MIMO Systems: An Introduction to Equalisation & Precoding Techniques for Spatial Interference

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Adaptive DSP course for MSc & PhD students — Lecture no. 1

May 7, 2011

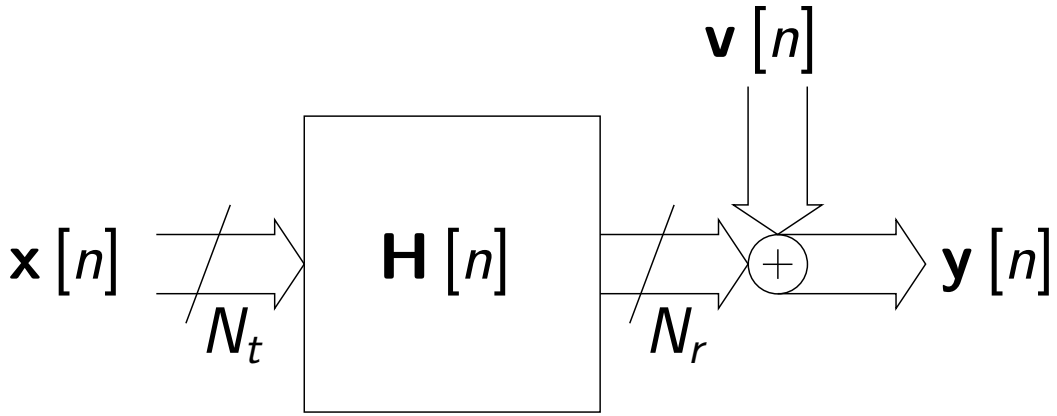
Overview

Why MIMO systems

- With the increased demand for high-quality wireless communication services and the scarcity of available radio spectrum, wireless communications with multiple-input multiple-output (MIMO) systems are emerged
- MIMO technology promises significant improvements in terms of:
  - Spectral efficiency which can be realised through spatial multiplexing
  - Or link reliability using space-time coding
- The focus here will be on multiplexing gain of narrowband MIMO systems
- In order to realise its anticipated gain an efficient equaliser/precoder should be aimed

What is a MIMO system?

General MIMO channel model:



A MIMO frequency selective (broadband) channel created by N_t transmit and N_r receive antennas can be described by a finite impulse response (FIR) filter $\mathbf{H}[n]$ of order Q or its corresponding transfer function $\mathbf{H}(z)$ given by

$$\mathbf{H}(z) = \sum_{n=0}^{Q} z^{-n} \mathbf{H}[n] \ . \tag{1}$$

What is a MIMO system?

The channel $\mathbf{H}(z)$in (1) results in a transmission system that suffers from both:

- spatial interference, sometimes refers to as co-channel interference (CCI)
- temporal interference or inter-symbol interference (ISI)

The received data vector $\mathbf{y}[n] \in \mathbb{C}^{N_r}$ is therefore given by

$$\mathbf{y}[n] = \sum_{\nu=0}^{Q} \mathbf{H}[\nu] \cdot \mathbf{x}[n-\nu] + \mathbf{v}[n], \tag{2}$$

where $\mathbf{x}[n] \in \mathbb{C}^{N_t}$ and $\mathbf{v}[n] \in \mathbb{C}^{N_r}$ are, respectively, the transmitted data and noise vectors at symbol period n. Later we will be interested only in MIMO narrowband systems

Some terms definition

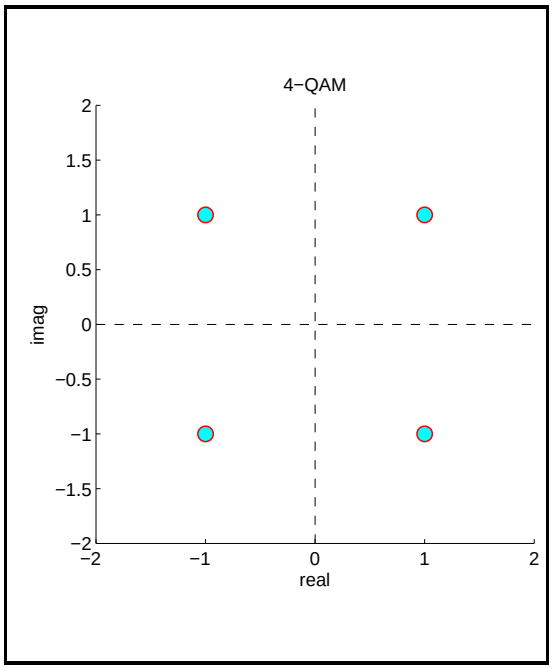
- Signal-to-noise ratio (SNR)
- Bit and symbol error ratios (BER & SER)
- QAM and PSK modulations
- Additive White Gaussian Noise (AWGN)
- An equaliser and a precoder

