

Preface

Background/Motivation

Multiple Input/Multiple Output (MIMO) systems, which rely on the availability of multiple antenna elements on the side of wireless transmitters and receivers, have been a topic of significant research activity over the last 15 years. Despite the great progress that has been achieved in the field, ranging from channel characterization to space–time coding architectures to low-feedback techniques to techniques for multiuser, multi-node, and multi-antenna (and even massive antenna) configurations, MIMO systems have been only scarcely made available to wireless handset terminals or sensor nodes. This has been mostly due to physical, cost, and power constraints: the small size of the terminal reduces the number of antennas that can be sufficiently decorrelated from each other, a key property for multiplexing multiple streams on a MIMO channel; the need for each antenna to be fed by its own radio frequency (RF) chain increases significantly the cost of the terminal; and the combined required baseband processing, as well as RF circuitry greatly increase the power dissipation of the unit, which in turn would drain its battery faster.

In this edited book, we offer a fresh look at the problem of MIMO communication, by waiving the requirement of each antenna to be linked to an RF chain. This constitutes a departure from the conventional MIMO and array processing paradigm, wherein the one-to-one mapping between RF signals and their baseband counterparts allows all the intelligent processing to take place at a digital signal processor in the baseband domain. To enable the new paradigm we make use of parasitic antenna arrays, an old technology that has been used mostly for fixed analog TV reception, but which we equip with advanced mixed digital analog processing techniques in order to make it suitable for MIMO communication. The underlying physical phenomenon that allows this is the mutual coupling that takes place between neighboring antenna elements on an array, allowing some of them (the so-called passive ones) to radiate as a result of the active excitation induced directly on their “active” neighbors. Taking advantage of the mutual coupling mechanism, as will be shown throughout the book, allows spatial

multiplexing/demultiplexing over the air, providing a performance that is often comparable to conventional MIMO systems. While the techniques for doing so are still at a rather early stage and require a careful, quite complex, and typically modulation and topology-specific design, they come with the significant benefit of allowing many more antenna elements on devices of a given size and with much fewer (possibly as few as one) RF chains for the entire array.

Comprising a collection of chapters from the early contributors in the field, this book is inspired by our collective feeling that there is by now enough theoretical and experimental evidence to support the consideration of parasitic antenna arrays for MIMO communication. Realizing that the field is not only quite new but also rather narrow in terms of the number of people working on it, we believe that this book could become a catalyst for more researchers to engage in it. This would in turn lead to a growing maturity of the field, which in our view would be required for these techniques to be adopted by real systems. It is our belief that given the appropriate attention, parasitic antenna arrays could in fact become a key technology enabler to allow small-sized wireless devices to benefit from high order MIMO communication, thus increasing substantially the communication throughput they can handle within a given spectrum.

Book Overview

The contents of the book are divided into eight chapters. Chapter 1 reviews the historical use of antenna arrays and multi-antenna systems in wireless communications and gives the main advantages provided by conventional MIMO systems. Then, the most important limitations of MIMO systems are highlighted and significant information-theoretic research results for MIMO networks are discussed. The chapter prepares the reader to accept mutual coupling as a blessing instead of a curse and implies the use of parasitic antenna arrays for mobile devices. In Chap. 2 fundamental antenna concepts are reviewed and a connection to the signal processing techniques applied in smart antennas is provided. An interesting discussion on the need for a reconsideration of the design paradigm of antennas and signal processing techniques is provided. The chapter discusses in detail the mutual coupling effect, present in parasitic antenna arrays, and shows how antenna design, RF engineering, and MIMO processing can be used in parallel in order to achieve the challenging goal of MIMO transmission. This goal is served by the strong beamforming capabilities held by parasitic antenna arrays and especially the Electronically Steerable Passive Antenna Radiator (ESPAR). The concept of Beam-space-MIMO (BS-MIMO) and the theoretical construction of MIMO transmission are presented in Chap. 3. The significance of the beam-space representation of MIMO systems is underlined and the idea of single-RF MIMO architectures is elaborated in this chapter. Moreover, the notion of aerial degrees of freedom (ADoF) is introduced and the available ADoF supported by ESPAR antennas is examined. The chapter discusses the effect of the array's geometry on the effective ADoF and

addresses the issue of adaptive/reconfigurable transmitting/receiving basis functions due to changing wireless channel conditions. Performance evaluation results for the channel-ignorant as well as the channel-aware single-RF BS-MIMO system are given. Chapter 4 focuses on the transmission techniques that enable single RF parasitic antenna arrays to support MIMO applications. These techniques are based on the calculation of the reactive loads of the parasitic elements, although complex valued loads are considered. Indeed, it is shown that the use of complex loading can improve dramatically the beamforming capabilities of ESPAR antennas and the corresponding spectral efficiency. A stochastic algorithm for the loading calculation is analyzed and performance evaluation results are discussed. The chapter focuses on loading architectures assuming purely imaginary loading. Having explored MIMO transmission techniques in previous chapters, Chap. 5 shows how to deal with the MIMO reception and achieve a multiplexing gain when parasitic antenna array with a single RF element is utilized at the receiver side. The main concept is based on a virtually fast rotating directional receiver antenna, which rotates several times per symbol interval. The antenna rotation results in the same spatial multiplexing, which is also obtained by conventional MIMO receivers with multiple active elements. The capacity achieved by the rotating antenna is considerably higher than that by a single receiver antenna. The chapter also highlights some potential problems due to adjacent channel interference. Chapter 6 contributes to the effective design and modeling of realistic parasitic antenna arrays for MIMO transmission/reception. It clearly explains why this design is essentially different for BS-MIMO operation, an application that sets different constraints. Moreover, it provides an extensive discussion on implementation issues and the major practical constraints. Issues like the use of realistic antenna elements for handheld applications, which differ from simple monopole and dipoles; the basic limitations in the controllable elements needed, such as switching speed and thermal losses; the implementation of a reconfigurable load structure achieving the desired reactive values; or the effect of the user on the radiation patterns are some important topics addressed therein. Chapter 7 describes the results of an early proof-of-concept experiment performed in AIT's B-WiSE Lab. The experiment validated the previously reported concept regarding the capability of single-RF BS-MIMO transmission using the ESPAR antenna presented in Chap. 6. The 2.6 GHz prototype was also used in a cognitive radio context, where the ESPAR antenna is the secondary transmitter and the text discusses the measured interference it causes to the primary receiver. A new printed parasitic antenna array with one active and four parasitic elements is presented. Finally, Chap. 8 focuses on extensions and foreseen applications of the parasitic antenna array technology. Moving beyond the single RF setup, Chap. 8 extends the analysis to generalized multi-active multi-passive (MAMP) antenna topologies and examines their use to reconfigurable MIMO transmission under variable channel conditions. The adaptive MAMP system targets at maximizing tight MIMO ergodic and outage rate bounds, relying on partial channel knowledge when tuning to a different loading state for optimizing the rate of communication. Moreover, this chapter extends the communication scenario to account for multiuser diversity systems, describing novel parasitic antenna-assisted switched beam array

architectures for enhanced selection combining with application to the downlink of cellular systems exploiting multiuser diversity. The simulation results show that the proposed enhanced diversity combining systems improve the average throughput of a multiuser network outperforming classic antenna selection especially for small user populations and compact user terminal size.

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