Wireless Communications project: comparison of different beamforming techniques in a mobile telecommunication system

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Abstract

In this project we implemented, using the MATLAB language and its toolboxes, a mobile communication system. We analyzed the impact of two different beamforming techniques: the Direction of Arrival (DoA) and the Least Mean Squares (LMS) algorithm in presence of multipath fading. Finally, comparisons between the two methods are presented.

1 Scenario description

The communication system is made by a Base Station (BS), positioned at a height, and by four terminals situated on the ground. Two of the terminals are the User Equipments (UEs) whose performance we want to analyze, while the other two are interferers. The terminals are free to move on the map. Movement is modeled by updating the UEs' coordinates in a while cycle: in each iteration the beamforming operations are performed. Both the distance traveled and the movement direction are random.

1.1 Communication equipment and modulation

The BS employs a 4x4 Uniform Rectangular Array (URA) of antennas. Each antenna is spaced by a distance equal to half a wavelength. The UEs transmit the signals and they have one antenna. The terminals employ an OFDM modulation with the following parameters:

- FFTLength = 64 (i.e. the total number of sub-carriers)
- Guard band sub-carriers = 2 (located at the beginning and at the end of the spectrum)
- Pilot sub-carriers = 2 (adjacent to the guard band ones)
- Cyclic prefix length = FFTLength/2
- Modulation transported: 8-QAM

The OFDM parameters are located in the OFDMSignal.m function and can be freely modified: the modulation order is otherwise specified in the main scripts.

2 Channel models

This project employs two channel models:

- **Line of Sight (LoS):** this model is used for the DoA beamforming and comparisons with LMS. Attenuation follows the free-space model (i.e $= L = \left(\frac{4\pi d}{\lambda}\right)^2$). The channel is additionally characterized by the presence of AWGN.

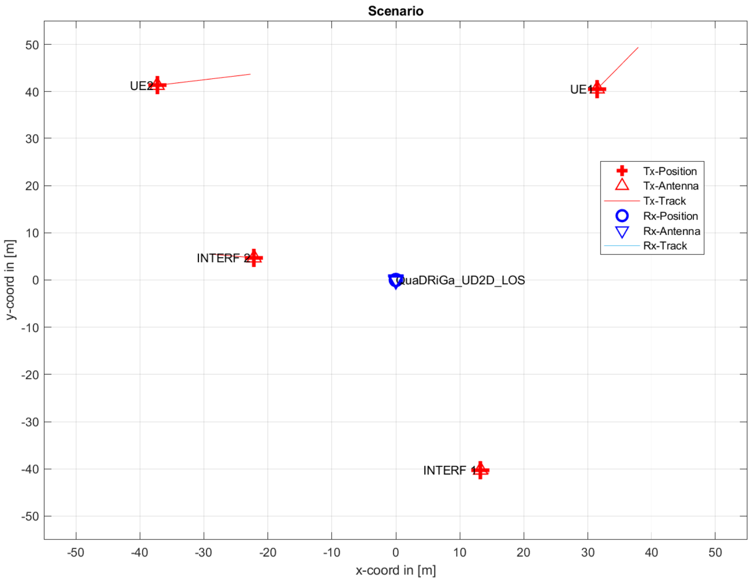

Figure 1: A bird's-eye visual representation of the scenario

- **QuaDriGa Channel Model:** it is a 3GPP compliant channel model used for characterizing systems affected by multipath fading. In this project it is used for the LMS beamforming algorithm (no DoA is available).The channel is generated as follows:
    1. At the start of the iteration, a track for the UEs is defined as stated before.
    2. Channel coefficients and delay taps are calculated for each terminal.
    3. To obtain the channel in the track we perform the interpolation between the delay taps and the transmitted signal: the result is then multiplied by the channel coefficient
    4. The four signals of each terminal are summed into a unique channel and AWGN is added.

For both models, the channel is calculated again at each iteration.

3 LMS beamforming

Given the transmitted signal $\mathbf{r}$, the channel matrix $\mathbf{C_{out}}$ and the number of elements in the URA n, the LMS algorithm calculates the weight vector $\mathbf{w}$ as follows:

$$\mathbf{w_{n+1}} = \mathbf{w_n} - \frac{1}{2}\mu\widehat{\nabla}_{\mathbf{w}}\mathbf{MSE}(\mathbf{w})|_{\mathbf{w}=\mathbf{w_n}}$$

with

$$\widehat{\nabla}_{\mathbf{w}}\mathbf{MSE}(\mathbf{w})|_{\mathbf{w}=\mathbf{w_n}} = 2\mathbf{u_n} + e_n$$

where $e_n = y_n - w_n$ is the error between the transmitted signal and the received one.
μ is the gradient step size and is defined as $\mu = \dfrac{2}{\mathrm{Tr}(\mathbf{C_{out}})}$

The MATLAB implementation of this algorithm may be found in the `LMSalgorithm.m` function file. After the weight vector is calculated, the script proceeds to multiply the signal received from the two UEs that we wish to track with it. Then a comparison between the BER calculated with and without beamforming is performed for different values of the SNR.

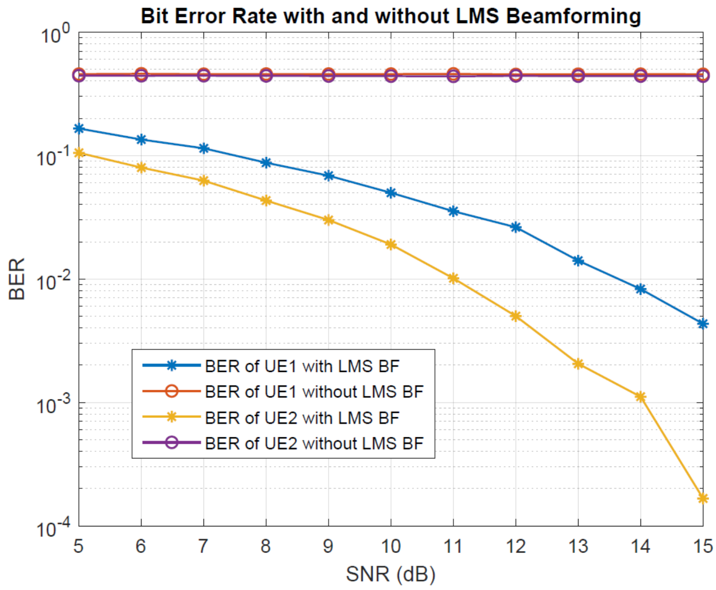

Figure 2: Results of the comparisons for different SNRs.

As we can see from Figure 2, the LMS beamforming dramatically improves performance, in particular for high values of SNR.