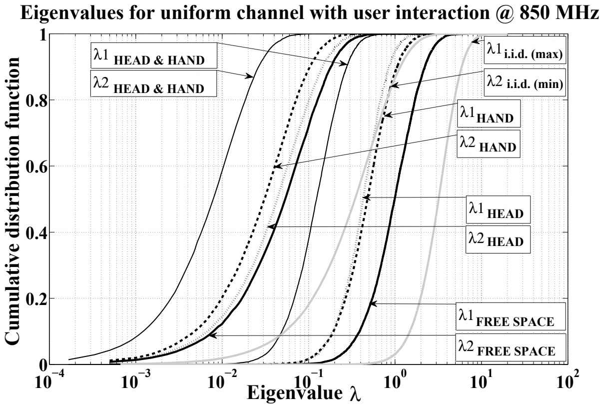

Fig. 5. Channel eigenvalues for different user cases at 850 MHz

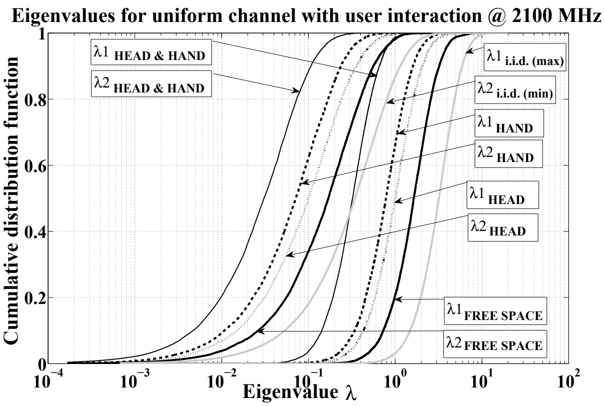

Fig. 6. Channel eigenvalues for different user cases at 2100 MHz

two SISO channels and user cases as compared to the lower band. Therefore, the user influence is less significant at the higher band. This phenomenon is explained as follows: At low frequencies such as 850 MHz, the chassis is part of the radiating antenna structure and its interaction with the user will affect the channel much more than the case at higher frequencies, where the radiation occurs mostly at the antenna elements on the prototype. The capacity increase from the SISO to MIMO cases is generally higher over all the different use interaction cases, 60-80%, and the greatest improvement is seen in the case of talk position without the hand, 80%, and the least in the data mode case, 61 %. In all cases, as in the lower band, the MIMO capacity is also significantly higher than the SIMO capacity.

CONCLUSIONS

In this paper, we show that replacing one antenna in a mobile terminal prototype with two antennas will increase the channel capacity for four different user interaction cases. This increase is noticeable for the SIMO case (receive diversity). However, the more significant increase is obtained by implementing MIMO. The study was performed for measured antenna radiation data of real prototypes in different user interaction cases, and in a channel with uniform 3D APS. Depending on the user interaction case, the MIMO capacity of a small dual antenna prototype with practical internal antennas increases between 40-90% at 850 MHz and 60-80% at 2100 MHz from the SISO performance of a single antenna prototype or the best antenna on the dual antenna prototype. The capacity performance in this study is dependent on the correlation and gain imbalance that change for different interactions and operating frequency bands. At lower frequencies, the capacity is general lower in proximity of the user, because the whole chassis is radiating and more energy absorbed by the user.

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