A MIMO SYSTEM EQUIPPED WITH MULTIFUNCTIONAL RECONFIGURABLE ANTENNAS

Bedri A. Cetiner*(1), Enis Akay (2), Ersin Sengul(2), and Ender Ayanoglu(2)
(1) Morehead State University, Space Science Center, Morehead, KY, 40351
(2) Center for Pervasive Communications and Computing,
University of California Irvine, Irvine, CA, 92697

Abstract

A MIMO system equipped with a new class of antenna arrays, henceforth referred to as multifunction reconfigurable antenna arrays (MRAAs), is investigated. The elements of MRAA, i.e. MRAs presented in this work are capable of dynamically changing the sense of polarization of the radiated field thereby providing two reconfigurable modes of operation, i.e. polarization diversity and space diversity. The transmission signaling scheme can also be switched between transmit diversity (TD) and spatial multiplexing (SM). The results show that the reconfigurable modes of operation of an MRAA used in conjunction with adaptive space-time modulation techniques provide additional degree of freedoms to the current adaptive MIMO systems, thereby resulting in more robust system in terms of quality, capacity and reliability. A substantial performance gain is achievable with the proposed system over conventional fixed antenna MIMO systems depending on the channel conditions.

Introduction and Motivation

Wireless communication technology, a fundamental part of modern information infrastructure, is evolving at a frantic pace in order to meet the ever demanding performance characteristics of highly integrated mobile wireless communication devices. The true benefits of MIMO can be exploited only through a smart design that is able to respond to the channel. The goal is to maximize the resources available in multiple antenna channels by using optimal schemes at all times. In a typical adaptive MIMO system, the adjustable parameters are the modulation level, coding rate, and the transmission signaling schemes such as SM, TD and beamforming. The performance of such an adaptive MIMO system can be superior in comparison to that of a non-adaptive one. However, when an interdisciplinary analysis is performed on the interrelationships of transmission signaling schemes, antenna properties and propagation conditions it becomes clear that there is still an additional room for further exploitation of the theoretical gains of the MIMO systems [1]. In today's adaptive MIMO systems the antenna element properties are fixed by the initial design and cannot be changed. In this work, we introduce *an additional degree of freedom* by treating the antenna element properties as an additional component in the joint optimization of the adaptive system parameters. We effectively integrate the antenna properties with the space-time processing techniques and the propagation environment. The goal of joint optimization of antenna array properties and the associated transmission algorithm can only be achieved if each individual element of the array can be dynamically reconfigured, i.e. MRA. In short, the adaptive MIMO system introduced in this paper will not be constrained to employ a fixed antenna design over varying channel conditions. This feature will permit the selection of the best antenna properties in conjunction with the adapted transmission

1-4244-0123-2/06/$20.00 ©2006 IEEE

scheme with respect to the channel condition. Thus the gap between theoretical MIMO performance and practice is minimized.

Adaptive MIMO with MRAA

It has been shown that, under certain channel conditions, the use of polarization diversity is beneficial in terms of improving symbol error rate of up to an order of magnitude if the space-time modulation technique employed is spatial multiplexing (SM) [2]. On the other hand, the use of polarization diversity, in general, typically yield performance degradation for transmit diversity (TD) schemes, such as Alamouti scheme [2]. Also, the practical MIMO systems require some trade-off between data rate and diversity which translates into switching between SM and TD, respectively. Given that space-time modulation schemes such as SM and TD will perform differently for different channel conditions a switching between SM and TD based on the instantaneous channel state information was recently proposed [3]. A MIMO system that adapts not only the space-time modulation technique but also the antenna properties with respect to channel is what we have developed in this work. MRA spiral that is capable of altering the state of polarization by morphing its physical structure has recently been introduced [4]. An MRAA consisting of two MRA spiral antennas is employed in this work. When TD is used MRAA is reconfigured into space diversity scheme where both MRA spiral radiate the same sense of polarization. If the space-time modulation technique is SM then the MRAA is reconfigured into polarization diversity scheme where each MRA spiral has the opposite sense of polarization. Fig.1 shows the schematic of this system.

