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Spatial Diversity and Multiplexing Gain Performance of MIMO Techniques in WiMAX System

Bertrand Muquet(1), Ezio Biglieri(2), and Hikmet Sari(1),(3)

(1) SEQUANS Communications, F-92073 Paris La Défense, France
(2) Universitat Pompeu Fabra, E-08003 Barcelona, Spain
(3) SUPELEC, F-91192 Gif sur Yvette, France

Presentation Outline

- ☐ Mobile WiMAX systems based on IEEE 802.16e – 2005 specifications
- ☐ Multiple antenna (MIMO) options:
  1. Alamouti's transmit diversity and its combination with MRC at the receiver,
  2. 2x2 spatial multiplexing
- ☐ Spatial multiplexing receivers
- ☐ Performance analysis
- ☐ Summary and conclusions

Introduction

- Mobile WiMAX systems are based on the IEEE 802.16e – 2005 specifications.
- These specifications actually include 3 different physical (PHY) layers: Single-carrier, OFDM and OFDMA. From these, OFDMA has been selected by the WiMAX Forum as the basic technology for mobile WiMAX.
- WiMAX systems include two mandatory MIMO profiles for the downlink. These can also be optionally used on the uplink.
- The first MIMO profile, referred to as Matrix A, is based on Alamouti's space-time code (STC), and the second, referred to as Matrix B, is a 2x2 spatial multiplexing scheme.

Profile 1: Alamouti's STC

- Alamouti's STC was developed to implement transmit diversity and avoid the use of multiple antennas at the subscriber stations.
- This technique can be described as follows: Suppose that (s_1, s_2) represent a group of two consecutive symbols to be transmitted. During the first symbol period t_1, Tx antenna 1 transmits s_1 and Tx antenna 2 transmits s_2.
- Next, during the second symbol interval t_2, Tx antenna 1 transmits s_2^* and Tx antenna 2 transmits $-s_1^*$, where * denotes complex conjugate.

Alamouti's STC (cont'd)

- ☐ Denoting the channel response from Tx antenna 1 to the receiver by h_1 and its response from Tx antenna 2 to the receiver by h_2, the received signal samples at the two transmission instants are respectively given by:

$$r_1 = h_1 s_1 + h_2 s_2 + n_1$$

and

$$r_2 = h_1 s_2^* - h_2 s_1^* + n_2$$

where n_1 and n_2 are the additive noise terms affecting the two channels.

Alamouti's STC (cont'd)

- The receiver computes the quantities:

$$x_1 = h_1^* r_1 - h_2 r_2^* = \left(|h_1|^2 + |h_2|^2\right) s_1 + h_1^* n_1 - h_2 n_2^*$$

and

$$x_2 = h_2^* r_1 + h_1 r_2^* = \left(|h_1|^2 + |h_2|^2\right) s_2 + h_2^* n_1 + h_1 n_2^*$$

- These expressions clearly show that symbols s_1 and s_2 can be recovered from x_1 and x_2 without any interference and that these estimations benefit from a perfect second-order diversity that is equivalent to receiver diversity based on maximum ratio combining (MRC).
- Alamouti's STC can also be combined with MRC, and the resulting 2x2 system benefits from fourth-order diversity.

Profile 2: Spatial Multiplexing

- ☐ The second multiple antenna profile included in the IEEE 802.16e specifications is the 2x2 MIMO technique based on the so-called matrix $B = (s_1, s_2)^T$.
- ☐ This system performs pure spatial multiplexing and does not benefit from any diversity on the transmitter side. But it does offer a second-order diversity on the receiver side when detected using maximum-likelihood (ML) detection.
- ☐ To describe this technique, we omit the time and frequency dimensions leaving only the space dimension. The symbols transmitted in parallel by transmit antenna 1 and transmit antenna 2 are denoted s_1 and s_2, respectively.

Spatial Multiplexing (cont'd)

- ❑ Denoting by h_{ji} the channel response from transmitter i to receiver j, the signals received by the two receiver antennas are given by:

$$r_1 = h_{11} s_1 + h_{12} s_2 + n_1$$

and

$$r_2 = h_{21} s_1 + h_{22} s_2 + n_2$$

- ❑ These two equations can be combined and written in matrix form as:

$$\begin{pmatrix} r_1 \\ r_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix}$$

Optimum Detection

- The ML detector makes an exhaustive search over all possible values of the transmitted symbols and decides in favor of (s_1, s_2) which minimizes the Euclidean distance:

$$D\left(s_1, s_2\right)=\left\{\left|r_1-h_{11}s_1-h_{12}s_2\right|^2+\left|r_2-h_{21}s_1-h_{22}s_2\right|^2\right\}$$

- The complexity of the ML detector grows quadratically with the size of the signal constellation, and this motivates the use of simpler suboptimum receivers in practical implementations.
- Indeed, with the largest signal constellation (64-QAM) included in the IEEE 802.16e specifications, the complexity is proportional to $64^2 = 4096$, which is clearly prohibitive.

