A REVIEW ON THE DESIGN OF MIMO ANTENNAS FOR UPGRADING 4G COMMUNICATIONS

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ABSTRACT

Multiple - Input- Multiple - output (MIMO) wireless systems forms a part of new research area, since nowadays the communication engineers are more interested in higher data rates and improved spectral efficiencies, leading to the 4G technologies. In MIMO systems, as multiple antennas are used at the transmitter and receiver side, studying the properties of various antenna array configurations and their behavior in multipath communications is required. In this paper, a brief review of recent research findings concerning the antennas and their design for MIMO systems is discussed. The future goals of MIMO antenna designers are also mentioned.

Keywords: MIMO System, Antenna Arrays, Microstrip Antennas, Mutual Coupling

I. INTRODUCTION

MIMO technology has recently emerged as a new paradigm to achieve very high bandwidth efficiencies and large data rates in modern wireless communications. The concept of MIMO technology was first studied by the pioneer Foschini (1998). The principle is based on employing multiple antennas at both transmitter and receiver along with proper MIMO encoding and detection algorithms. The data rates that can be achieved depends strongly on the multidimensional statistical behavior of the MIMO fading channel, as well as on the design parameters of the antennas that are taken at the transmitter and receiver side as discussed by O. Weikert et al. (2005).

Most of the research on MIMO mainly focuses on the communication systems, information theory, signal processing and coding issues. Thus far, only a little importance is given to the aspects of antenna designing and their impact on channel capacity, system performance, diversity reception etc. Thus, in the present paper we mainly focus on the areas related to the antenna designing and their selection for improving the system performance. Here, we discuss various aspects like radiation pattern of antenna array configuration, mutual coupling reduction techniques, correlation between the antennas, polarization of the pattern and their impact on channel capacity, etc.

In a normal communication system, usually a single antenna at the transmitter and another single antenna at the receiver is employed. The signal reaching the receiver has to travel through various paths, affected by noise in the path and finally reaches the receiver. In a system with N transmit and M receive antennas (Figure.1), assuming the path gains between individual antenna pairs are independent and identically distributed (i.i.d.) Rayleigh faded, the maximal diversity gain is MN , which is the total number of fading gains that one can average over. Usually, multipath effects are drawback for a normal system, where as in MIMO system, this multipath propagation is taken as advantage for transmitting multiple data streams. Essentially, if the path gains between individual transmit–receive antenna pairs fade independently, the channel matrix is well conditioned with high probability, in which case multiple parallel spatial channels are created, thus improving the channel capacity. By transmitting independent information streams in parallel through the spatial channels, the data rate can be increased as mentioned by F. Hagebolling et al. (2006).This effect is also called spatial multiplexing.

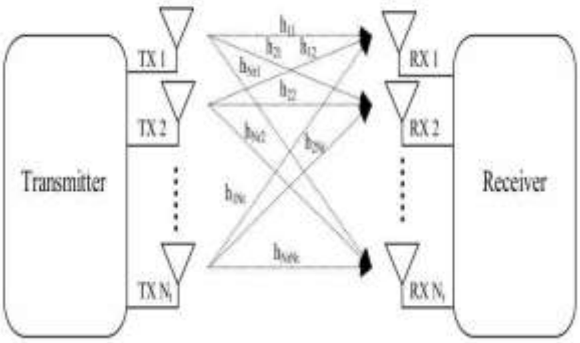

Figure 1: Basic Mimo System

For a MIMO system with M no. of transmit antennas and N no. of receive antennas the channel coefficient matrix is given in Eq. (1)

$$H = \begin{matrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & h_{2N} \\ \vdots & \vdots & \cdots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{matrix} \quad \ldots\ldots. (1)$$

Here, it is assumed that all the elements of the channel matrix are independent and identically distributed (i.i.d.). If the input signals of the system are denoted as ***x*** and the Gaussian noise is represented as ***n*** then the output response of the MIMO system ***y*** is given as,

$$y = xH + n \quad \ldots\ldots.(2)$$

Then the capacity of the channel for a MIMO system is given in eqn (3)

$$C = log_2[\det\left(I_M + \frac{\rho}{N} HH^T\right)] \quad \ldots\ldots\ldots(3)$$

The mentioned equation suggests that the channel capacity increases with increasing the SNR(ρ) and no. of antennas up to certain level.

II. MIMO ANTENNA DESIGN CONSIDERATIONS

As previously mentioned, MIMO systems perform best when it can answer to the issues related to antenna theory such as array configuration, radiation pattern, type of polarization and mutual coupling. Here, various interesting concepts of antenna design for a MIMO system are listed briefly.

2.1 Antenna Array Configuration

The recent research suggests that the channel transfer matrix depends not only on the signal propagation environment but also on the MIMO array configurations. The important point to decide is which array topology is best in terms of maximizing capacity or minimizing symbol error rates. This is difficult to answer definitively, since the optimal array shape depends on the site-specific propagation characteristics, although some general observations are possible.

