Contents

```
% ECE408 - Wireless Communications
% Jongoh (Andy) Jeong
% Simple CDMA - Message Decoding
% Date: April 1, 2020
clear all; close all; clc;
```

1. Parameter setup

```
% load received bits received at the mobile station
Rcvd = load('../data/Rcvd_Jeong.mat').Rcvd;

% parameters
% transmit filter coefficients (RRC)
RRC_rolloff = 0.75;      % rolloff factor for the RRC filter
B_RCOS = [0.0038,0.0052,-0.0044,-0.0121,-0.0023,0.0143, ...
          0.0044,-0.0385,-0.0563,0.0363,0.2554,0.4968,  ...
          0.6025,0.4968,0.2554,0.0363,-0.0563,-0.0385,  ...
          0.0044,0.0143,-0.0023,-0.0121,-0.0044,0.0052,0.0038].';
chipRate = 1e6;          % 1 MHz
upRate = 4;              % 4x upsampled before applying tx filter
cpf = 255;               % 255 chips per frame
H = hadamard(8);         % 8-ary Hadamard transform for Walsh channel

nFrames = length(Rcvd)/upRate/cpf;
```

2. Generate maximal length sequence (M-sequence)

```
% reference:
% 'https://web.archive.org/web/20180119232153/http://www.newwaveinstruments.com/resources/
articles/m_sequence_linear_feedback_shift_register_lfsr.htm',
% taps [8 7 6 1] == [8 1 2 7] == [8 7 2 1] in order (in Fibonacci form)
% >> LFSR: Fibonacci equivalent of the Galois taps [8 7 6 1] is [8 7 2 1]
taps = [8 7 6 1];
taps = [max(taps), fliplr(max(taps) - taps(taps ~= max(taps)))];
initial_state = ones(max(taps),1);

PNsequence = LFSR(taps, initial_state);
```

3. Apply receive filter (Root Raised Cosine with B_RCOS coefficients)

```
% apply the same filter used for Tx
```

```
rx_filtered = filter(B_RCOS, 1, Rcvd);
% downsample back
rcvd = downsample(rx_filtered, upRate);
```

4. Prepare pilot

```
% generate pilot from zero stream
num_bit_per_ascii_char = 8; % 8 bits per ASCII character
num_char_per_frame_pilot = 4;
pilotframe = zeros([num_bit_per_ascii_char*num_char_per_frame_pilot, 1]);
% encode
pilot_modbpsk = bpsk.modBPSK(pilotframe); % BSPK encode
pilot_h_chan = H(1,:); % Walsh channel 0 for pilot stream
pilot_hadamard = (pilot_modbpsk * pilot_h_chan).'; % Walsh encode
% decode
pilot_rcvd = decodePilot(pilot_hadamard, PNsequence);

% prepare pilot in BPSK to compare with data later
pilot_mod = bpsk.modBPSK(pilot_rcvd);

% pilot extraction from the received data
firstframe = rcvd(1:cpf);
thresh = 0.5;
dataStartIdx = find(abs(firstframe) > thresh, 1, 'first');

% pilot can be present in both first and last frame in the data stream
pilotFirstFrame = rcvd(dataStartIdx : (dataStartIdx-1)+cpf);
pilotLastFrame = rcvd(end-(cpf-1) : end);

% cross-correlate the generated pilot to data frames to determine where the data starts
% >> it starts from the second frame

loc_pilotframe = 0;
loc_pilotframe_corr = 0;
for i = linspace(1,floor(length(rcvd)/cpf)-1,floor(length(rcvd)/cpf)-1)
    rho = corr(real(pilot_mod), real(rcvd(dataStartIdx+(i-1)*cpf : (dataStartIdx+cpf*(i)-1
))'));
    if rho > 0.9
       loc_pilotframe = i;
       loc_pilotframe_corr = rho;
    end
end
fprintf("\ninitial pilots end at frame #%i : cross-corr: %1.6f\n", loc_pilotframe, loc_pil
otframe_corr)
```

```
initial pilots end at frame #1 : cross-corr: 0.993629
```

