ETIN85: Wireless Communication Channels
Assignment 2

Course Lecturer: Harsh Tataria
Handed Out: Lecture time, 18 February 2019
Due Date: 5 pm, 25 February 2019

1 Introduction and Preparation

This assignment is distributed in **two** parts: The **first** part aims to understand wideband propagation channel properties, while part **two** composes of investigations on multiple-input multiple-output (MIMO), and directional aspects of the propagation channel. To ensure that you are fully prepared to take on the questions in the assignment, it is strongly recommended that you revise the material from the relevant lectures, as well as the corresponding chapters and sections in the course textbook by Prof. Andreas F. Molisch.

2 Part 1 - Wideband Propagation Channel Characterization

2.1 Aim

The aim of this part is to analyze the distribution of the received power, and amplitudes for an indoor, small range wireless system. Furthermore, the aim is to investigate the behavior of the channel impulse response, and how this relates to the bandwidth of the system. Finally, the power delay profile (PDP), the root mean square (RMS) delay spread, as well as time and frequency correlation properties will be investigated. We will be using channel measurement data to evaluate the aforementioned properties, where the measurement setup utilized is described below:

2.2 Measurement setup

The channel measurements are performed with a vector network analyzer (VNA) connected to two broadband antennas. These antennas are positioned along a straight rail with stepper motor control, interfaced with a host computer running LabView (software from National Instruments Inc.) to control the measurement apparatus. An overview of the system is found in Figure 1. The network analyzer measures the channel transfer function, $H(t, f)$, at a given number of frequency points. Both the number of points,
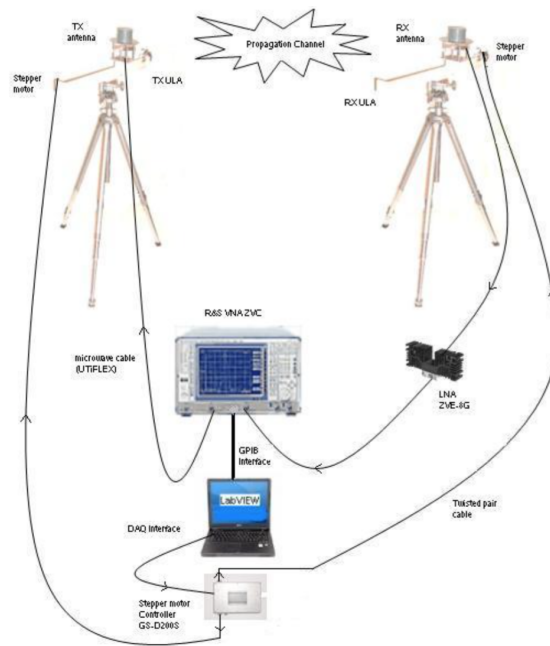
Figure 1: Measurement setup with a VNA, and two rails for positioning the Tx and Rx antennas. Both the VNA and the stepper motors connected to the rails are controlled through software via a LabView program. The antennas are broadband antennas for the 5 GHz band.

N_f, and the frequency band, is controlled by the LabView program. Due to frequency regulations, we use the 5 GHz band for conducting the experiment. By moving the antennas between each measurement, we can follow the transfer function along the straight trajectory. Since the run time of the measurements is in the order of minutes, we must make sure that the channel remains relatively static during this time. Furthermore, provided we know the distance between the measurements we can then evaluate the channel response for an arbitrary receiver or transmitter location and velocity afterwards. We have already discussed the measurement setup and the different measurement settings. The transfer function is measured using the following settings:

- Frequency band: $5.4 - 5.6$ GHz

- Frequency points: $N_f = 401$

- Number of positions along the linear rail/linear trajectory: 91

- Antenna spacing along the linear rail/trajectory: $\Delta d = 0.5$ cm.

2.3 Measurement data and tasks

You have access to the MATLAB data set, which is called `Hcorrected.mat`. Load this measurement data set into MATLAB using the `load` command. Then proceed to investigate the following:

- Plot, identify, and comment on the behavior of the time-dependent (or position-dependent in this case) freqeuncy transfer function $H(t, f)$.

- Plot, identify, and comment the behavior of the channel impulse response $h(t, \tau)$. Do this for the full bandwidth, as well as for a moderate and small bandwidth. Feel free to select appropriate bandwidth values for these cases, obviously less than 20 MHz.

- Investigate and comment on the distribution of the amplitude of the frequency transfer function. You do not have to fit the measured data to a certain distribution, but please discuss possible distributions that could be appropriate, and compare the results you obtain from these distributions.

- Investigate and comment on the distribution of the amplitude for different taps of the impulse response.

- Derive, plot and comment on the measured PDP.

- Based on the PDP, calculate the RMS delay spread of the channel.