E. H. Miller (2001) made a notable study, where several different array types were explored for both the base station and the Personal Digital Assistant (PDA) in an outdoor environment. The base station antennas included single and dual polarization array and multi beam structures. The arrays on the PDAs usually consist of monopoles or patch antennas or PIFA antennas. In the MIMO arrays either in base stations or mobile units, the correlation between the multiple signals must be minimum, otherwise it may lead to the reduction in channel capacities. The gain in capacities can be achieved by using various diversity techniques like spatial diversity, polarization diversity and pattern diversity (Arny Adila Salwa et al. 2007).

In spatial diversity, various elements are separated with optimum spacing to increase the no. of channels between TX and RX. For smaller units, this technique is not feasible, as it needs more area. If area is reduced, the smaller distance between the elements results in mutual coupling reducing the channel capacity. For such cases the polarization diversity is preferred (M.F Abdul Kadir 2008),in which the elements in the array are fed with differently polarized signals. Orthogonal polarization is the best technique to reduce the correlation among the signals. In pattern diversity, the signals with different angles are given to the different antennas in the array. In this technique, multimode diversity is the leading one and here only single element is used to transmit different signals in different exciting modes (Alper Öcalan 2009 and Robert W. Heath 2005)

Ramya (2006) presented the base station design for MIMO systems. Here the design of two popular base stations using Grassmannian precoding is discussed. One is an array of two dual polarized and another one is the array of four vertically polarized elements. The results suggest the better performance of two dual polarized arrays.

All of the array configurations provided very similar performance, with the exception of the multi beam base station antennas which resulted in a 40–50% reduction in measured capacity since generally only one of the beams pointed in the direction of the mobile. These results suggest that average capacity is relatively insensitive to array configuration. The conclusions drawn above are based on comparisons of average capacity for different array configurations.

2.2 Selective Antennas

Alternatively, there is an adaptive system that selectively connects a set of available antennas to the array system. Recent Studies have shown that an intelligently-selected sub-array can provide improved capacity and lower probability of symbol error relative to the performance of fixed arrays. Yang yang et al. (2009), successfully achieved the intelligent selection of antennas for improving the system performance. According to the analysis the selection of antennas can be hard selection and soft selection. In hard selection only part of the antennas are active, where as in soft selection all the antennas are used. The work concluded the efficiency of soft selection in the presence of mutual coupling. The soft selection can be FFT based and phase shift based, where later one is proved to be the efficient one. The work also suggests that, by placing additional antennas in the presence of mutual coupling, the spectral efficiency can be improved.

Adarsh et al. (2009) mentioned that, Antenna Selection for STF-coded MIMO-OFDM systems over frequency-selective channels in the presence of the CEE has been studied. The maximum received power AS rule has been proposed here with the LMMSE-based channel estimator. When compared with the full complexity system, it has been shown by simulations that a loss of about 2.4 dB is incurred in the AS scheme at a high SNR, whereas a gain of 2.3 dB is observed compared with the system not employing the AS.

2.3 Reconfigurable Antennas

The recent work mainly focuses on reconfigurable antennas, which can enhance the system performance by attaining diversity gain without using multiple antennas. Reconfigurable antennas with variable geometries have been designed to exhibit pattern diversity through electrical length changes to their physical structure. BedriA.Cetiner (2005) designed reconfigurable spiral antennas are for achieving pattern diversity in MIMO system. It is shown that, by varying the arm length of spiral antenna using MEM actuators for different radiation patterns of same frequency, the RHCP (Right hand circular polarization) and LHCP (Left hand polarization) are achieved. The length of the spiral antenna can be altered by using PIN diodes.

Prataban Mookiah (2007) developed a reconfigurable multiport circular patch antenna**.** Here, the main objective of the design is to reduce the spatial correlation and subsequently maximize the link capacity. The dimension of the antenna is modified using microstrip line switches. The system is made to operate at 2.46GHz and SNR taken at 10dB. Joshua D. Boerman and Jennifer T. Bernhard (2008) have examined and analyzed the potential improvements in MIMO system capacity attainable through use of a small number of pattern reconfigurable antennas. The simulation and experimental results presented here in various multipath propagation scenarios indicates that large performance enhancements are possible compared to systems that use either fixed or randomly directed pattern reconfigurable antennas. The advantages are specifically significant when the antenna patterns can be directed optimally to not only possess a high degree of diversity but also to provide enhanced SNR through increased antenna gain. Future scope in this area includes to determine that, what kind of antenna pattern reconfigurability will be most advantageous and responsive in a particular environment, leading to the development of new kinds of reconfigurable antennas. Additionally, for all of these cases, an overall system performance analysis will be conducted that includes the effects of receiver noise.

