Labs in Information and Communication Technologies **Assignment 3**
Spring Semester
Telecommunications Circuits Laboratory
EPFL

Digital Communications: Receiver

In modern digital communication systems, the reliable reception of transmitted signals is challenged by a range of physical-layer impairments, including additive noise, multipath propagation, and synchronization errors. Understanding these phenomena is critical as they affect almost every transmission systems from copper wire to optical fiber and from Bluetooth to 6G.

This laboratory is structured in two parts:

1. Characterization of receiver impairments
   - Investigate the impact of Additive White Gaussian Noise (AWGN), multipath fading, and synchronization offsets (timing/phase/frequency) on demodulation performance.
   - Quantify the relationship between modulation order (BPSK, QPSK, QAM) and error resilience using constellation diagrams and eye patterns.
2. Practical signal recovery with SDR
   - Apply synchronization techniques to recover a BPSK signal transmitted over a real channel.

1 Transmission Impairments

During transmission, signals are subject to multiple physical-layer impairments that degrade signal integrity and limit reception quality. These distortions arise from fundamental limitations of communication channels and hardware implementations.
In this section, we will study the effect of the main impairments on the received signal to build an intuition on the challenges of digital communications.
Open the flowgraph `digital_tx_rx.grc` in GNU Radio Companion and run it.

Between each of the following sections (impairment types), reset the flowgraph to its initial state. You will experiment with impairments individually, not cumulatively, unless explicitely asked.

1.1 Additive White Gaussian Noise (AWGN)

AWGN represents the fundamental noise process in communication systems, arising from thermal agitation of electrons and other random phenomena in receiver components. It is called additive because the noise is added to the signal. The term white means the noise has equal power across all frequencies. The noise is Gaussian because its amplitude follows a normal distribution.

In the flowgraph, you can choose how much noise you want to add to the signal in dBm. The relationship between the power in dBm and the power in mW is given by the following equation:

$$P_{mW} = 10^{\frac{P_{dBm}}{10}} \text{ mW} \tag{1}$$

Task-1.1 The received signal power is 0 dBm. Calculate the noise power (in dBm) that is 1/100th of the signal power.

What is the vertical eye opening of the received signal, does it depend on the rolloff factor?

Task-1.2 For which constellation(s) would you see demodulation errors at the noise level you set in Task 1.1?

Task-1.3 When using BPSK, what is the maximum noise value you can set in the flowgraph before you start seeing demodulation errors?

Provide a screenshot of the received constellation.

1.2 Multipath

In real-world environments, signals reach the receiver through multiple paths that are delayed in time and have different amplitudes. The signal from these different paths will add together and create a new signal measured by the receiver as illustrated in Figure 1.

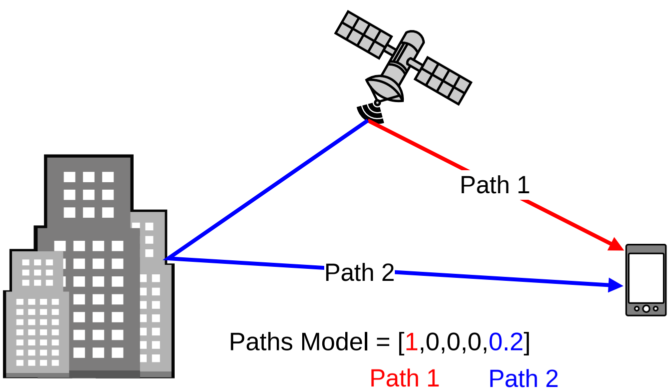

Figure 1: Multipath Illustration

In the flowgraph, you can define how late different paths arrive at the receiver and what is their ratio of power. By default, we have only one path with 100% of the energy, described by the vector [1,0,0,0,0,0,0]. Each entry of the vector indicates the path received at an interval of $0.1\,\mu$s.

Task-2.1 What is difference in length (in meter) of the paths described by two consecutive entries of the vector?

Task-2.2 Configure the flowgraph to have one direct path, and one additional path arriving with a delay of $0.8\,\mu$s with half the power of the first path.
What is your *Multipath taps* configuration?
What is the eye opening of the received signal when using a filter with a rolloff factor of 1? (Remember to measure the exe opening at the sampling time)
Provide a screenshot of the received constellation for QPSK.
Would you have systematic demodulation errors with this configuration for QAM16?

Task-2.3 What if there was an additional path arriving with the same energy as the first path with a delay of $0.1\,\mu$s?
What if you use a filter with a rolloff factor of 0.1?

1.3 Sampling Time Offset

The receiver must sample the incoming signal at optimal time to maximize the eye opening. However, the sampling time is not known at the receiver and must be estimated.

Task-3.1 What is the minimum rolloff factor needed for a QAM16 modulation to not have any systematic demodulation errors with a sampling time offset of $0.2\,\mu$s? Provide a screenshot of the eye diagram

1.4 Phase Offset

At the receiver, the phase of the signal is not known. It depends on the distance between the transmitter and the receiver, the Doppler effect, and the local oscillator used in the receiver.

Task-4.1 What is the maximum phase offset you can have before you start seeing systematic demodulation errors using QPSK?
What about BPSK and QAM64?

1.5 Carrier Frequency Offset

Due to the mismatch between the local oscillator and the carrier frequency, the receiver will suffer from carrier frequency offset (CFO).
The CFO causes the error of phase to accumulate over time, and make the received constellation rotate if not taken care of.

Task-5.1 With a carrier frequency offset of 0.1 Hz, how long will it take for the signal to rotate $90°$?

Task-5.2 For BPSK, the eye diagram is opening and closing periodically.
What values will the demodulated bit take when the offset is between 90 and $270°$?

2 BPSK Signal Reception

You will now use an SDR to receive and decode a real signal. Borrow the radio and antenna from the TA. Open the flowgraph `bpsk_rx.grc` and run it.
Someone is transmitting an RF signal, however you only have partial information about the transmission parameters. Your objective is to use what you have learned until now to decode the transmitted data.
Here are the parameters you know about the transmitted signal:

Parameter	**Value**
Carrier Frequency	Somewhere between 860 and 880 MHz
Bandwidth	130 kHz
Modulation	BPSK
Pulse shape	Root raised cosine with rolloff $\in [0.1, 1]$
Data rate	64 kb/s
Payload	4 B
Preamble	[10111101]

Table 1: Transmitted Signal Parameters

Task-6.1 What is the center frequency of the transmission? Provide a screenshot of the received constellation.

Task-6.2 Unless particularly lucky, the received signal suffers from a large carrier frequency offset (CFO). This offsets makes the constellation rotate very fast and needs to be compensated to read any meaningful values.
The value of the estimated CFO is given in the GUI. What happens if you try using this value as a carrier offset compensation?

Task-6.3 Compensating for the phase by hand is very difficult. Therefore, we implemented a simple synchronization algorithm that can track the phase drift.
Turn the `Auto CFO` ON.
What happens to the constellation?

Task-6.4 Find the rolloff factor that gives the best eye opening and provide a screenshot of the eye diagram.

Task-6.5 Choose the optimal sampling time offset. Is it constant, if not why?
Provide a screenshot of the constellation, eye diagram and sampled signal at the best sampling time offset.

Task-6.6 Finally, we want to decode the received data. To identify when the data starts, the transmitter sends first the sequence [10111101] as a preamble followed by the data bits. This sequence of preamble and payload is repeated indefinitely.
Knowing that data bit are a text encoded in ASCII, what is the transmitted message?

Task-6.7 Can you recover the same bit sequence without using the *Auto CFO* feature?
Provide a screenshot of the complete window except the spectrogram.