

Multiple Antenna Techniques for WiMAX Systems

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Presentation Outline

- ❑ Mobile WiMAX systems based on IEEE 802.16e – 2005 specifications
- ❑ Multiple antenna (MIMO) options:
 1. Alamouti's transmit diversity (Matrix A) and its combination with MRC at the receiver,
 2. 2x2 spatial multiplexing (Matrix B)
- ❑ Spatial multiplexing receivers (ML and suboptimum)
- ❑ Performance analysis
- ❑ Link adaptation
- ❑ 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/TDMA, OFDM/TDMA 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 used on the uplink, but this is not mandatory.
- ❑ 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 originally developed to implement transmit diversity at the base station and avoid the use of multiple antennas at the subscriber stations.
- ❑ This technique can be described as follows: Suppose that (s_1, s_2) represents 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:

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

and

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

- 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:

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

- ❑ 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 detectors reduce the number of symbol values used in the ML detector. Note that this type of detectors may preserve optimality while reducing complexity.

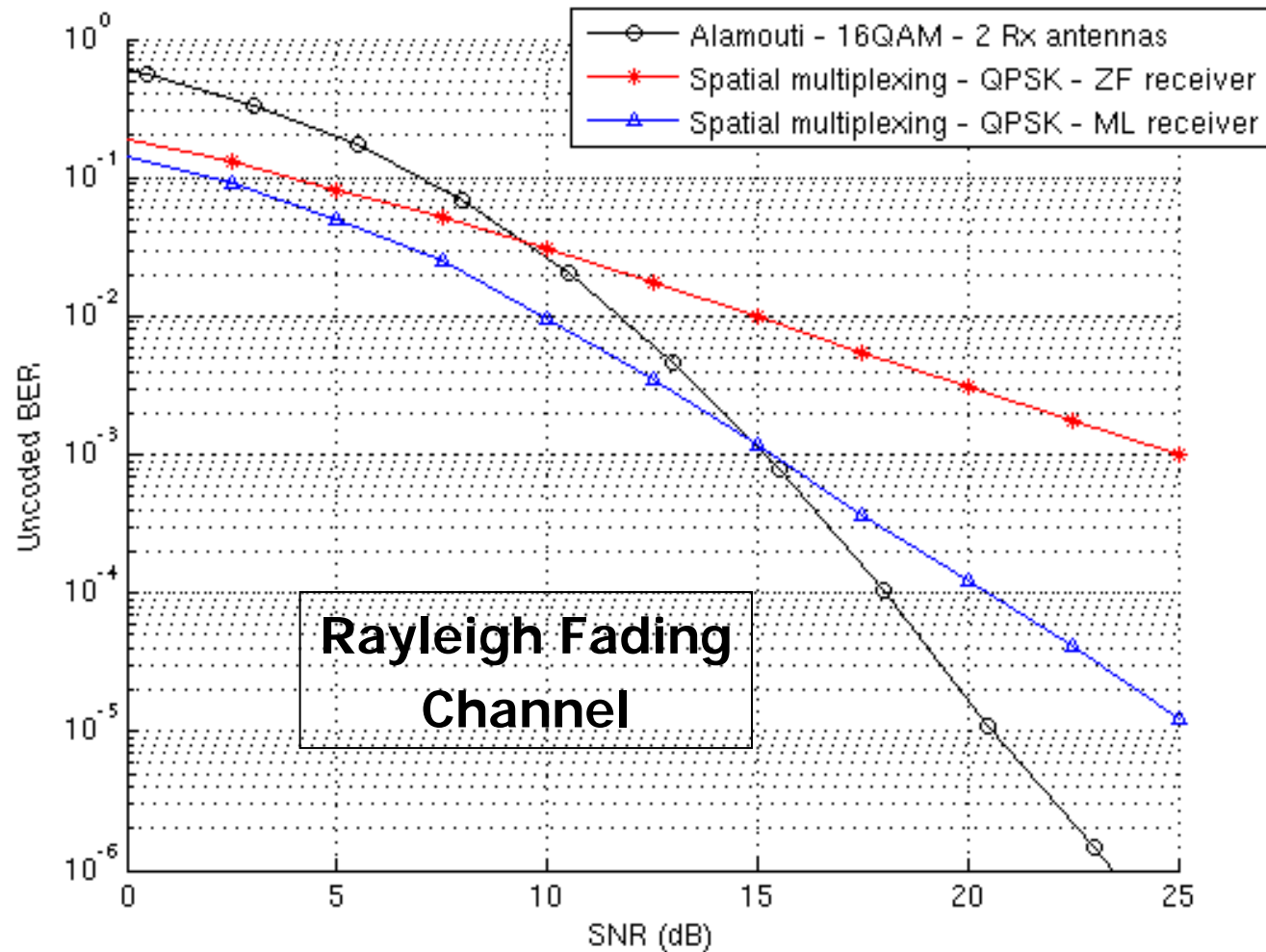
The Sequans Approach

- ❑ When sphere decoders are designed to preserve optimality, they only reduce average complexity, the detection complexity being a variable as in the classical sequential decoding.
- ❑ This is undesirable in practical implementations. Also, the other suboptimum receivers lead to a significant performance loss with respect to the ML receiver.
- ❑ For those reasons, Sequans Communications opted for implementation of the optimum receiver using its recently patented receiver architecture which leads to a complexity that grows only linearly with the size of the signal constellation.

Performance Comparison of MIMO Options

- ❑ 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 can be expected to have 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 Spatial Multiplexing system with a modulation transmitting m bits per symbol.