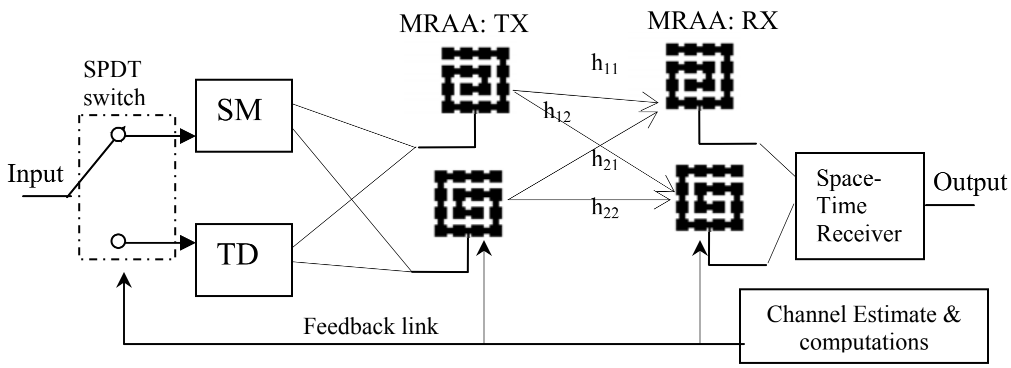


Fig. 1 The schematic of MIMO system employing MRAA

Results

In this section we provide the simulation results for various values of the system parameters. These parameters are chosen as follows:
- MRA element spacing; d=λ/2
- Diversity schemes; polarization diversity, space diversity
- Space-time modulation technique; SM, TD
- Ricean K-factor; K=0 (pure NLOS), K=10 (near LOS)

The 2x2 MIMO channel, **H**, is modeled as follows [5]

$$\mathbf{H} = \sqrt{\frac{K}{K+1}}\mathbf{H}_{LOS} + \sqrt{\frac{1}{K+1}}\mathbf{H}_{NLOS}$$

$$\mathbf{H}_{LOS} = \begin{bmatrix} 1 & \sqrt{\beta} \\ \sqrt{\beta} & 1 \end{bmatrix} \quad \mathbf{H}_{NLOS} = (\mathbf{R}_{RX})^{1/2}\mathbf{H}_{iid}(\mathbf{R}_{TX})^{1/2} = \begin{bmatrix} h_{11} & \sqrt{\alpha}h_{12} \\ \sqrt{\alpha}h_{21} & h_{22} \end{bmatrix}$$

where K is the Ricean K-factor, α and β are the attenuated cross coupling coefficients for the polarization case. $\mathbf{H}_{iid}$ is the flat-fading Rayleigh component of the MIMO channel. The elements of $\mathbf{H}_{iid}$ are complex Gaussian random variables with zero mean and unit variance. $\mathbf{R}_{RX}$ and $\mathbf{R}_{TX}$ are the receiver and transmitter side correlation matrices, respectively, and given by

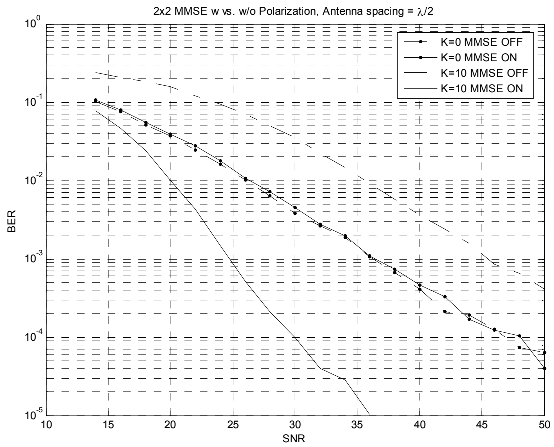
$$\mathbf{R}_{RX} = \begin{bmatrix} 1 & r \\ r & 1 \end{bmatrix}, \ \mathbf{R}_{TX} = \begin{bmatrix} 1 & t \\ t & 1 \end{bmatrix}, \quad \begin{matrix} r = \rho(\text{spacing at } RX) \times \rho(\text{polarization}) \\ t = \rho(\text{spacing at } TX) \times \rho(\text{polarization}) \end{matrix}$$

where r is the correlation coefficient between two receive antennas, and t is the correlation coefficient between two transmit antennas. $\rho(\cdot)$ denotes the real correlation coefficient due to either the spacing between antennas, or due to polarization. Note that, if both antennas are of the same polarization, then $\rho(\text{polarization}) = 1$. In the simulations, if polarization scheme is selected, the first transmit and the first receive antennas, and the second transmit and the second receive antennas use the same sense of polarization where the polarization of the first antennas are the opposite of the second ones.

