Analysis of the electromagnetic degrees of freedom in multi-antennas communications systems

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Abstract

The channel capacity enhancement is of great interest in broadband wireless communications. The spatial dimension is being investigated with the use of multi-antennas systems. The role of the antennas, their numbers and their positions are to be understood through an electromagnetic analysis. The degrees of freedom of an electromagnetic system are related to the capacity of a transmission channel. In this paper, we investigate all these notions through different case studies using full-wave electromagnetic simulations. The capacity of a multi-antennas system is thus being analyzed on a physical ground.

1. Introduction

In wireless communications, one way to gain further capacity or throughput is to use the spatial dimension of the channel through multi-antennas systems. Multiple Input Multiple Output (MIMO) is an area of active research since the first development by Forshini [1]. Instead of suffering from the impairments of the propagation channel, i.e. fading, multipath due to a complex environment, MIMO can on the contrary take advantage of the multiple scattering environments to increase the performance of the system. It is then interesting to analyze it from an electromagnetic perspective to gain insight from the physics and to determine the limits of the channel capacity. Some authors have investigated these questions [2-3]. Loyka [3] has interestingly analyzed the capacity jointly by information theory and the laws of electromagnetics. Specifically, the modal expansion technique is used in overmoded waveguides or cavities to find the modes or the degrees of freedom of the channel over which the information is conveyed independently. However the antennas are ideally considered such that the calculations remain analytical. In this paper, we propose to use FDTD (Finite Difference Time Domain). It allows to model more realistically the antennas, their mutual coupling and the excitations of the modes inside the waveguide.

2. Case Study 1: waveguide

As in (Loyka, 2005), we consider an over-moded waveguide which could be a model for a tunnel. However we use here non-ideal antennas which is closer to actual configurations. The FDTD is used to compute the electromagnetic solution. The case study is sketched in Figure 1. The width of 3 wavelengths makes that five propagating modes exist in this waveguide. The 14 antennas are considered as ports and the S-parameters for these ports are computed. Then the transmission channel is SVD decomposed and the singular values and eigenvectors are obtained. Five significant singular values are obtained and the eigenvectors can be plotted. Due to superposition of solutions, there is no need to recompute the field solution. For example in Figure 2, we can recognize the propagation of the dominant mode but it corresponds to the fifth ordered singular value meaning a better transmission is achieved through other modes. The first rank mode in the SVD decomposition is displayed in Figure 3. It corresponds to the third mode in a hollow waveguide. In fact, the SVD modes ordering corresponds to the hollow waveguides in reverse order. The placement of the antennas and the distance between the two sets of antennas can explain this re-ordering of the expected modes. By increasing the distance between the antennas, as expected the number of modes remains the same.

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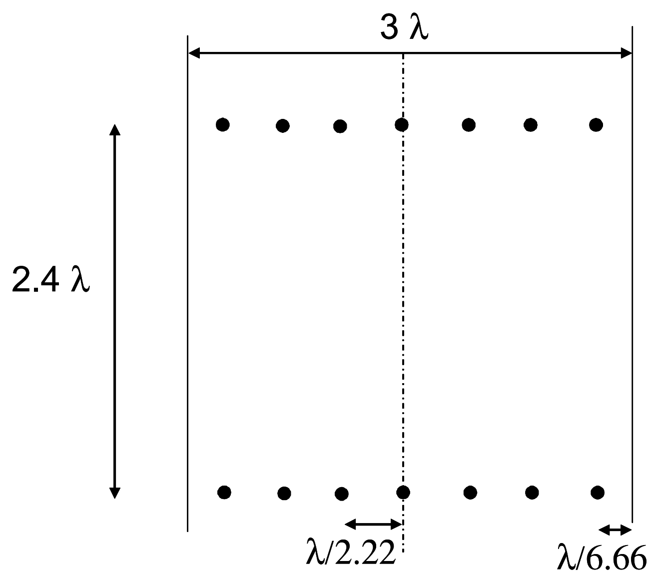