5. Determine offsets

```
pfirst_demod = bpsk.demodBPSK(real(pilotFirstFrame));
% verify that the generated pilot (demodulated) matches
% the pilot (first frame) in the data stream
assert(sum(pilot_rcvd==pfirst_demod)==cpf);

% from Figure 1, the pilot in the last frame is offset by 180 deg in phase
% so when demodulating, take this into account by inverting with 'NOT'
plast_demod = bpsk.demodBPSK(real(pilotLastFrame));
```

```
% verify that the generated pilot (demodulated) matches
% the pilot (last frame) in the data stream
assert(sum(pilot_rcvd==plast_demod)==int8(cpf/2));

% shift phases
pfirst_phase = angle(pilotFirstFrame);
plast_phase = angle(pilotLastFrame);
pfirst_phase_shifted = pfirst_phase - not(pfirst_demod')*pi;
plast_phase_shifted = plast_phase - not(plast_demod')*pi;

% take differential phase to get freq offset
diffphase1 = diff(pfirst_phase_shifted);
diffphase2 = diff(plast_phase_shifted);

% take mean of differential phases of first, last pilot frames to get freq offset
freq_offset_per_chip = mean([mean(mod(diffphase1,2*pi)),mean(mod(diffphase2,2*pi))]);
% [Hertz]
freq_offset_hz = freq_offset_per_chip/2/pi*chipRate;

% compute phase offset from first pilot frame of the data stream
freq_offset_phasor = exp(-1j*freq_offset_per_chip * (0:size(pilotFirstFrame,2)-1));
phase_shift = -1 * (pfirst_demod') * pi;
% [radian]
phase_offset = mean(angle(pilotFirstFrame .* freq_offset_phasor) + phase_shift);
% [degrees]
phase_offset_deg = phase_offset * (180/pi);
```

6. Shift data frames and decode message

```
% truncate data stream by removing first and last frames
num_remove_last_pilot = 1;
data_frames = rcvd(dataStartIdx+cpf*loc_pilotframe ...
                    :(dataStartIdx-1)+(nFrames-num_remove_last_pilot)*cpf);
phasor1_freq_offset = exp(-1j*freq_offset_per_chip*(cpf:cpf+length(data_frames)-1));
phasor2_phase_offset = exp(-1j*phase_offset);
data_frames_shifted = data_frames ...
                        .* phasor1_freq_offset ...
                        .* phasor2_phase_offset;
data_minus_pilot = data_frames_shifted - repmat(pilot_mod',1,nFrames-2);
decoded1 = decodeData(real(data_minus_pilot))';
walshchan = H(6,:); % Walsh channel 5 for message
message = translate(decoded1, PNsequence, walshchan);
```