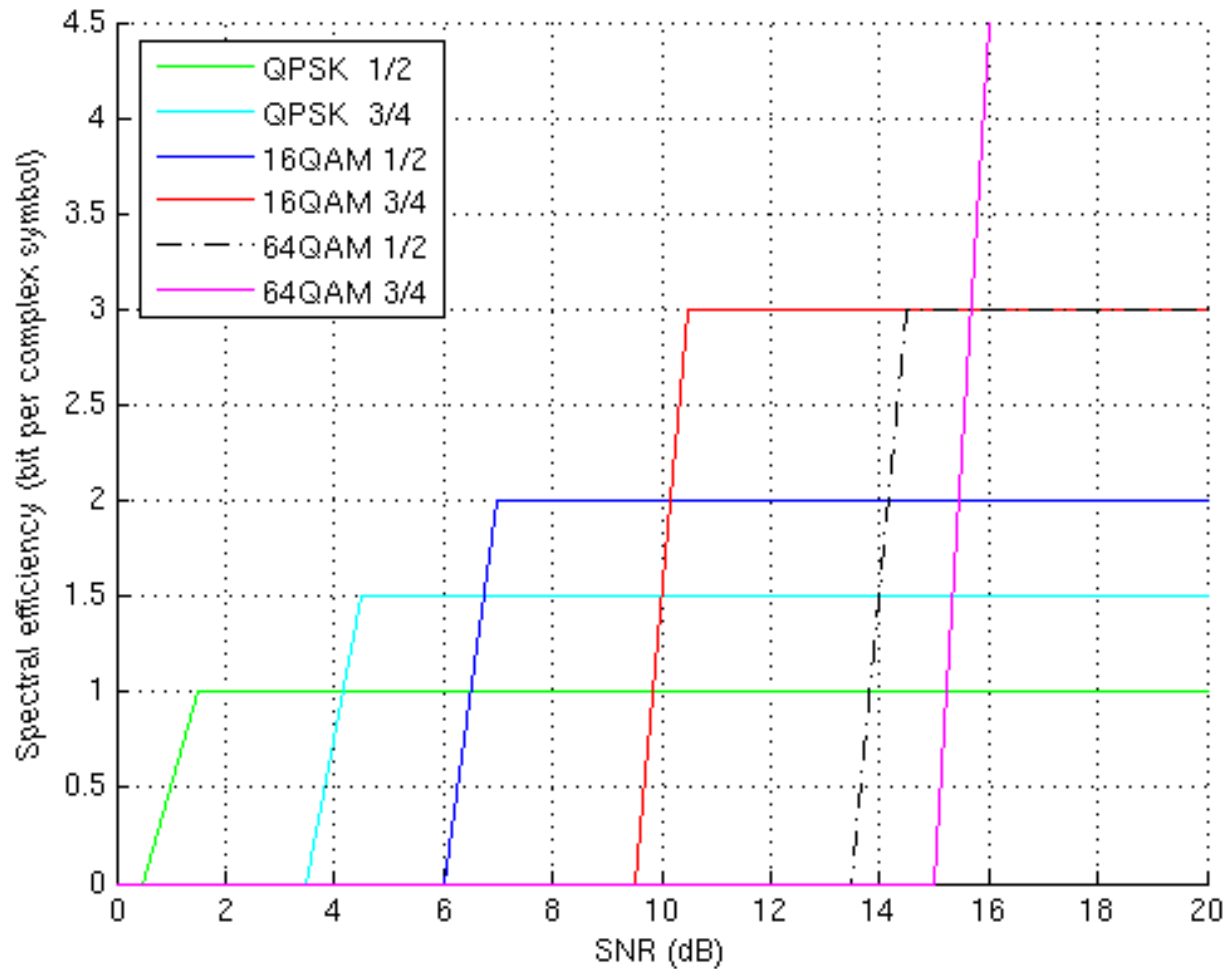
Alamouti/MRC vs. Spatial Multiplexing