Figure 1: A 2D waveguide with 7 input antennas (below) and 7 output antennas (above)

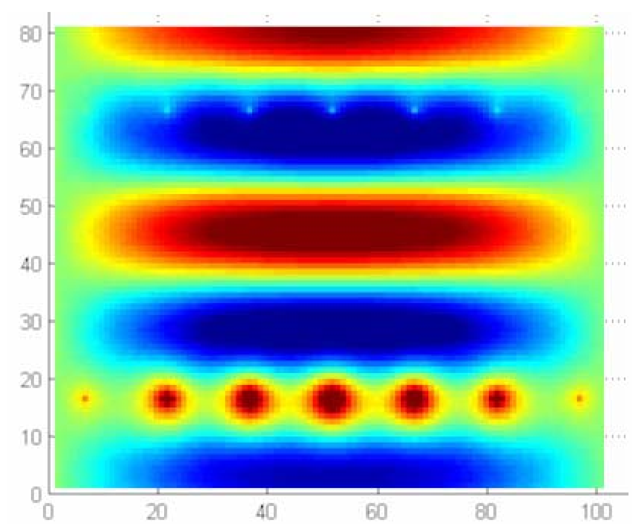

Figure 2: the eigenvector corresponding to the fifth most important singular value for the waveguide

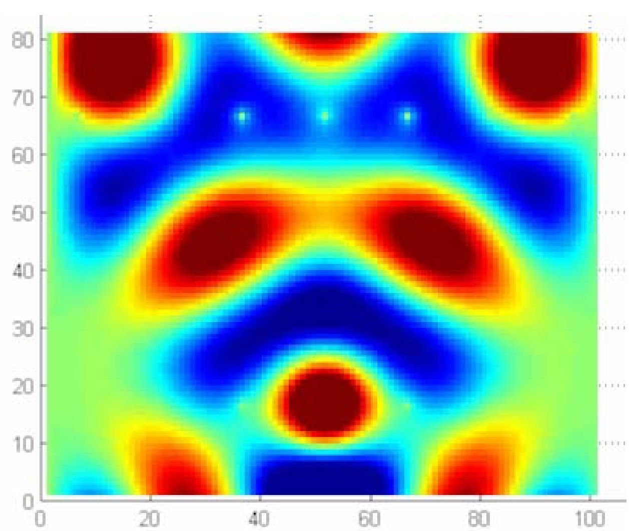

Figure 3: the eigenvector corresponding to the first singular value in the waveguide

3. Case Study 2: free space, close antennas separation

Another important point is that the distance between the two arrays is rather close. To emphasize this point, the metallic walls are removed, thus giving two close antenna arrays in free space. This time, the number of significant singular values is 4, meaning that with this antenna configuration, 4 independent channels could be used. Figure 4 shows the eigenvector corresponding to the third singular value which looks like the first mode of a hollow waveguide. The igenvector corresponding to the first singular value looks like a single dipole propagation (Fig. 5).

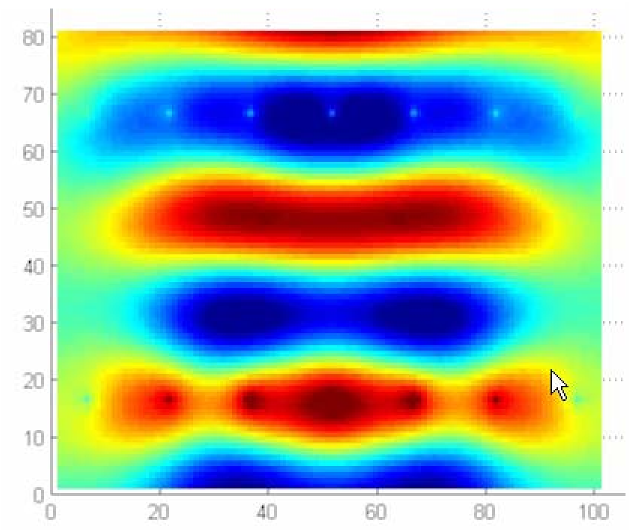

Figure 4: the eigenvector corresponding to the third most important singular value for the free space case

