International Journal of Scientific and Technical Advancements

ISSN: 2454-1532

MIMO Technology- An Overview of Mutual Coupling Effects on the Channel Capacity and Techniques for its Reduction

Asma Iqbal Wani [1*], Aaqib Iqbal Wani[2$], Raof Ahmad Khan[3#]

[1]Deptt. of Electrical and Electronics Engg, Govt. College of Engg and Technology, Safapora, Kashmir, J&K, India-193504

[2]Deptt. of Computer Science Engineering, Shri Mata Vaishno Devi University, Jammu, J&K, India-182320

[3]Deptt. of Mechanical Engineering, Government College of Engineering and Technology, Safapora, Kashmir, J&K, India-193504

[#]asmaiqbalwani@gmail.com, 15mms008@smvdu.ac.in, roofkhanmech@gmail.com

***Abstract*—** Antennas which provide an increased reliability and efficiency, at the same time being smaller and compact in size form the backbone of modern day wireless technology. MIMO (Multiple Input Multiple Output systems) is one such configuration which uses the space diversity to achieve this goal. Planar antennas which are light, compact and can be attached to a surface are thus becoming popular. As such MIMO planar antennas can be used to meet these challenges quite effectively. In this paper an insight is provided into the various advantages of MIMO antennas, the effect of mutual coupling on the reliability of MIMO design and the ways to tackle the problem**.**

***Keywords*—** Correlation ; isolation ; MIMO ; mutual couplig.

I. INTRODUCTION

The performance requirements for wireless systems are ever increasing. Higher data rates, good link gain, small size and a higher bandwidth , increased channel capacity, reduced transmitting power, better reliability, improved network throughput, improved coverage without requiring additional bandwidth being a few. An approach for achieving these targets is the introduction of MIMO (Multiple Input Multiple Output systems) in modern day wireless systems and involves the sending of several signals at the same time through a single channel, at the same time increasing the signal quality and strength.

Many paths are taken by the signal to travel from the transmitter to the receiver in MIMO technology. In conventional antenna technology these different paths cause interference and cause multipath fading. However in MIMO design these additional paths are manipulated by the user and are used to increase the spatial diversity, add robustness to the communication channel by improving the SNR and for increasing the data capacity.

II. INCREASED CAPACITY USING MIMO ANTENNAS

Shannon's theorem defines the maximum capacity of a given bandwidth in the presence of noise. The capacity is given as

$$\text{Capacity} = BW \log_2 (1 + SNR) \tag{1}$$

where C is the channel capacity in bits per second, BW is the bandwidth in Hertz, SNR is Signal to Noise Ratio. Capacity can be increased by increasing the SNR or the bandwidth. However the increase in SNR is limited and difficult to achieve because of the nature of the communication channel to hold some noise [1].

Another way to achieve the increased capacity is by increasing the signal bandwidth. However, increasing the signal bandwidth of a communications channel by increasing the symbol rate of carrier increases its susceptibility to multipath fading, while needing a higher transmission power at the same time. Also the tradeoff of the channel bandwidth with the SNR as is clear from the Shannon's formula. Thus, this method of increasing the capacity is limited in its approach.

Other solution that comes to mind is to use a series of narrowband overlapping subcarriers for increased spectral efficiency, but the lower symbol rates reduce the effectiveness of multipath signal products.

MIMO provides an interesting solution by using the spatial dimension of a communications link. The maximum channel capacity of a MIMO system, the channel capacity is now a function of N spatial streams and is given as:-

$$\text{Capacity} = N \{BW \log_2 (1 + SNR)\} \tag{2}$$

Here it is clear that as the number of streams increases the capacity of the channel increases. However it is assumed that the multiple streams are independent of each other i.e. they have not correlation with each other [2]**.**

III. MUTUAL COUPLING IN MIMO DESIGN

In order to realize the MIMO communication link, the use of multiple, small sized, compact antennas supporting multiband operation in the equipment is needed. This results in the interference of signals from the different antennas which is parameterized by the phenomenon called as Mutual coupling, correlation coefficient and Isolation

A. Co- relation coefficient: - The correlation Coefficient is a describes how much the communication channels of different antenna elements are related, isolated or correlated with each other. This also considers the radiation pattern of antenna system, and tells us to what extent the voltage and current pattern from one antenna affects pattern from another when operated in MIMO configuration [3].

Asma Iqbal Wani, Aaqib Iqbal Wani, and Raof Ahmad Khan, "MIMO Technology- An Overview of Mutual Coupling Effects on the Channel Capacity and Techniques for its Reduction," *International Journal of Scientific and Technical Advancements*, Volume 5, Issue 1, pp. 01-04, 2019.

B. Mutual Coupling: - when an antenna converts the electromagnetic field into induced voltage or current, the measured values at each antenna element depends on the incident field as well as the voltages of the other neighboring elements. Thus the received voltage on each element induces a current , which in turn radiates a field that affects the surrounding element, i.e. the elements are said to be mutually coupled [4]

C. Isolation: - sometimes it's a common practice to use the words coupling and isolation in place of each other. Low coupling yields high isolation. Lower coupling (high isolation) also means lower correlation, but it does not necessarily mean a low correlation coefficient, and vice versa.