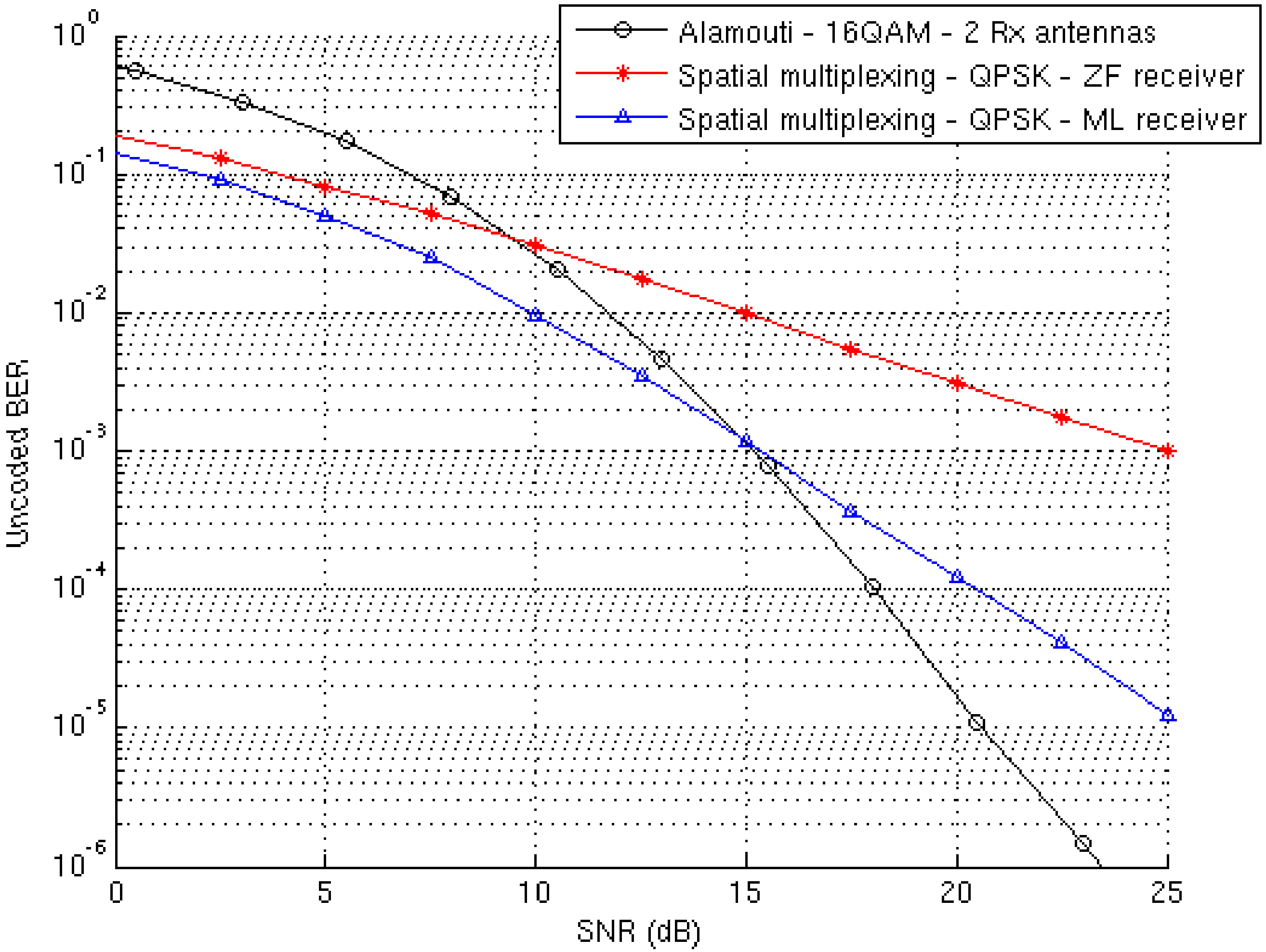
Suboptimum Receivers

- ❑ Zero-forcing (ZF) receivers invert the channel matrix. These receivers ignore the additive noise.
- ❑ Minimum mean-square error (MMSE) receivers minimize the combined effect of additive noise and interference between the two parallel channels.
- ❑ Decision-feedback receivers make a decision on one of the symbols and subtract its interference on the other symbol based on that decision.
- ❑ Sphere detector reduce the number of symbol values used in the ML detector. Note that this type of detectors may preserve optimality while reducing complexity.