- **Optional:** Plot the Doppler power spectra and investigate the time and frequency correlation behavior of these channels.
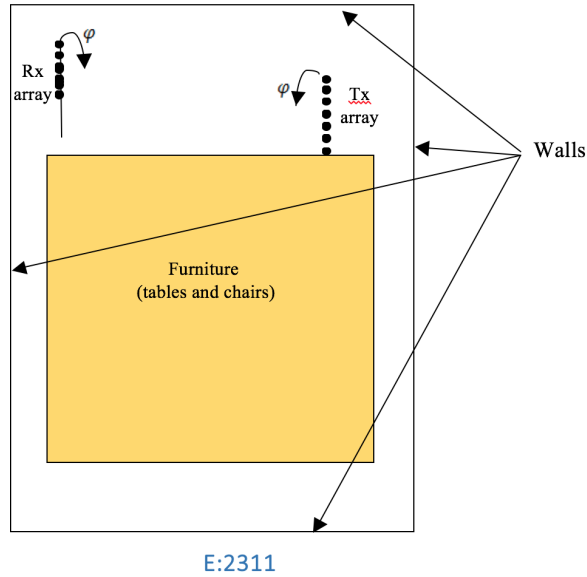
Figure 2: Measurement setup for the 8×8 MIMO case.

3 Part 2 - MIMO Systems and Directional Propagation

3.1 Aim

For the second part of the assignment, our aim is to estimate the directions-of-departure, and directions-of-arrival-based on a measured 8×8 MIMO system. As discussed in class, this can be done using a simple beamforming method and the minimum variance distortionless response (MVDR) beamformer.

3.2 Measurement setup

This measurement setup is similar to that of part 1, but is for an 8×8 MIMO system with uniform linear arrays (ULAs) at each link end. The measurements were performed in E:2311, and the basic measurement setup is shown in Figure 2.

The transfer function is measured in a similar manner as in part 1, using the following settings on the VNA:

- Frequency band: $5.1 - 5.3$ GHz

- Frequency points: $N_f = 201$

- Number of (virtual) Tx elements: 8

- Number of (virtual) Rx elements: 8

- Antenna spacing for the uniform linear arrays (same at Tx and Rx): $\Delta d = \lambda/2$.

3.3 Measurement data and tasks

Load the data set `T_MIMO.mat` into Matlab. You should now see a MIMO channel matrix in the workspace. This matrix, $H(n_{\mathrm{Rx}}, n_{\mathrm{Tx}}, f)$ is of size $8 \times 8 \times 201$, where n_{Rx} and n_{Tx} denote the indices of the receive and transmit antenna elements, respectively. The measured signal can be modelled as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n},$$

where $\mathbf{y}$ is the received signal, $\mathbf{x}$ is the transmitted signal and $\mathbf{n}$ is a noise vector. The goal is now to estimate the directions-of-arrival and departures for the line-of-sight (LOS) components. In order to do this, we need the correlation matrix describing the signal at Rx array for the DOA, which is given by

$$\mathbf{R}_{rr} = \mathcal{E}[\mathbf{r}(t)\mathbf{r}^H(t)],$$

where $r(t)$ is the array response, i.e., the received signal at all the antenna elements. Since this matrix (of size 8 by 8) is defined as an expected value, we have to estimate it as well as we can. For the measurement we can use the fact that the signal is transmitted from 8 independent positions to get an estimate of the expected value. The beamforming can be performed in either the delay-domain or in the frequency domain.

We also have to define the beamsteering vector, which is a function of the direction of arrival, θ, which for an 8 element ULA is given by:

$$\mathbf{a}(\theta) = [1 \ \ \mathrm{e}^{-j\frac{2\pi}{\lambda}\Delta d\cos(\theta)} \ \ \mathrm{e}^{-j2\frac{2\pi}{\lambda}\Delta d\cos(\theta)} \ \ \ldots \ \ \mathrm{e}^{-j7\frac{2\pi}{\lambda}\Delta d\cos(\theta)}]^T.$$

Now, we can find the angular spectrum (spectrum of all directions-of-departures and arrivals) for the **conventional beamformer**, which is given by

$$P_{BF}(\theta) = \frac{\mathbf{a}^H(\theta)\mathbf{R}_{rr}\mathbf{a}(\theta)}{\mathbf{a}^H(\theta)\mathbf{a}(\theta)}.$$

Now find the same angles via the MVDR beamformer, which is given by

$$P_{BF}(\theta) = \frac{1}{\mathbf{a}^H(\theta)\mathbf{R}_{rr}^{-1}\mathbf{a}(\theta)}.$$

Discuss your findings and the trends you observe.

Assignment Submission

Submit your assignment no later than on 5 pm on 25 February. Your submission should include the following:

- A technical document, where you discuss and adress your findings and present your results using different figures and by giving different experimental parameters estimates that you have derived.

- Include plots of your results. Those plots should be nice and clear with labels on the axes and decent units. Note that jpeg-files do not produce nice and clear MATLAB plots, jpeg is good for photos but not for graphs.

- Submit your code as an appendix in the same document. This should be added as an appendix in the technical document that you provide. Do not submit m-files separately.

Submit a pdf-file to the course lecturer, before the deadline. Name your file EITN85-ASSIGN2-Lastname1.pdf. If you discuss ANY part of the assignment with anyone else in the class, you need to declare this on the front page of the assignment report document.

Good luck!
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