High isolation and low correlation coefficients are required for a MIMO antenna system to provide good diversity performance.

IV. EFFECT OF MUTUAL COUPLING ON THE CAPACITY

MIMO advantages can be realized to their fullest only in presence of a rich scattering environment, and accurate channel state information (CSI) at the receiver [5]. This ensures the formation of statistically independent virtual channels, which then transfers the data in parallel.

Also reduced spatial correlation between the virtual channels leads to the increased MIMO capacity. Thus the available accurate CSI is required to decode the received signal and to reach the MIMO capacity [6]. On the other hand if an inaccurate CSI is present it will lead to an increased bit error rate (BER) that degrades the overall capacity of the system [7].

The reduced antenna spacing so as to incorporate more and more antennas and to make maximum utilization of available space introduces spatial correlation. Thus finite spacing results in mutual coupling which affects signal transmission and reception due to impedance mismatch and has to be taken into account while measuring the MIMO performance. The problem of mutual coupling in MIMO systems for the case of peer-to-peer communication has been addressed via simulations and measurements in [8].

Some researchers are of the view that the mutual coupling may improve the channel capacity when the spacing of antenna elements in transmit and receive array antennas is between 0.2 to 0.4λ (carrier wavelength). The reason is that in this case the mutual coupling decreases the spatial correlation and increases the channel effective degree of freedom (EDOF).

However, these results obtained on the assumption that the accurate channel state information (CSI) was available at the receiver end. Practically, perfect CSI is not achievable due to estimation errors. To function properly, the MIMO system has to estimate properties of the channel before decoding the received data. This can be achieved by making use of proper channel estimation methods such as the training-based channel estimation methods. In [9], training-based methods have been investigated and compared. It is clear that these channel estimation methods are a function of the transmitted signal to noise ratio (SNR) in the training mode, and the number of antennas present at the transmitter and receiver. In [10], it has been shown that the performance of these methods can be increased when the channels exhibit a higher spatial correlation level. According to [11], when the antenna element spacing is within 0.2 and 0.4λ, the mutual coupling can decrease the spatial correlation level. Therefore in such cases, the accuracy of these channel estimation methods is not perfectly calculated. Sharawi [12] states that closely positioned antennas tend to have a high coupling between them through the system level ground plane as well as the radiated fields. . This becomes more and more increased with additional antennas aimed at increasing the capacity.

It has been seen that the mutual coupling tends to be more prominent on the receiver side as compared to the transmitter one as the spacing is large enough and multiple antennas can be placed at half or quarter wavelength apart so as to reduce the coupling This results in a degraded efficiency as well as the channel capacity that can be achieved. Thus it can be said that the mutual coupling in MIMO degrades the channel capacity

V. REDUCTION OF MUTUAL COUPLING IN MIMO DESIGN

Chi-Chun et. al [13] state that the mutual coupling is due to the finite spacing of the antenna elements. The mechanism of constructive and destructive interference is achieved via the phase difference between the waves transmitted by the individual radiators, and this phase difference is dependent on inter-element spacing. The gain is proportional to the antenna elements, but with the increment of the antenna elements the coupling between the elements increases; this introduces high coupling coefficient and lower data rates which reduces the capacity of the channel. They have proposed the use of metamaterial isolator arrays in between two antenna elements to reduce the coupling effect. The metamaterials with negative permittivity and negative permeability have geometrical sizes less than the operating wavelengths making them feasible for the small MIMO antenna design having space constraints

Zhang [14] suggested phase cancellation as a way to reduce these effects is by placing the antennas far apart within the mobile terminal, i.e. the two top corners, or one at the top and another at the bottom edges. The orientation of the antennas affects the phase of the coupling currents as well as the polarization of the radiated fields. Adjacent antennas can be oriented in quadrature with each other (i.e. 90 degrees) to minimize the ground coupling as well as field coupling

Chen et.al [15] state that the use of multi-element antennas, such as multiple-input multiple-output (MIMO)

Asma Iqbal Wani, Aaqib Iqbal Wani, and Raof Ahmad Khan, "MIMO Technology- An Overview of Mutual Coupling Effects on the Channel Capacity and Techniques for its Reduction," *International Journal of Scientific and Technical Advancements*, Volume 5, Issue 1, pp. 01-04, 2019.

ISSN: 2454-1532

antenna systems, is one of the most effective ways for improving reliability and increasing the channel capacity. However, it is very difficult to integrate multiple antennas closely in a small and compact mobile handset while maintaining good isolation between antenna elements since the antennas couple strongly to each other and to the ground plane by sharing the surface currents on them. The mutual coupling between adjacent antenna elements can be reduced using decoupling networks. Such networks will decouple the input ports of adjacent antennas thus increasing their radiation efficiency and lowering their radiation correlation

Mak et. al [16] used parasitic elements between the antennas to cancel part (or most) of the coupled fields between them. The parasitic element will create an opposite coupling field that reduces the original one, thus reducing the overall coupling on the victim antenna. The idea of using parasitic elements is to reduce mutual coupling by creating opposite fields to the original ones created by the excited antenna.