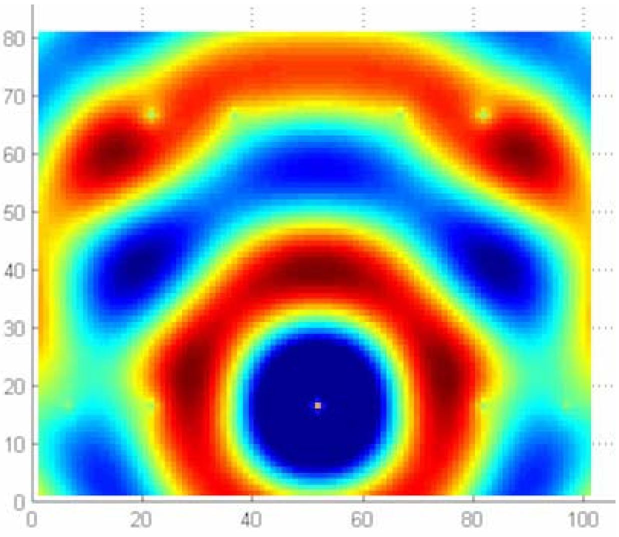

Figure 5: the eigenvector corresponding to the first singular value in free space case

4. Case Study 3: free space, large antennas separation

To go further, the case when the 2 arrays in free space are far is simulated, and as expected only 1 mode is propagating. The eigenvector shows a beamforming mode maximizing the energy transfer (Fig.6).

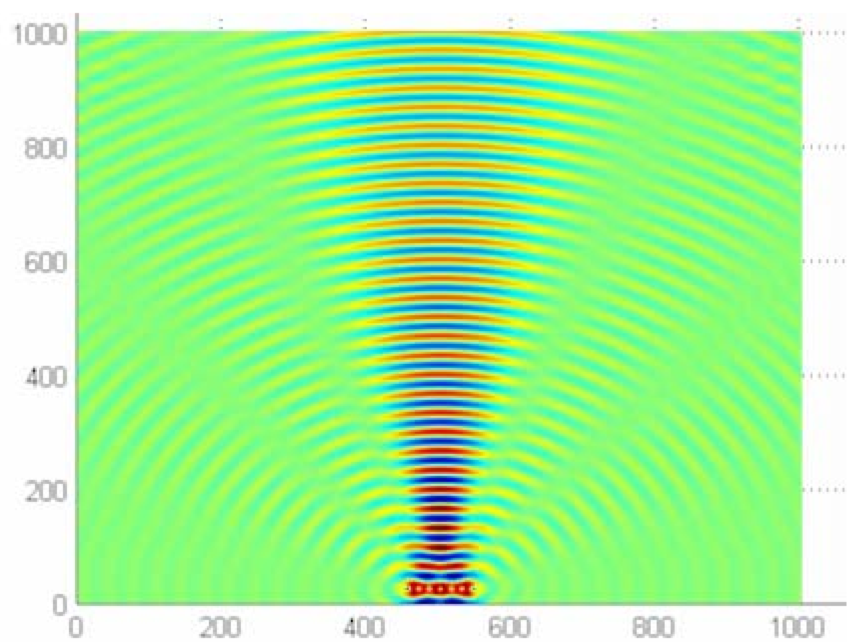

Figure 6: the eigenvector corresponding to the first singular value in free space case

5. Conclusion

These case studies are very insightful to relate the MIMO system view to the electromagnetics in complex media. The authors believe that it is helpful to explore the physics based limits of MIMO systems.

6. References

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