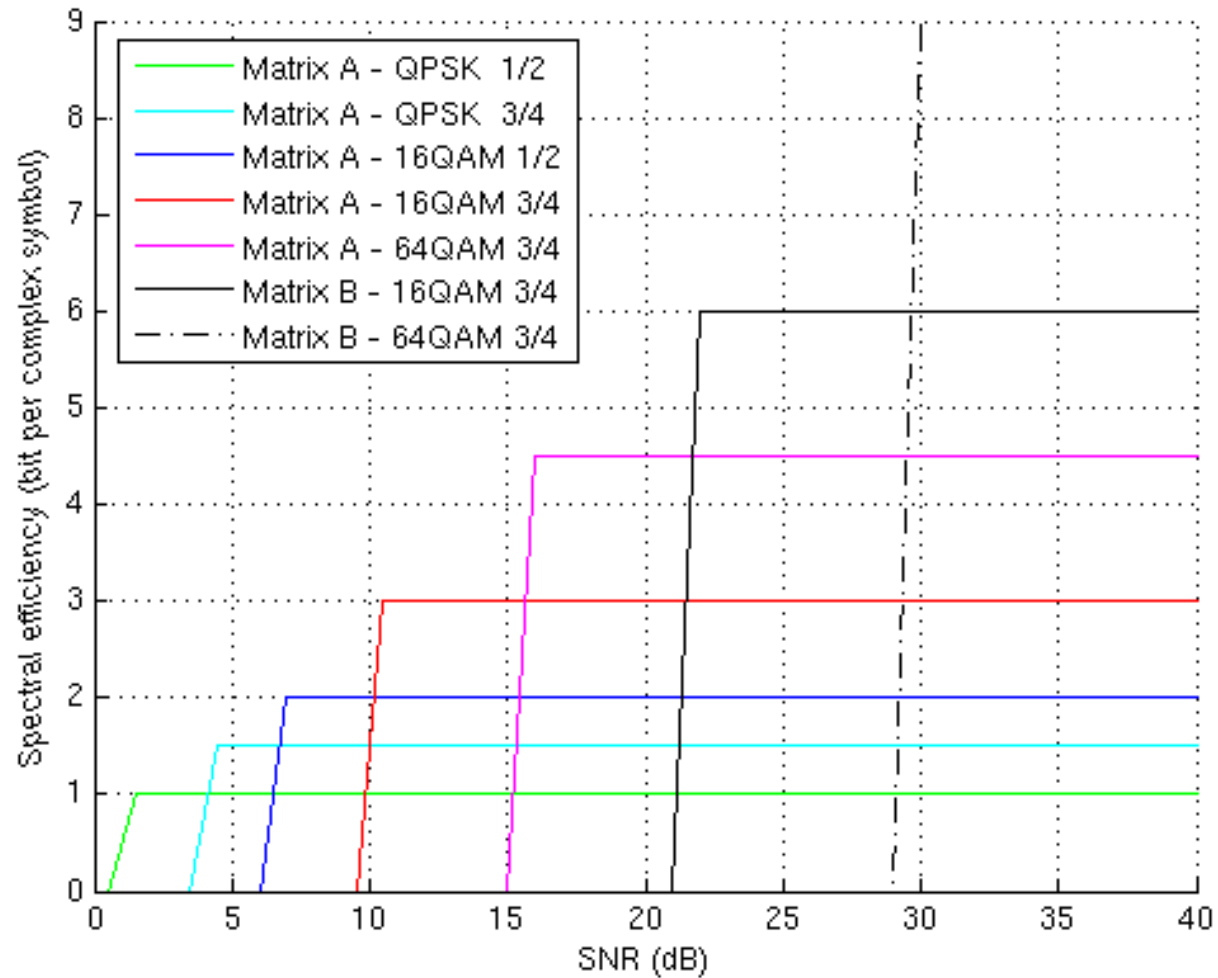
MIMO Link Adaptation

- ❑ 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.