# Chapter IV On the Employment of SMI Beamforming for Cochannel Interference Mitigation in Digital Radio

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# ABSTRACT

Many common adaptive beamforming methods are based on a sample matrix inversion (SMI). The schemes can be applied in two ways. The sample covariance matrices are either computed over preambles, or the sample basis for the SMI and the target of the beamforming are identical. A vector space representation provides insight into the classic SMI-based beamforming variants, and enables elegant derivations of the well-known second-order statistical properties of the output signals. Moreover, the vector space representation is helpful in the definition of appropriate interfaces between beamforing and soft-decision signal decoding in receivers aiming at adaptive cochannel interference mitigation. It turns out that the performance of standard receivers incorporating SMI-based beamforming on short signal intervals and decoding of BICM (bit-interleaved coded modulation) signals can be significantly improved by proper interface design.

### INTRODUCTION

Cochannel interference (CCI) becomes a major performance limiting factor in today's growing variety and density of wireless links and networks. Cellular systems occupying licensed frequency bands may evade CCI by a smart channel reuse policy. But in emerging decentralized peer-to-peer networks an efficient management of the channel access with the guarantee of limited CCI is a complex task, especially if the peers have directional transmission and reception capabilities. And proactive interference control across different systems sharing an unlicensed band is even more difficult to realize. Receiver techniques aiming at *reactive* interference mitigation, on the other hand, do not require cooperation between transceivers or systems, and they are thus a more viable approach to limit outages in decentralized or heterogeneous networking scenarios.

Data streams are normally split up and conveyed in short frames from sender to receiver. In multi-hop networks the frames need to be lightweight in order to limit latency in links over multiple hops since the relaying peers can usually not receive and transmit simultaneously. Moreover, besides of the data frames a multitude of even shorter control frames

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conveying "Hello", "Request/Clear to Transmit", "Acknowledge" messages and others are exchanged. As a consequence, if a channel is shared without coordination the interference may fluctuate at a much higher rate than the actual channel gain does due to multipath fading. This necessitates interference mitigation techniques which can adapt to CCI characteristics within short signal periods.

Equipped with array antennas, receivers can suppress interference via beamforming, i.e., a weighting and combining of the signals from the multiple antennas. Classic beamforming methods include the minimum variance distortionless response (MVDR) beamformer, which maximizes the signal-to-interference-plus-noise ratio (SINR) under the constraint of undistorted desired signal, and the minimum mean squared error estimator. When the spatial signatures of the interfering signals are completely unknown, an adaptive beamforming becomes necessary. Many of the popular adaptive beamforming techniques, discussed in textbooks like (Monzingo et al, 1980; Van Trees, 2002), rely on an inversion of a sample covariance matrix (SCM). The methods presented in (Vorobyov et al, 2003; Feldman et al, 1994; Bell et al, 2000; Lorenz et al, 2005; Li et al, 2003) feature enhanced robustness to mismatches in the spatial signature of the desired signal and other uncertainties via a diagonal loading of the SCM or more elaborate arrangements. The properties of the output of classic SCM-based spatial filters are analyzed in (Richmond, 1996; Van Veen, 1991), exposing the performance degradation compared to ideal beamforming based on perfectly known CCI statistics.

The above referenced literature focuses on beamforming in general, with the aim to optimize the second-order statistics of the residual error in the filtered signals. Simply attaching such an optimized beamforming scheme to a standard baseband receiver does not necessarily result in a favourable architecture. In fact, optimal receivers perform interference mitigation and decoding jointly. Optimal maximum-likelihood signal decoding in the presence of CCI with unknown characteristics is discussed in (Hunziker et al, 2007), along with a suboptimal iterative procedure. Iterative solutions, which often clearly outperform their non-iterative equivalents, are also investigated in (Kuzminskiy et al, 2003; Swindlehurst et al, 1995; Biedka et al, 2000; Hunziker et al, 2004). On the other hand, joint beamforming and decoding as well as suboptimal iterative schemes do have the drawback of high complexity. Efficient algorithms are available for the sample matrix inversion (SMI), whereas iterative methods scale up receiver complexity by a factor two or more. In the following we shall thus restrict our attention to conventional baseband receiver architectures comprising an adaptive beamforming via an SMI, followed by the information decoding on the basis of the combined signal. Our concern is to amend the output of the beamforming subsystem such that it facilitates the subsequent soft-decision decoding.

#### SYSTEM MODEL

In the following boldfaced lowercase characters are used for row and column vectors and boldfaced uppercase characters for matrices. The Hermitian transpose of **X** is written as  $\mathbf{X}^{H}$ ,  $\mathbf{I}_{K}$  denotes the *K*×*K*-identity matrix, and [**X Y**] represents the horizontal concatenation of **X** and **Y**. Furthermore,  $\|\cdot\|$  denotes the 2-norm of a row/column vector.

Assume a staggered, block-wise transmission of an information-bearing signal over a narrow-band single-input/*N*-output channel. A block comprises *K* data symbols. The channel gain is constant over many blocks and perfectly known, however, the characteristics of the CCI vary arbitrarily from block to block, and they are unknown. Following a proper sampling of the array signal at the symbol rate, the baseband receiver observes a block as the sequence  $\mathbf{y}_1, \dots, \mathbf{y}_K$  of complex *N*×1-vectors, where  $\mathbf{Y} = [\mathbf{y}_1 \dots \mathbf{y}_K]$  is given as

(1)

The column vector  $\mathbf{h} \in \mathbb{C}^N$  defines the signal attenuation at the *N* receiver antennas, the 1×*K*-row vector  $\mathbf{s} = [s_1 \dots s_K]$  comprises the data symbols, and  $\mathbf{W} = [\mathbf{w}_1 \dots \mathbf{w}_K]$  includes the CCI and front end noise.

The interference may stem from an arbitrary number of unsynchronized sources. In many scenarios it is reasonable to model the composite CCI and noise as temporally white, spatially correlated Gaussian. Hence, the independent random vectors  $\mathbf{w}_1, \dots, \mathbf{w}_k$  are  $CN(\mathbf{0}, \mathbf{R})$ , i.e., zero-mean circularly symmetric complex Gaussian with the covariance matrix  $\mathbf{R}$ . The matrix  $\mathbf{R}$  depends on the radio channels between the sources of interference and the receiver. In environments with multipath signal propagation  $\mathbf{R}$  is solely known to be Hermitian positive definite.

Preambles in the form of a number of leading zeros may facilitate the beamforming at the receiver end. Including a preamble of length M, the vector **s** comprises M zeros and K-M data symbols, i.e.,  $\mathbf{s} = [\mathbf{0} \ \mathbf{s}_D]$ . Likewise,  $\mathbf{Y} = [\mathbf{Y}_P \ \mathbf{Y}_D]$ , where  $\mathbf{Y}_P$  and  $\mathbf{Y}_D$  relate to the preamble and the data sections, respectively, of the block.

Figure 1 shows the structure of a typical receiver employing beamforming. Following the radio-frequency front ends and analog-digital (A/D) conversions, the signals from the N antennas, represented by the rows of **Y**, are linearly

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