SDR in ORBIT:

Spectrum Sensing

WINLAB Summer Internship 2015
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Three groups currently working with software-defined radio:

- Indoor Localization
- Spectrum Sensing
- LTE-Unlicensed

Software-defined radio - radio communication system in which components that would usually be implemented using hardware are instead implemented using software
SDR in ORBIT

- The ORBIT testbed has an array of Universal Software Radio Peripherals for use in software-defined radio applications.
- USRPs can transmit or receive signals ranging from DC to 6 GHz.
- Controlled by software applications such as GNU Radio
Spectrum Sensing

Project Goals

- Using ORBIT, configure radio receiver(s) to collect IQ time samples
- Process the samples to obtain frequency-domain data
- Analyze frequency data to identify any unknown signals
- Repeat with modified receiver carrier frequency, sampling rate, etc. to scan the available frequency spectrum for signals
- Implement methods above in real-time
Spectrum Sensing

Project Divisions

- **CPU Implementation** - Mike Collins, Nicole DiLeo
  - Design of signal processing algorithms, data visualization tools
  - Implementation in MATLAB and C++

- **FPGA Implementation** - Christina Baaklini, Nick Cooper
  - Performance improvement on high-speed processor
  - Implementation in VHDL
CPU Division

Current Progress

- Basic Research in Digital Signal Processing
- Familiarization with ORBIT Framework
- Familiarization with MATLAB Signal Processing Tools
- Design of ORBIT Grid Experiments
- Development of MATLAB Spectrogram Script
- Beginning of C++ Implementation
Preliminary Research and Training

● Learned basic Digital Signal Processing concepts such as:
  ○ **Sampling** - measurement of analog signal at discrete time intervals
  ○ **Quantization** - conversion of a continuous range of values into discrete values using a certain number of bits
  ○ **Nyquist Frequency** - twice the highest frequency of the continuous-time signal

● Learned to use the ORBIT Measurement Framework and Wiserd application to run tests and take measurements on ORBIT

● Learned MATLAB signal processing tools such as:
  ○ **fft/ifft** - Fast Fourier Transform and Inverse
  ○ **fft_shift** - Adjusts zero-frequency component in FFTs
ORBIT Grid Experiments

- Used the ORBIT Experiment Description Language and the Wiserd application to run experiments on the ORBIT testbed
- Started with one transmitter and one receiver and collected preprocessed frequency-domain data
- Expanded experiments to multiple transmitters/receivers and extracted raw IQ time samples
MATLAB Spectrogram Script

- Converts time-domain signal into frequency-domain
- Applies moving average filter to reduce noise
- Calculates power magnitudes at given frequencies
- Generates a waterfall plot
- Plots individual FFTs and applies a simple peak-finding algorithm
function [ffts,moving_avg,peaks]=spectro(m,c_fr,s_fr,k,o,w,avg)
% m = row matrix of IQ samples
% c_fr = carrier frequency
% s_fr = sampling frequency
% k = size of FFTs
% o = overlap between FFTs (between 0 and 1)
% w = row matrix of size k to be used as a window function
% avg = number of ffts to be averaged together
o = 1-o; N = numel(m);
start = @(j) k*o*j+1; % beginning of each FFT
stop = @(j) start(j)+k-1; % end of each FFT
ffts = [];
i = 0;
fprintf('Generating FFTs ... ');
while stop(i) < N
    s = m(start(i):stop(i));
    s2 = w.*s;
    s2f = fft(s2,k);
    s2f_shift = fftshift(s2f);
    ffts = [ffts;s2f_shift];
i = i+1;
end
fprintf('Done
');

void fft_avg::spectro()
{
    overlap_ = 1-overlap_;
    unsigned int N = iq_samples_.size();
    int index = 0;
    
    vector<complex<float> > s;
    vector<complex<float> > s2;
    s.resize(fft_size_);
    s2.resize(fft_size_);
    empty_vector_.resize(fft_size_, 0);

    out_ = (fftwf_complex*) &empty_vector_.front();
    plan_ = fftwf_plan_dft_1d(fft_size_, in_, out_, FFTW_FORWARD, FFTW_ESTIMATE);

    while (stop(index, fft_size_, overlap_) < N) {
        for (unsigned int i = start(index, fft_size_, overlap_); i <= stop(index, fft_size_, overlap_); i++) {
            s.push_back(iq_samples_[i]);
            s2.push_back((window_[i])*(s[i]));
        }
        in_ = (fftwf_complex*) &s2.front();
        fftwf_execute(plan_);
        fft_data_.push_back(empty_vector_);
        index++;}
}
Goals

● Implement spectrum sensing programs onto a Xilinx FPGA (ZedBoard)
● Use this to identify available frequencies using an FMC receiver.
VHDL/FPGA Division

Progress

- Over the course of the last two weeks we have been learning the basics of VHDL coding and implementation onto an FPGA
- Programs created and sent to ZedBoard:
  - Simple Combinatorial Logic
  - Binary Counter (Sequential Logic)
  - Basic 4-1 multiplexer
Examples (Code and Sim Waveforms)

Simple Combinatorial Logic (and gate)
Examples (Cont.)
Sequential Circuit (Binary Counter)
Examples (Cont.)

4-1 Multiplexer
Moving Forward

**CPU Division**
- Continue C++ implementation
- Start running tests with real-time analysis
- Create a user interface for scanning the frequency spectrum

**VHDL/FPGA Division**
- Apply VHDL to enhance SDR features on ZedBoard
- Eventually run tests with receiver attached to board