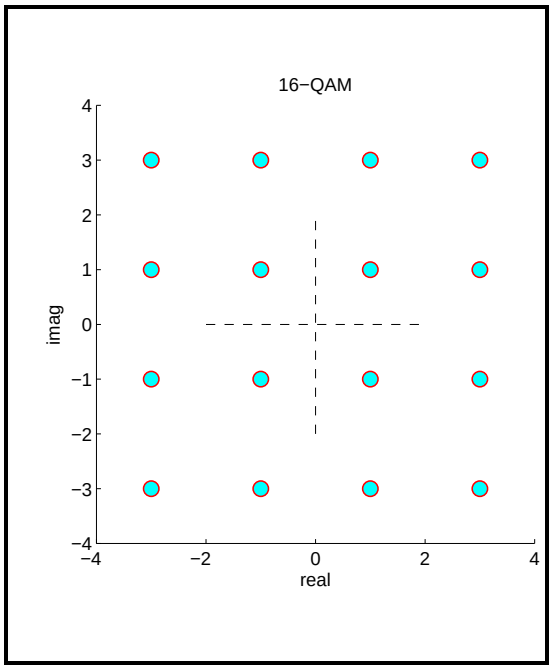
Common QAM constellations

A transmitted symbol $s \in \mathcal{S}$of a QAM constellation of size (order) M can be defined as

$$\mathcal{S} \stackrel{d}{=} \left\{ s^I + js^Q \mid s^I, s^Q \in \left\{ \pm 1, \pm 3, \cdots, \pm \left(\sqrt{M} - 1 \right) \right\} \right\}, \tag{3}$$

where $\mathcal{S}$ is the set of the possible alphabets





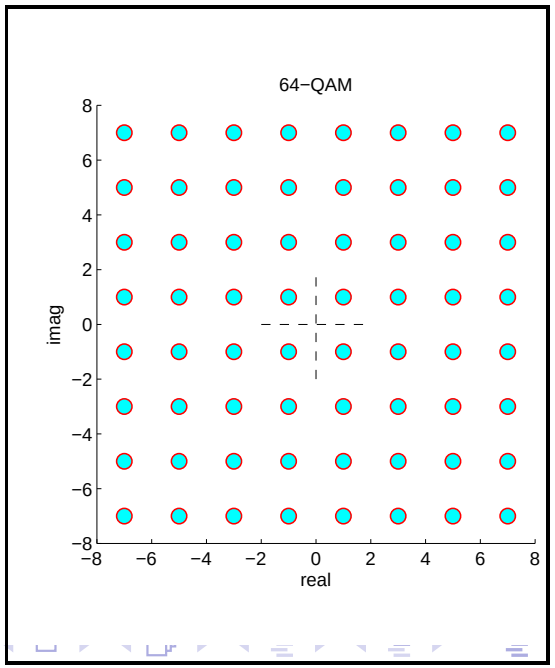
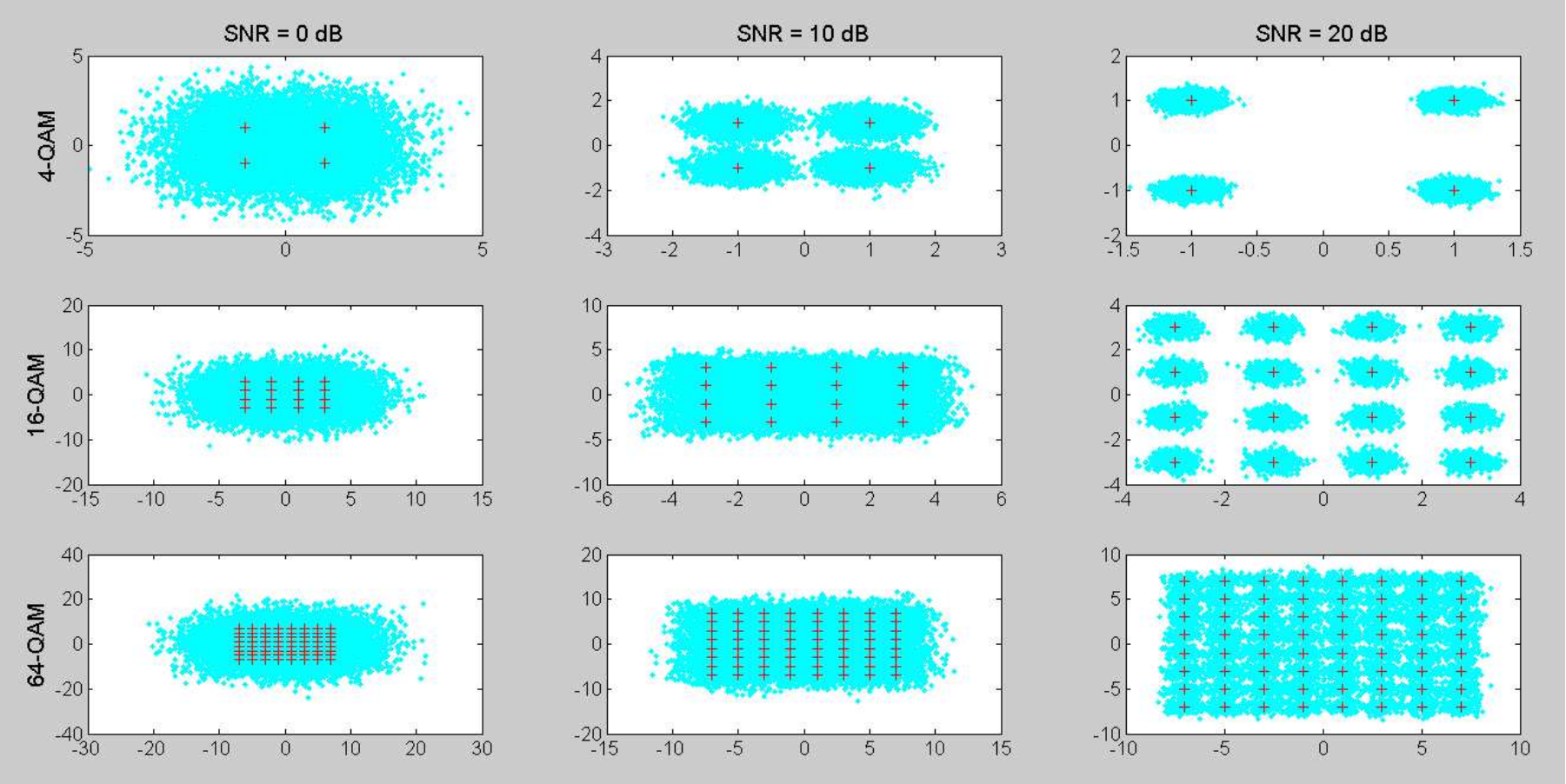


