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Digital Communications

Lab Session I

November 2nd, 2015

1 Receiver for LTE Primary Synchronization Signals (PSS)

The goal of this lab session is to investigate the receivers for the PSS signals used 3GPP-LTE systems. These are the most basic signals that a terminal must detect prior to initiating a connection with the basestation. This detection is the first step in the so-called *cell search* procedure.

You are to hand-in a report answering all the questions outlined here along with corresponding MATLAB code and figure files. If you do not finish in the supervised period of the session, you can continue to work on your own time.

1.1 PSS signals

We are concerned with complex baseband equivalent transmit signals of the form

$$\tilde{s}_{\mathrm{PSS},i}(n) = \sum_k x_i(n-kN), i = 0,1,2$$

where N is the periodicity of the PSS signals which is 76800 samples for a 10 MHz channel. i is the index of the transmitted PSS signal and can have one of three values. $x_i(n)$ is the PSS signal itself which is of duration $N_{\mathrm{PSS}} = 1104$ samples, again for a 10MHz channel. For all signals in this lab session, the sampling rate is assumed to be 15.36 Msamples/s.

1.1.1 Questions

1. Using the supplied MATLAB file (`pss.m`) plot the real, imaginary components and magnitude of the one of the PSS signals. What do you see?
2. Plot the power spectrum of the PSS signal on a dB-scale (using the MATLAB FFT). Estimate the bandwidth as closely as possible (in terms of physical frequencies). What do you observe about the PSS signal?
3. Plot the three auto-correlation functions and the three cross-correlation functions. To what extent can we say that these three signals are orthogonal? When using one PSS as a basis function, what is the ratio of signal energy to interference in dB if we assume that these are orthogonal?

1.2 Channel Model

The received signal is assumed to be of the form

$$y(n) = e^{2\pi j\Delta fn}\tilde{s}_{\mathrm{PSS},i}(n) * h(n) + z(n)$$

where $h(n)$ is assumed to a finite-impulse channel which is unknown to the receiver, $z(n)$ is complex circularly-symmetric and additive white Gaussian noise, and Δf is an unknown frequency-offset. We can assume that the channel is of the form

$$h(n) = \sum_{l=-L/2+1}^{L/2} a_l \delta(n - N_f - l)$$

for some even number L. The a_l are complex amplitudes unknown to the receiver and N_f is a presentation of the unknown timing offset between the transmitter and receiver.

1.2.1 Questions

1. Acquire several signal snapshots of 10 ms duration using the USRP. Hold the antenna in a different position for each snapshot.
2. Plot the time and frequency representations of the signals on a dB scale. What do you see?
3. Estimate the bandwidth of the received signal? What are the signal components that are located outside the band of interest?
4. In your opinion what contributes to the "changing shape" of the main signal component?

1.3 Receiver

The primary objective is to determine the most likely i, or index of the transmitted PSS. In addition we would like to have the best estimate of N_f and Δf since these are required to detect the other signal components after the PSS. This will be investigated in other lab sessions. There are different approaches to doing this, but here we will take the approach where N_f and Δf are discretized and are detected in a similar fashion to i. Let us assume that N_f is discretized to the resolution of one sample. Since the periodicity of the PSS is $N = 76800$ samples, N_f can assume the values $\{0, 1, \cdots, N-1\}$. Although a purely continuous random variable, we will also discretize Δf as $\Delta f = m\Delta f_{\mathrm{min}}, m = -\Delta f_{\mathrm{max}}/\Delta_f \mathrm{min}, \cdots, \Delta f_{\mathrm{max}}/\Delta_f \mathrm{min}$, where Δf_{max} is the largest frequency-offset we are likely to encounter. Under these assumptions we will consider the following detection rule for the triple (i, N_f, m)

$$(\hat{i}, \hat{N}_f, \hat{m}) = \underset{i, N_f, m}{\mathrm{argmax}} Y(i, N_f, m)$$

where $Y(i, N_f, m)$ is the following statistic

$$Y(i, N_f, m) = \left| \sum_{n=0}^{N_{\mathrm{PSS}}} e^{-2\pi j m \Delta f_{\mathrm{min}}} x_i^*(n) y(n + N_f) \right|^2 + \left| \sum_{n=0}^{N_{\mathrm{PSS}}} e^{-2\pi j m \Delta f_{\mathrm{min}}} x_i^*(n) y(n + N_{\mathrm{PSS}} N_f) \right|^2$$

This assumes that we are performing the detection across two periods of the PSS waveform (one LTE frame).

1.3.1 Questions

1. How is the above statistic related to the maximum-likelihood detector we considered in class? What is the reason for the difference?
2. What is the effect of the channel in all of this? How is it taken into account?
3. Show how you can use the convolution operator with the matched filter to implement the above maximization in a compact form (think of the basic receiver structures we explored in class). Plot the output of the three matched filters for $m = 0$ (i.e. no frequency offset). Which PSS is most likely and try to determine N_f.

4. For the most likely PSS index i and N_f with $m = 0$, plot the peak value of the statistic in 100 Hz steps and a $\pm 7.5kHz$ window around the carrier frequency (i.e. $\Delta f_{\max}/\Delta f_{\min} = 75$). What is the most likely frequency-offset? Based on the shape of the statistic can you think of a efficient way to implement the frequency-offset estimator to obtain even finer resolution and to minimize the number of correlations that are required? (hint: think of a binary search applied to this)

2 MATLAB Files

The supplied MATLAB/OCTAVE files are

1. `pss.m` - generates the three PSS signals for 10 MHz bandwidth
2. `TP1_top.m` - reads in the signal file produced by the usrp