Effect of Antenna Configuration in Multiple Input Multiple Output (MIMO) Communication System and the Relevance of Electromagnetics in Communication System Design.

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Abstract

In this paper, the relevance of electromagnetics has been emphasized for communication system design. Two different antenna configurations have been studied and their effect on the number of modes possible for communication has been carried out by numerical examples. In most cases the mode in a MIMO system that is really effective is the dominant phased array mode as simultaneously the various orthogonal modes from the antennas cannot be combined effectively. The various electromagnetic effects and the mutual coupling between the antennas are taken into account in evaluating the system performance. The total power input in all the simulations is kept constant rather than the radiated power.

1. Introduction

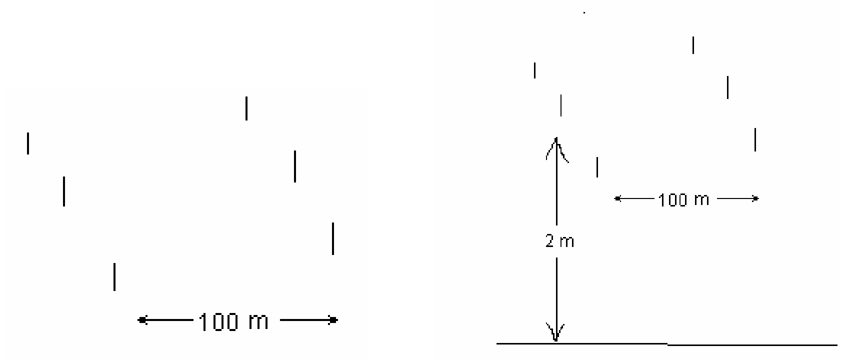
Multiple-Input-Multiple-Output (MIMO) wireless communication has become an active research area for sometimes after Foschini [1] developed the Bell Laboratories layered space-time system (BLAST). Since then the potential of using multiple antennas to improve the performance of communication systems, especially the capacity, has become more promising. The MIMO systems offer another domain, i.e. spatial domain, in a system design consideration.

Research areas in MIMO antenna systems range from information theory, communication system, signal processing to antenna design. While signal processing and coding are key elements in the development of a MIMO antenna system, antennas and propagations also have a great impact to MIMO system performance. Recently, many researchers have investigated MIMO systems from an electromagnetic perspective [2-4]. It will be shown in this paper that the electromagnetic effect can deteriorate the performance of MIMO systems. Without considering the electromagnetic effects in the system design, one might not reach the best performance or the performance may even get worse over than a SISO system.

The objective of MIMO is to provide spatial diversity through the use of multiple transmit and receive antennas. So, if there are N transmitting antennas and N receiving antennas, then one can generate N spatially orthogonal modes to communicate between these transmit-receive systems. The goal in MIMO then is to simultaneously communicate with these N spatial modes using N transmit and N receive antennas. We consider several different cases of antenna arrays oriented along the broadside directions and antenna arrays oriented along the end fire directions. In addition we consider the radiation efficiency of these various spatial modes for a constant input power.

2. Parallel Antenna elements oriented along the broad-side direction

In this study we consider several different cases, where we have 0.5λ long dipole antenna elements with a radius of 1mm all oriented vertically. We consider a 1×1 MIMO system, which is a SISO, to a 5×5 MIMO system, where there are 5 transmit and 5 receive antennas. In an array, both the transmit and the receive antennas are located half a wavelength apart as shown in Figure 1a. The transmit and the receive antenna arrays are horizontally separated by 100m and it is operating at 1GHz. We consider several scenarios of the transmit and the receive antenna arrays, where the entire array may be located in free space or situated at different heights of the transmitting array whereas the received array is situated 2m above a perfect ground plane as seen in Fig. 1b. We use an electromagnetic analysis code [5], excite one antenna at a time and compute the channel matrix using a voltage excitation to each of the antennas of this MIMO array. Furthermore, each antenna element both in the transmit and receive array are conjugately matched with a complex value of the load impedance so that they can efficiently radiate and receive the various electromagnetic signals. For a N×N MIMO system we compute the voltage channel matrix $[H_v]_{N\times N}$ which will be a N×N square matrix. In this case, N can take any value between 1 and 5. We perform a singular value decomposition of the matrix $[H_v]$ to observe how effectively each spatial mode will radiate with respect to the SISO case. This is accomplished by squaring the ratio of the singular values for the voltage channel matrix scaled by the singular value of the 1×1 MIMO system. For these conjugately matched antennas, the square of the voltage singular values will represent how efficiently each spatial mode of a MIMO system is radiating with respect to the SISO case for the same input power.



Case a: Located in free space Case b: Located over a ground plane

Figure 1. A typical 3×3 MIMO system consisting of half wave dipoles and half wavelength spaced.

Table 1 provides the square of the ratio of the various singular values with respect to the SISO case. So if we consider the radiation efficiency for the SISO case to be unity, a value greater than one will indicate that the radiation efficiency of that particular spatial MIMO mode is better than the SISO case. In that case, the use of this spatial MIMO mode has a definite advantage over the use of a SISO. For this example, there is a direct line of sight connection between the transmitter and the receiver.

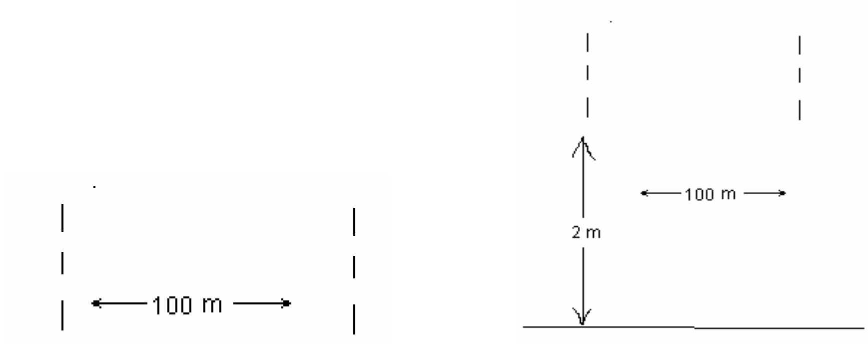
Table 1. Ratio of the square of the singular values for the various spatial MIMO modes with respect to the SISO.