Illustration of AWGN channels



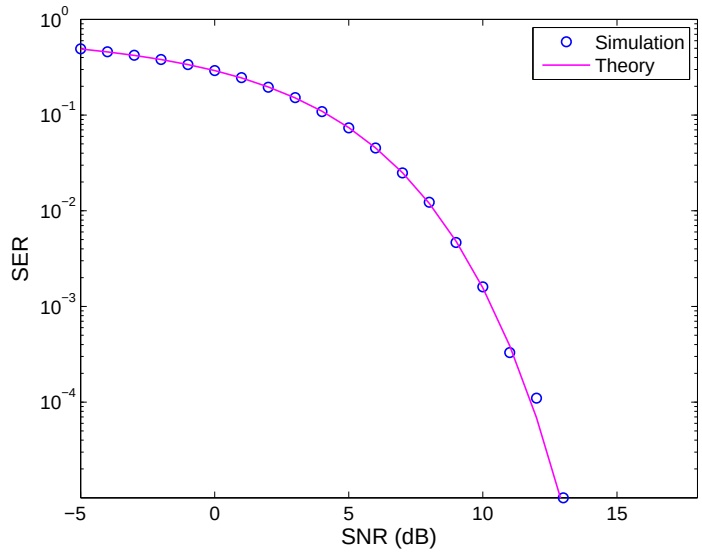
Performance of AWGN channels

The BER of M-QAM modulation scheme can be given by [1]

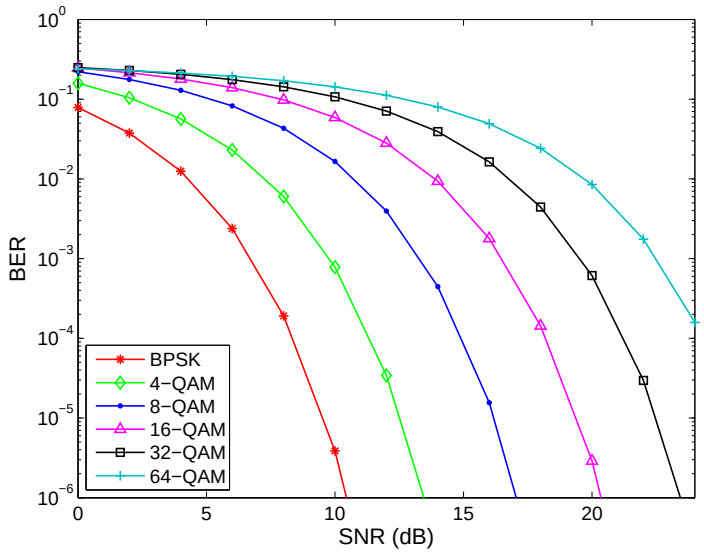
$$\mathrm{BER} = \begin{cases} Q\left(\sqrt{2\gamma}\right) & \text{for BPSK,} \\ \dfrac{1-\left[1-2\left(1-\frac{1}{\sqrt{M}}\right)Q\left(\sqrt{\frac{3\gamma}{M-1}}\right)\right]^2}{\log_2 M} & \text{for } M\,\mathrm{QAM,} \end{cases} \tag{4}$$

where γ is the operating SNR and $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-u^2/2} du$, is the well-known Q-function

AWGN performance for 4-QAM transmission



AWGN performance for different QAM modulations



Conclusion

Concluding remarks

- A brief introduction of MIMO technology is introduced highlighted by some terms definition
- AWGN channels with simulation results of BER performance for different QAM orders have been introduced
- Both multiplexing and diversity gains of MIMO systems have been summarised
- Next — linear equalisation/precoding systems for a MIMO channel will be studied

 A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.