Performance Analysis

- ☐ Since the 2x2 spatial multiplexing (SM) technique has only a 2nd-order diversity and Alamouti's STC has a 4th-order diversity when combined with MRC, the latter technique has better bit error rate (BER) performance.
- ☐ But spatial multiplexing offers a doubled bit rate when it uses the same modulation scheme as the Alamouti/MRC system.
- ☐ To make an objective and meaningful comparison between the two MIMO profiles, we need to use them at the same spectral efficiency rather than with the same modulation.
- ☐ Note that the Alamouti/MRC system with a modulation transmitting 2m bits per symbol has the same spectral efficiency as the 2x2 SM system with a modulation transmitting m bits per symbol.

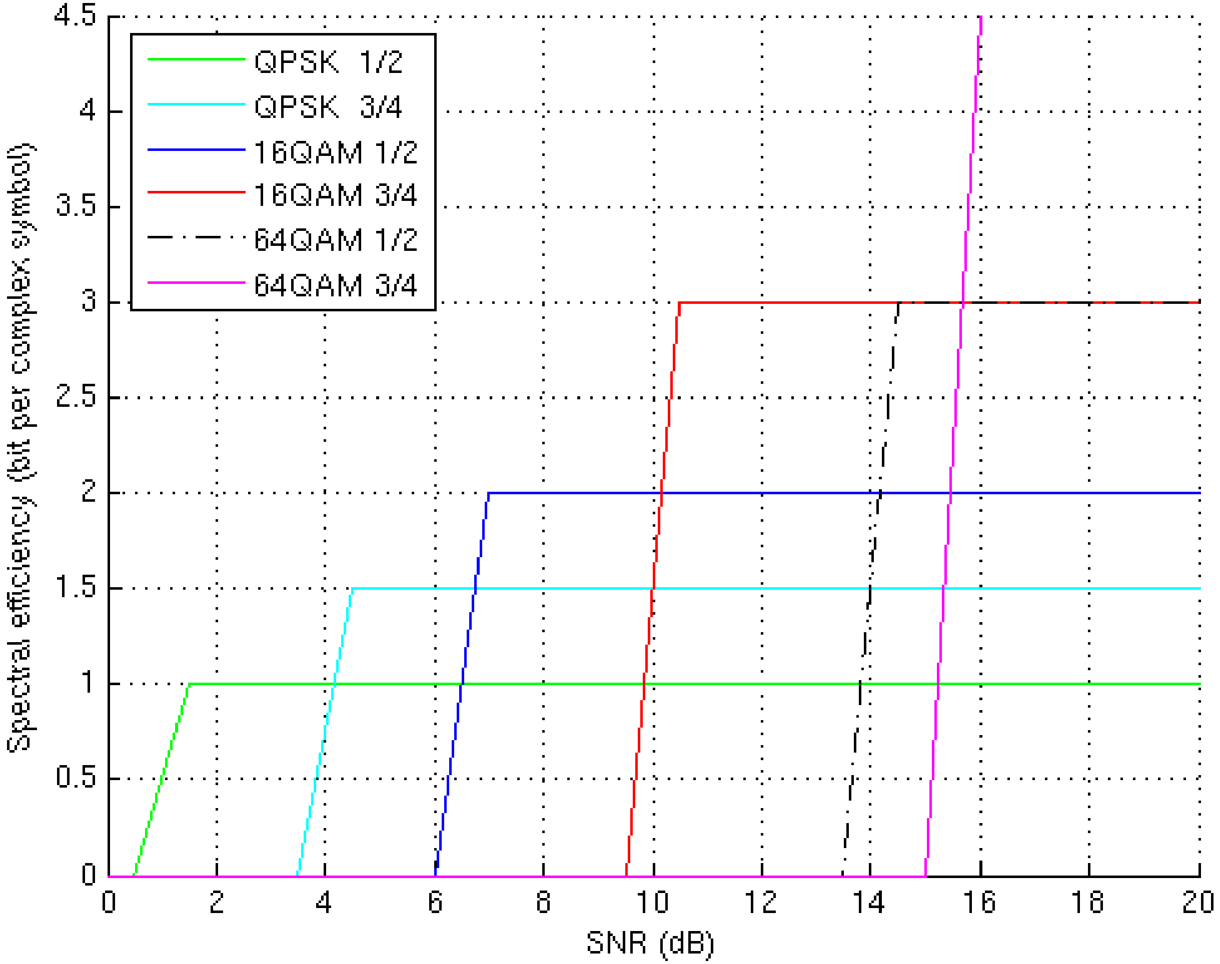
Alamouti/MRC vs. Spatial Multiplexing



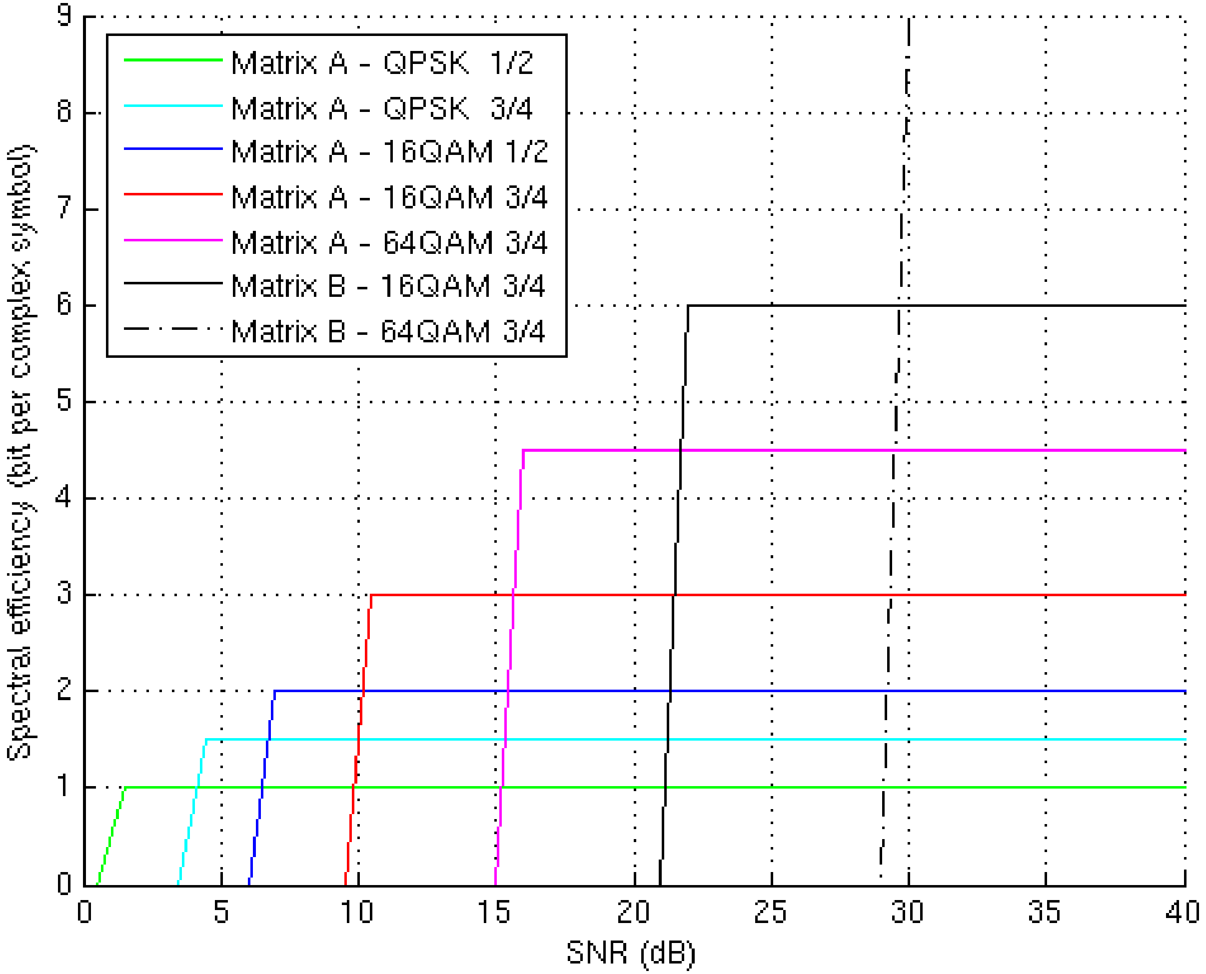
Selecting a MIMO Option

- ☐ The BER results in the previous figure suggest that the MIMO option to be used is a function of the channel SNR and the throughput required.
- ☐ In single-antenna systems, the throughput is optimized through link adaptation, which selects a signal constellation and a code rate as a function of the channel.
- ☐ This concept, called adaptive modulation and coding (AMC), must be extended to the space dimension in multi-antenna systems to make the best use of available MIMO options.
- ☐ We now illustrate MIMO link adaptation for the ITU Pedestrian Channel A corresponding to a speed of 3 km/hour.

AMC in Single-Antenna Systems



Extension of AMC to MIMO Systems



Summary and Conclusions

- We have described and analyzed the two multiple antenna profiles of WiMAX systems. The first is Alamouti's STC and the second is a 2x2 spatial multiplexing scheme.
- When two antennas are available at the receiver, Alamouti's STC can be combined with MRC and the resulting 2x2 MIMO scheme gives a diversity order of 4.
- It was shown that when the two MIMO schemes are used at the same spectral efficiency, STC/MRC significantly outperforms 2x2 spatial multiplexing at high SNR values.
- Finally, including the selection of a particular MIMO option in link adaptation, it was shown that 2x2 spatial multiplexing (Matrix B) is useful when the SNR exceeds 20 – 25 dB.