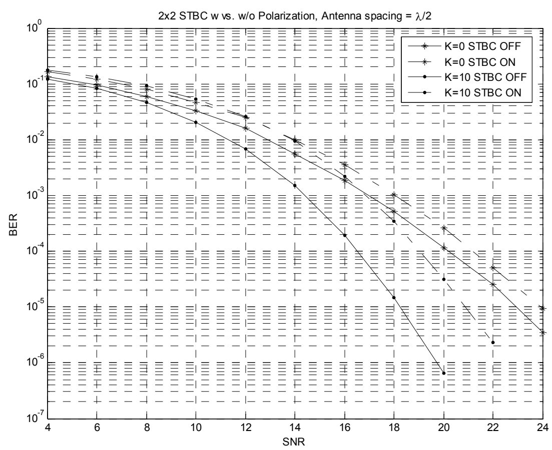
Fig. 2 provides simulation results for 2x2 SM-MMSE (minimum mean square error receiver) and 2x2 TD-Alamouti using 16 QAM constellation [5]. The spacing between MRAs is $\lambda/2$. The coefficients used for the simulations are as follows: $\rho(\text{spacing at } \lambda/2) = 0.3$, $\rho(\text{polarization}) = 0.3$, $\beta = 0.1$, and $\alpha = 0.5$. As can be seen from the figures, while polarization provides substantial gain for SM-MMSE (especially for highly *LOS* channel environment), TD-Alamouti suffers from deploying different polarization between antennas. Therefore, it is crucial for a multi-mode system (a system deploying SM, or TD depending on the instantaneous application needs) to incorporate reconfigurable antennas to achieve the maximum gains. In a LOS environment, i.e. $K=10$, when a high data rate is desirable, SM will be the winning strategy for the transmission signaling. Changing the polarization using the adaptive spiral-MRAA system, more than 20 dB performance gain can be achieved at 10^{-3} bit error rate (BER). However, when low data rate is required TD-Alamouti will be used and the system will use the uni-polarized mode of operation without any performance loss. Simulation results show that the proposed system will be very robust against several channel conditions and as the channel becomes more LOS, significant gains will be achieved compared to fixed-antenna adaptive MIMO systems.

Conclusions

Wireless applications that are increasingly bandwidth- and mobility-intensive have driven MIMO research to push against the physical limits of coding and signaling. The multifunctional reconfigurable antenna technology presented in this work greatly impacts adaptive MIMO performance through the capability to change antenna properties. The reconfigurable antenna properties integrated with signaling schemes to the propagation environment provides an additional degree of freedom in adaptive optimization. Depending on the channel conditions a substantial performance gain is achieved over existing adaptive MIMO systems. A long awaited design space where interplay between reconfigurable antenna and adaptive signaling feed-back-to-each-other is likely to revolutionize broadband MIMO system design methodology.



(a) SM-MMSE



(b) TD-Alamouti

Fig. 2 Bit-error-rate versus SNR for the MIMO system employing MRAA. (On indicates polarization diversity activated, off indicates polarization diversity deactivated.)

References:

[1] B. A. Cetiner, H. Jafarkhani, et al., "Multifunctional Reconfigurable MEMS Integrated Antennas for Adaptive MIMO Systems" *IEEE Communications Magazine*, Vol. 42, No. 12, pp. 62-70, December 2004

[2] Nabar, R.U.; Bolcskei, H.; et al., "Performance of multiantenna signaling techniques in the presence of polarization diversity," *IEEE Trans. on Signal Processing*, vol.50, no.10pp. 2553- 2562, Oct 2002

[3] R. W. Heath, A. J. Paulraj "Switching between diversity and multiplexing in MIMO systems" *IEEE Trans. on Commun.*, vol. 53, no.6, pp. 962-968, June 2005

[4] B. A. Cetiner, J.Y.Qian, G.P.Li, "A Reconfigurable Spiral Antenna for Adaptive Wireless Communications" presented at the IEEE AP-S 2005

[5] A. Paulraj, R. Nabar, and D. Gore, *Introduction to Space-Time Wireless Communications*. Cambridge University Press, 2003.