

# Chapter III

## Adaptive Beamforming Assisted Receiver

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### ABSTRACT

*Adaptive beamforming is capable of separating user signals transmitted on the same carrier frequency, and thus provides a practical means of supporting multiusers in a space-division multiple-access scenario. Moreover, for the sake of further improving the achievable bandwidth efficiency, high-throughput quadrature amplitude modulation (QAM) schemes have become popular in numerous wireless network standards, notably, in the recent WiMax standard. This contribution focuses on the design of adaptive beamforming assisted detection for the employment in multiple-antenna aided multiuser systems that employ the high-order QAM signalling. Traditionally, the minimum mean square error (MMSE) design is regarded as the state-of-the-art for adaptive beamforming assisted receiver. However, the recent work (Chen et al., 2006) proposed a novel minimum symbol error rate (MSER) design for the beamforming assisted receiver, and it was demonstrated that this MSER design provides significant performance enhancement, in terms of achievable symbol error rate, over the standard MMSE design. This MSER beamforming design is developed fully in this contribution. In particular, an adaptive implementation of the MSER beamforming solution, referred to as the least symbol error rate algorithm, is investigated extensively. The proposed adaptive MSER beamforming scheme is evaluated in simulation, in comparison with the adaptive MMSE beamforming benchmark.*

### INTRODUCTION

The ever-increasing demand for mobile communication capacity has motivated the development of antenna array assisted spatial processing techniques (Winters *et al.*, 1994; Litva & Lo, 1996; Godara, 1997; Kohno, 1998; Winters, 1998; Petrus *et al.*, 1998; Tsoulos, 1999; Vandenameele *et al.*, 2001; Bloch & Hanzo, 2002; Soni *et al.*, 2002; Paulraj *et al.*, 2003; Paulraj *et al.*, 2004; Tse & Viswanath, 2005) in order to further improve the achievable spectral efficiency. A specific technique that has shown real promise in achieving substantial capacity enhancements is the use of adaptive beamforming with antenna arrays (Litva & Lo, 1996; Bloch & Hanzo, 2002). Through appropriately combining the signals received by the different elements of an antenna array, adaptive beamforming is capable of separating user signals transmitted on the same carrier frequency, provided that they are separated sufficiently in the angular or spatial domain. Adaptive beamforming technique thus provides a practical means of supporting multiusers in a space-division multiple-access

scenario. For the sake of further improving the achievable bandwidth efficiency, high-throughput quadrature amplitude modulation (QAM) schemes (Hanzo *et al.*, 2004) have become popular in numerous wireless network standards. For example, the 16-QAM and 64-QAM schemes were adopted in the recent WiMax standard (IEEE 802.16). Classically, the beamforming process is carried out by minimising the mean square error (MSE) between the desired output and the actual array output, and this principle is rooted in the traditional beamforming employed in sonar and radar systems. An advantage of this minimum MSE (MMSE) beamforming design is that its adaptive implementation can readily be achieved using the well-known least mean square (LMS) algorithm, recursive least squares algorithm and many other adaptive schemes (Widrow *et al.*, 1967; Griffiths, 1969; Reed *et al.*, 1974; Widrow & Stearns, 1985; Ganz *et al.*, 1990; Haykin, 1996). For potential use in downlink adaptive beamforming receiver, we will only consider the stochastic gradient-based LMS algorithm in this study owing to the computational simplicity of this adaptive algorithm. The MMSE design has been regarded as the state-of-the-art for adaptive beamforming assisted receiver, despite of the fact that, for a communication system, it is the bit error rate (BER) or symbol error rate (SER) that really matters.

Ideally, the system design should be based directly on minimising the BER or SER, rather than the MSE. Adaptive beamforming design based directly on minimising the system's BER has been proposed for the binary phase shift keying (BPSK) modulation (Chen *et al.*, 2003; Wolfgang *et al.*, 2004; Garcia *et al.*, 2004; Liu & Yang, 2004; Chen *et al.*, 2005; Fan *et al.*, 2005; Ahmad, 2005) and quadrature phase shift keying (QPSK) modulation (Chen *et al.*, 2004; Chen *et al.*, 2005a). These studies have demonstrated that the adaptive minimum BER (MBER) beamforming design can significantly improve the system performance, in terms of achievable BER, over the conventional MMSE design. The MBER beamforming is the true state-of-the-art and it is more intelligent than the MMSE solution, since it directly optimises the system's BER performance, rather than minimising the MSE, where the latter strategy often turns out to be deficient in the rank-deficient situation when the number of the users supported exceeds the number of the receiver antennas. Thus, the adaptive MBER beamforming design has a larger user capacity than its adaptive MMSE counterpart. Simulation results also show that the MBER design is more robust in near-far situations than the MMSE design. For the system that employs high-order QAM signalling, it is computationally more attractive by minimising the system's SER. This has led to the adaptive minimum SER (MSER) beamforming design for QAM systems (Chen *et al.*, 2006). The present contribution expands the work by Chen *et al.* (2006) and provides a detailed investigation for the adaptive MSER beamforming design for the generic multiple-antenna assisted multiuser system employing high-order QAM signalling.

The organisation of this contribution is as follows. Section 2 introduces the system model, which is used in Section 3 for studying the adaptive MMSE and MSER beamforming designs. Section 4 concentrates on investigating the achievable SER performance of the proposed adaptive MSER scheme in both the stationary and Rayleigh fading channels, using the adaptive MMSE scheme as a benchmark, while Section 5 presents the concluding remarks.

## SYSTEM MODEL

The system supports  $S$  users, and each user transmits an  $M$ -QAM signal on the same carrier frequency of  $\omega = 2\pi f$ . For such a system, user separation can be achieved in the spatial or angular domain (Paulraj *et al.*, 2003; Tse & Viswanath, 2005) and the receiver is equipped with a linear antenna array consisting of  $L$  uniformly spaced elements. Assume that the channel is narrow-band which does not induce intersymbol interference. Then the symbol-rate received signal samples can be expressed as

$$x_l(k) = \sum_{i=1}^S A_i b_i(k) e^{j\omega t_l(\theta_i)} + n_l(k) = \bar{x}_l(k) + n_l(k), \quad (1)$$

for  $1 \leq l \leq L$ , where  $t_l(\theta_i)$  is the relative time delay at array element  $l$  for source  $i$  with  $\theta_i$  being the direction of arrival for source  $i$ ,  $n_l(k)$  is a complex-valued Gaussian white noise with  $E[|n_l(k)|^2] = 2\sigma_n^2$ ,  $A_i$  is the narrow-band channel coefficient for user  $i$ ,  $\bar{x}_l(k)$  denotes the noiseless part of  $x_l(k)$  and  $b_i(k)$  is the  $k$ -th symbol of user  $i$  which takes the value from the  $M$ -QAM symbol set

$$B = \{b_{l,q} = u_l + ju_q, 1 \leq l, q \leq \sqrt{M}\} \quad (2)$$

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