Wireless communications
-
Adaptive beamforming

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https://github.com/BernardoCama/WirelessCommunicationProject

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1 Introduction

In this section, we describe briefly the key concepts that are mandatory for the comprehension of the project.

1.1 OFDM signal

OFDM (Orthogonal Frequency Division Multiplexing) is a multi-carrier modulation that is able to obtain:

1. **Flexibilty** By means of:
   - **Adaptive Bit Loading** Adaptive modulation, coding for each subcarrier.
   - **Multiple Access** Multiple Access Feature with the use of OFDMA.
2. **Digital Implementation** With the use of DFT and IDFT at Tx and Rx side respectively to pass from Samples in frequency domain to time domain and viceversa.
3. **Simple Equalization** Through the use of Cyclic Prefix that permits the rapresentation of the channel with a single tap (Flat Ch) in each subcarrier.
4. **MIMO Implemetaion** Suited for the use of MIMO/MMIMO Systems.

The main parameters of the Modulation are:

1. **Nsc** Number of sub-carrier which usually is in the form 2^b since it is optimized for the FFT and IFFT implementaion.
   In our case: Nsc = 64.
2. **CyclicPrefixLength** The length of Cyclic Prefix that must be much smaller than Ts (OFDM Symbol Time).
   In our case: CyclicPrefixLength = 4.
3. **NumGuardBandCarriers** The number of Guard Bands in frequency domain to protect the OFDM Spectrum from other adjacent trasmissions.
   In our case: NumGuardBandCarriers = [1;1] one for each side.
4. **Pilot Positions** The sub-carrier location of Pilot signals, known sequence of symbols that are used to estimate tha channel.
   In our case: Pilotindices = [2]. We really don'use use the Pilot, since we consider the first symbols of the transmission as known, but for completeness we dropped off at least one Pilot.

1.2 3GPP Standard

3GPP (3rd Generation Partnership Project) was founded in December 1998 when the European Telecommunications Standards Institute (ETSI) and other standard development organizations (SDOs) from around the world to develop new technologies (technology specifications).

As Channel Model we use QuaDRiGa (QUAsi Deterministic RadIo channel GenerAtor) that generates realistic radio channel impulse responses for system-level simulations of mobile radio networks. Quadriga indeed is able to simulate 3GPP channel models like 3GPP-3D and also the latest New Radio channel model.

1.3 Beamforming

A beamformer can be considered a spatial filter that suppresses the signal from all directions, except the desired ones by means of weights applied to the signals coming from the single array elements; resulting in controlling the radiation pattern of the array.

The **Array Pattern Function** $AF(\theta, \phi)$ is the gain that we can obtain with the Beamformer in a given direction specified by:

- θ = Elevation ($\pi/2$ - zenith of arrival)
- ϕ = AoA (angle of arrival)

and it is defined as:

$AF(\theta, \phi) = w^H s$ where:

- s are the Steering Vectors
- w are the weigths of the Beamformer

In the project, in particular in Section 4., we compare the different **Array Pattern Function** of various type of Beamformer.

2 Project description

In this section, we describe the structure of out project with a brief description of the main points of all the parts composing our work.

2.1 Beamforming techniques

We have implemented 5 beamforming techniques:

1. **Simple beamforming** The phases are selected to steer the array in a particular direction.

2. **Null-steering beamforming** Used to cancel K ¡= N-2 plane waves arriving from known directions.

3. **Minimun variance distiortionless response (MVDR) beamforming** This beamformer minimizes the interference-plus- noise power at the output of the beamformer.

4. **Minimum mean square error (MMSE) beamforming** The weigths of the antennas are adjusted in a way that the MSE between the output of the beamformer and the reference signal is minimized.

5. **Least mean square (LMS) beamforming** This iterative algorithms adjust the weights by estimating the gradient of the MSE and moving them in the negative direction of the gradient at each iteration. We have implemented this iterative algorithm both in the time and in the frequency domain.

2.2 Channels

All the 5 beamformers have been tested on 3 different channel:

1. **LOS channel** A simple line of sigth channel with no reflections.

2. **Two-ray channel** For each signal, we consider a direct path (LOS) and a single reflection.

3. **Quadriga channel** Here, the scenario we have used is the *QuaDRiGa_UD2D_LOS*.

2.3 Signals

For all the beamformers and in all the channel, the bits we transmit are generated randomly and modulated fist with a 4QAM modulation (we have also tested the beamformers with a 16QAM); then, the QAM symbols are modulated with OFDM for transmission.

2.4 Reported results

In this report, we only describe the three most important simulations we have done:

1. Comparison between the SNR at the input and at the output of all the five beamformers in a LOS channel (section 3).
2. Comparison of the performance in terms of constellations revealed, weigths of the antennas and BER for all the five beamformers considering different antenna arrays (section 4). This has been done in the quadriga channel and using the LMS beamformer in the time domain.
3. Traking of two vehicles using LMS beamforming in the frequency domain (section 5).

All the other simulations we have done can be found on the *Github* repository of the project (link in title page).

3 SNR comparison

4 Antenna array comparison

5 Tracking

6 Conclusions