2.4 Microstrip Antennas

The most preferred antennas on any mobile unit for a MIMO system are microstrip or patch antennas, due to their low cost and ease of fabrication. The main drawback of these antennas is low bandwidth and there are various techniques proposed for improving the bandwidth.

The bandwidth of the microstrip patch antenna can be improved by increasing the thickness of substrate or by decreasing its electric permittivity value (D. Orban and G.J.K. Moernaut 2009). M.S. Karoui et al.(2010) proposed an antenna with wide bandwidth of 95.8% by reducing the ground plane area. This is because, if the ground area is reduced the capacitance between ground plane and patch decreases, thus increasing the bandwidth. X.L. Bao (2009) achieved an improvement in the impedance bandwidth on a relatively thin substrate by employing slots and an annular ring in the ground plane. The bandwidth can also be improved by employing a pair of L shaped slots in the ground plane as done by Reza Zaker et al.(2009).The present authors (2010) developed a modified E shaped patch antenna (Figure. 2) by employing multiple slots in a normal E shaped patch antenna for improving the bandwidth. In the present technology, the patch antennas are designed in variety of shapes like E shape (A. A. Deshmukh et al., 2005), H shape (S.-C. Gao et al., 2001), U shape (R. Chair et al.2005), spiral (Andrea Alj et al. 2004) etc. for achieving different purposes like wide impedance bandwidth, improved gain, reduced cross polarization and good isolation with surrounding elements.

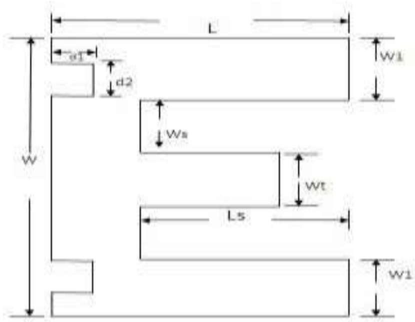

Figure 2: Modified E Shaped Patch Antenna

2.5 Mutual Coupling

The major problem faced by MIMO system engineers for small electronic modules is mutual coupling, which mainly arises due to the smaller spacing between the elements. However, when multiple antennas are involved at closer spacing the technical challenges are more pronounced compared to a SISO (Single Input Single Output) system. Hence, the basic aim of MIMO antenna design is to minimize the correlation between the multiple signals as discussed by T. Svantesson (2002).

The parameter that describes the correlation between the received signals in highly diversified environments is mutual coupling, as it may affect the performance of the system. By calculating the mutual coupling, one can analyze the electromagnetic field interactions that exist between antenna elements of a MIMO system. Higher mutual coupling may result in higher correlation coefficients thus reducing the antenna e c iencies. The impact of mutual coupling on the capacity of MIMO systems is studied by Abouda, A. A. and S. G. H¨ gagman (2006).

The mutual coupling mainly depends on the distance between the elements of an antenna array. By increasing the distance between the elements of the antennas, the mutual coupling can be reduced. However, the distance between the antennas cannot be maintained too large, since MIMO systems have their major applications in Mobile terminals, laptops, MODEMs, WLAN Access Points etc., where miniaturization is the main concern. Not only the physical constraints but also the concerns on ergonomics and aesthetics are few other important aspects in the design of MIMO systems. The distance between antenna elements in practice cannot be extended beyond a certain level which limits the use of spatial diversity to achieve the desired spectral efficiencies and transmission qualities.

There are various techniques for minimizing this mutual coupling like, using EBG Structures (F. Caminita 2009).The main source of mutual coupling is surface currents flowing on the ground and these currents can be reduced by employing electronic band gap (EBG) structures on ground plane. This is one of the leading technologies for reducing mutual coupling. Next method is by employing, defected ground structures, studied by Fangfang Fan, Zehong yan (2010), which also mainly focus on reducing surface currents to minimize the mutual coupling. In another method, discussed by Matthew L. Morris and Michael A. Jensen (2005), matching networks are used to analyze and to minimize the mutual coupling However, in all these concepts the reduction is achieved with complexity of the structures.

Dielectric Resonant Antennas (DRA) are another prominent option for developing the MIMO systems with low mutual coupling as discussed by M. F. Ain (2007). The dielectric resonator antenna (DRA) consists of high dielectric constant materials, high quality factors and mounted on a grounded dielectric substrate of lower permittivity. M.S.M. Aras et al. (2008) discussed the DRAs of various shapes and their performance. Though these antennas are costlier to implement, they are proved to be versatile in achieving the task of minimizing mutual coupling.

III. Conclusion

This paper presents a brief review of recent research findings concerning the antennas and their design for MIMO systems. Various issues like antenna array configuration and their impact on channel capacity, selective antenna concepts, the scope of research involved in reconfigurable antennas, types of patch antennas and their usability and the main sources for mutual coupling and the ways to reduce it are discussed. Finally, it is concluded that a lot of research is required to be done in antenna design for the better performance of MIMO systems, which form a main part for the future 4G communications.

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