SISO 1×1	MIMO 2×2	MIMO 3×3	MIMO 4×4	MIMO 5×5
1.0	5.21	11.95	22.18	34.85
	3.73×10^{-6}	9.67×10^{-5}	6.26×10^{-4}	2.75×10^{-3}
		2.85×10^{-11}	1.88×10^{-9}	2.40×10^{-8}
			4.28×10^{-16}	5.42×10^{-14}
				9.15×10^{-21}

Table 1 presents the results when the transmit and the receive antenna array is operating in free space. We also consider cases, where these antenna arrays are placed over a ground plane with the receive antenna array located at 2m above a perfect ground plane whereas the height of the transmit antenna is varied from 2m and 20m above the ground plane. It is important to note that these ratios of the singular values do not change up to the second place of decimal for different widely varying scenarios for the deployment of the arrays, when the ratio of the square of the singular values is less than $\leq 10^{-15}$, even though the individual values may change greatly for the different MIMO systems. There is in fact only one spatial mode that is really useful and provides a real gain over the SISO case. This is the classical broadside, phased array mode when all the antennas are excited in phase. Beside this dominate mode, the other spatial modes are essentially useless for real applications as they are at least 10^{-6} lower than the dominant mode.

3. Collinear Antenna elements along Vertical Direction

In this study we consider the antenna elements for each of the transmit and receive antenna array system to be located as a collinear array as shown in Figure 2a,when they are located in free space and in Figure 2b when they are located over a perfectly conducting ground plane. In this form of the deployment all the antenna elements are vertically oriented and located one on top of the other. This end fire configuration may be perhaps useful as it has smaller mutual coupling between the elements in the array.



Case a: Located in free space　　　　Case b: Located over a ground plane

Figure 2. A typical 3×3 collinear array MIMO system consisting of half wave dipoles, half wavelength spaced and separated by 100m.

The antenna elements are of the same length and radius as in the previous case. However, in this situation their center to center separation along the vertical direction is 1λ. They are again conjugately matched with their respective loads so that they radiate in the most efficient manner. Table 2 provides the square of the singular values of the transfer voltage matrix normalized with respect to the SISO case. The transmit and the receive array are separated by 100m.

Table 2 provides the results when the transmit and the receive array are operating in free space with a line of sight link existing between them. As before there is one dominant mode, and the second spatial mode is at least down by 10^{-2} over that of a SISO. This mode may perhaps work for N = 4 and 5. However, this endfire array system is more sensitive to the deployment of these antennas over a perfectly conducting ground plane representing moist earth, than when they are deployed in free space. For example, when both the transmitter and the receiver are located 2m above a perfectly conducting ground plane as shown in Fig 2b, the respective ratios of the singular values are now given by Table 3.

Table 2. Ratio of the square of the singular values for various spatial MIMO modes with respect to the SISO case

SISO 1×1	MIMO 2×2	MIMO 3×3	MIMO 4×4	MIMO 5×5
1.0	4.46	10.58	19.45	31.05
	7.96×10^{-5}	1.38×10^{-3}	9.13×10^{-3}	3.79×10^{-2}
		1.22×10^{-8}	4.68×10^{-7}	6.00×10^{-6}
			3.47×10^{-12}	2.33×10^{-10}
				1.60×10^{-5}

Table 3. Ratio of the square of the singular values for the various spatial MIMO modes for endfire arrays with respect to the SISO case (collinear array over a ground plane)

SISO 1×1	MIMO 2×2	MIMO 3×3	MIMO 4×4	MIMO 5×5
1.0	3.22	5.02	5.66	5.68
	$1.12 \times 15^{--3}$	3.18×10^{-2}	3.44×10^{-1}	2.16
		7.53×10^{-8}	4.74×10^{-6}	9.53×10^{-5}
			8.66×10^{-12}	1.21×10^{-9}
				1.23×10^{-15}

In this case for the 5×5 case presence of the ground plane may make 2 spatial modes of transmission viable, but the gain of each of the spatial modes over that of the SISO case is quite small. Hence, one need to see whether it is cost effective to deploy a 5×5 MIMO system over two SISO systems in this case. In addition the other spatial modes are not that useful as they are at least down by several orders of magnitude over that of the SISO case. However, a collinear array has a better promise than a broadside oriented array.

4. Conclusion

In this paper, the MIMO technology is discussed from an electromagnetic perspective. Using multiple antennas at the transmitter and/or at the receiver, the performance of a wireless communication system can sometimes be improved. However, from a system point of view, whether the system will actually work in practice or not cannot solely be determined from a numerical value obtained from a statistical analysis. For proper operation of the system, one needs to know the actual power exchanged between the transmitter and the receiver.

Multiple antennas allow us to transmit signals spatially through a number of independent paths caused by multipath fading. The transmission rate, or multiplexing gain, can also be increased by using multiple antennas depending on whether the knowledge of channels is available or not. With the knowledge of the channels, the MIMO systems provide a number of independent paths for the transmission. Diversity and multiplexing gain tradeoff is discussed as a criterion for consideration in a MIMO system design. The electromagnetic effects to the MIMO channels are also illustrated through numerical simulations. It becomes obvious that without taking into account the electromagnetic effects the expected MIMO system performance may not be realized to its full potential [6-7].

7. References

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