Chung et al [17] state that the system ground plane directly affects the behavior of printed antenna elements as it serves as the path of the return current and sometimes becomes part of the radiating structure. Since all antennas with a printed MIMO antenna system share the same system ground plane, the current induced on the ground plane can easily couple to adjacent antenna elements causing high coupling levels that degrade the MIMO antenna system isolation and correlation performance. The mutual coupling between adjacent MIMO antenna elements can be reduced by introducing defects within the ground plane. The defects will act as band reject filters and will suppress the coupled fields between adjacent parts when properly designed. This mechanism of reducing mutual coupling is denoted as defected ground structures.

VI. Conclusion

In the light of above it can be concluded that MIMO provides a reliable solution for the present day demands of wireless technology. However the reduction of mutual coupling is important for its proper design and a number of ways are present in the literature which can help in achieving the same.

References

[1] Jamil, A., M.Z. Yusoff, and N. Yahya. Current issues and challenges of MIMO antenna designs. in Intelligent and Advanced Systems (ICIAS), 2010 International Conference on. 2010. IEEE.

[2] Sharawi, M.S., Printed MIMO antenna engineering. 2014: Artech House.

[3] Blanch, S., J. Romeu, and I. Corbella, Exact representation of antenna system diversity performance from input parameter description. Electronics letters, 2003. 39(9): p. 705-707.

[4] Svantesson, T. and A. Ranheim. Mutual coupling effects on the capacity of multielement antenna systems. in Acoustics, Speech, and Signal Processing, 2001. Proceedings.(ICASSP'01). 2001 IEEE International Conference on. 2001. IEEE.

[5] Budianu, C. and L. Tong, Channel estimation for space-time orthogonal block codes. IEEE Transactions on Signal Processing, 2002. 50(10): p. 2515-2528.

[6] Grant, A., Joint decoding and channel estimation for linear MIMO channels. Vol. 3. 2000: IEEE.

[7] Ahn, K.S., R.W. Heath, and H.K. Baik, Shannon capacity and symbol error rate of space-time block codes in MIMO Rayleigh channels with channel estimation error. IEEE Transactions on Wireless Communications, 2008. 7(1).

[8] Wallace, J.W. and M.A. Jensen. The capacity of MIMO wireless systems with mutual coupling. in IEEE Vehicular Technology Conference. 2002. IEEE; 1999.

[9] Biguesh, M. and A.B. Gershman. MIMO channel estimation: optimal training and tradeoffs between estimation techniques. in Communications, 2004 IEEE International Conference on. 2004. IEEE.

[10] Liu, X. and M.E. Bialkowski, Effect of antenna mutual coupling on MIMO channel estimation and capacity. International Journal of Antennas and Propagation, 2010. 2010.

[11] Fletcher, P., M. Dean, and A. Nix, Mutual coupling in multi-element array antennas and its influence on MIMO channel capacity. Electronics Letters, 2003. 39(4): p. 342-344.

[12] Sharawi, M.S. Printed MIMO antenna systems: performance metrics, implementations and challenges. in Forum for Electromagnetic Research Methods and Application Technologies (FERMAT). 2014.

[13] Chiu, C.-Y., et al., Reduction of mutual coupling between closely-packed antenna elements. IEEE Transactions on Antennas and Propagation, 2007. 55(6): p. 1732-1738.

[14] Zhang, S., P. Zetterberg, and S. He, Printed MIMO antenna system of four closely-spaced elements with large bandwidth and high isolation. Electronics letters, 2010. 46(15): p. 1052-1053.

[15] Chen, S.-C., Y.-S. Wang, and S.-J. Chun, A decoupling technique for increasing the port isolation between two strongly coupled antennas. IEEE Transactions on Antennas and Propagation, 2008. 56(12): p. 3650-3658.

[16] Mak, A.C., C.R. Rowell, and R.D. Murch, Isolation enhancement between two closely packed antennas. IEEE Transactions on Antennas and Propagation, 2008. 56(11): p. 3411-3419.

[17] Chung, Y., et al., High isolation dual-polarized patch antenna using integrated defected ground structure. IEEE Microwave and Wireless Components Letters, 2004. 14(1): p. 4-6.

Asma Iqbal Wani, Aaqib Iqbal Wani, and Raof Ahmad Khan, "MIMO Technology- An Overview of Mutual Coupling Effects on the Channel Capacity and Techniques for its Reduction," *International Journal of Scientific and Technical Advancements*, Volume 5, Issue 1, pp. 01-04, 2019.

Asma Iqbal Wani, Aaqib Iqbal Wani, and Raof Ahmad Khan, "MIMO Technology- An Overview of Mutual Coupling Effects on the Channel Capacity and Techniques for its Reduction," *International Journal of Scientific and Technical Advancements*, Volume 5, Issue 1, pp. 01-04, 2019.