Chapter XIV

Novel Multi-Antenna and Smart Antenna Techniques for Next Generation Wireless Communication Networks

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ABSTRACT

Multi-antenna systems incorporating smart antenna techniques present numerous advantages compared to their single antenna counterparts including increased capacity and range, by exploring spatial diversity. The current status and novel research directions in the framework of such array systems are presented. Furthermore, the application of nonlinear antenna arrays in the design of novel RF/microwave front-ends, that present compact, low cost and energy efficient solutions for smart antenna array applications is demonstrated. In this manner, the advantages of such systems in terms of their application within next generation networks are highlighted both from the point of view of digital signal processing techniques, as well as alternative analog radio front-end architectures.

INTRODUCTION

Research efforts on next generation wireless communication networks focus on the integration of coexisting heterogeneous types of networks, while providing an increasing number of applications and services, which, in turn, require a high quality of service (QoS). On the other hand, there is an increasing demand for energy efficiency and low cost solutions.

Multi-antenna systems offer higher speed and range compared to single antenna systems, by exploring spatial diversity. Smart antenna techniques applied in multiple antenna systems have a significant impact on the efficient use of the spectrum, the minimization of the cost of establishing new wireless networks, the enhancement of the
quality of service, and the realization of re-configurable, robust and transparent operation across multi-technology wireless networks.

This chapter provides an overview on novel research directions in the framework of such antenna arrays. First, the capability of increasing the capacity of traditional mobile communication links by placing multiple antennas at the receiver and at the transmitter (MIMO systems) is demonstrated. Second, multi-antenna architectures are presented, analyzing the various advantages, disadvantages, as well as challenges that have to be addressed by implementing the transmitter and receiver functions in the digital domain versus the analog domain. The use of digital signal processing techniques applied in beam-forming and adaptive beam-forming methodologies is then presented. Finally, an introduction to nonlinear antenna arrays is provided, followed by a demonstration of their potential application as novel analog front-ends with beam-forming capabilities within the framework of smart antenna arrays.

**MIMO Techniques**

The recent introduction of multi-antenna “multiple-input multiple-output” (MIMO) techniques in terrestrial mobile communications has received a lot of interest in the past decade (Figure 1). The possibility to boost the capacity of traditional mobile communication links by placing multiple antennas at the receiver and at the transmitter has spurred a considerable volume of research. Nowadays, MIMO architectures are fairly well studied and understood, up to the point that MIMO techniques are currently being introduced in multiple mobile communication standards. For example, the IEEE 802.11n extension to the IEEE 802.11 standard for wireless LAN (WiFi) (http://standards.ieee.org/getieee802/802.11.html) supports MIMO links up to 4 by 4 (4 spatial streams), space-time block coding techniques and rates up to 600 Mbps over a 40 MHz bandwidth. Another example is given by the IEEE 802.16e amendment to the 802.16 standard for wireless MAN (WiMAX) (http://standards.ieee.org/getieee802/802.16.html), which also provides support for MIMO operation with beamforming, space-time coding, and spatial multiplexing. In the following, we present the fundamental advantages and trade-offs of this kind of systems.

**Multiplexing Gain**

A narrowband time-invariant wireless channel with \( N_t \) transmit and \( N_r \) receive antennas is described by an \( N_r \times N_t \) deterministic matrix \( H \). What are the key properties of \( H \) that determine how much spatial multiplexing it can support? We answer this question by looking at the capacity of the channel.

The observation obtained at one channel access assuming a time-invariant channel model can be mathematically described at a particular channel access by

\[
y = Hx + w
\]

where \( x \in \mathbb{C}^{N_t} \), \( y \in \mathbb{C}^{N_r} \), \( w \sim \mathcal{CN}(0, N_r I_{N_r}) \) respectively denote the transmitted signals at the \( N_t \) transmit antennas, the corresponding \( N_r \) received signals and an additive spatially white Gaussian noise respectively. The channel matrix \( H \in \mathbb{C}^{N_r \times N_t} \) is initially assumed to be deterministic, constant at all times.

*Figure 1. A new file has been sent for this figure*