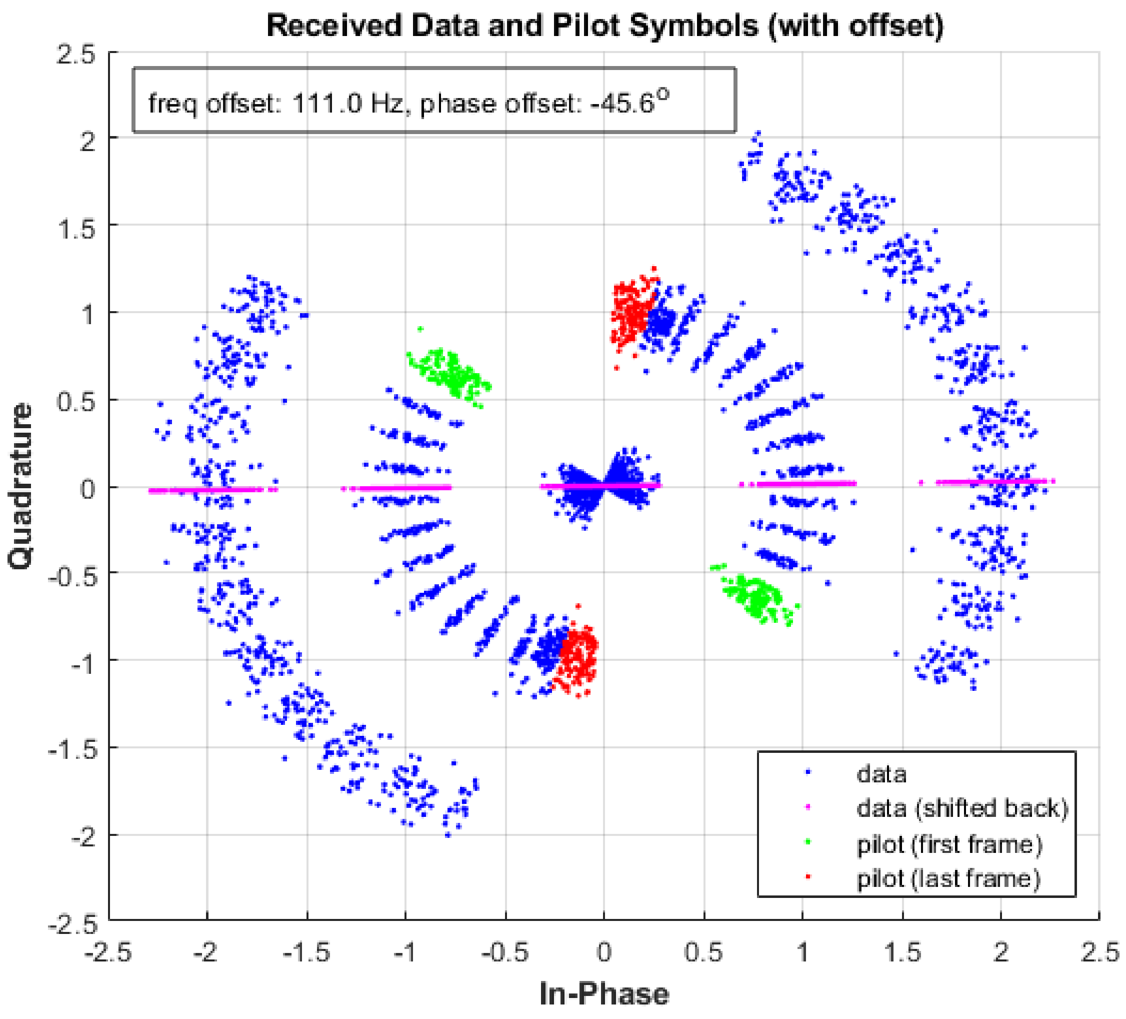
Results

```
figure('Position',[550 300 600 500]);
hold on;
scatter(real(data_frames),imag(data_frames),'b.');
scatter(real(data_frames_shifted),imag(data_frames_shifted),'m.');
plot(real(pilotFirstFrame),imag(pilotFirstFrame),'g.', ...
     real(pilotLastFrame),imag(pilotLastFrame),'r.'); hold off;
annotation('textbox', [.15 .85 .47 .06], ...
        'Color', 'k', ...
        'String', sprintf('freq offset: %1.1f Hz, phase offset: %1.1f^o', ...
        freq_offset_hz, phase_offset_deg));
legend('data', 'data (shifted back)','pilot (first frame)','pilot (last frame)','Location'
,'southeast');
title('Received Data and Pilot Symbols (with offset)');
```

```
xlabel('In-Phase','FontWeight','bold');
ylabel('Quadrature','FontWeight','bold');
grid on;

fprintf('- Freq offset: %1.4f (radians) per chip, or %1.4f (Hz) total\n', ...
        freq_offset_per_chip, freq_offset_hz)
fprintf('- Phase offset: %1.4f (radians) per chip, or %1.4f (degrees) total\n', ...
    phase_offset, phase_offset_deg)
fprintf('- Message: %s\n', message)
fprintf(">> %s %s\n", "this message comes from a scene from 'A Christmas Story' movie", ..
.
    "in which Ralphie gets his decoder ring and learns something about the world.")
```

```
- Freq offset: 0.0007 (radians) per chip, or 111.0028 (Hz) total
- Phase offset: -0.7956 (radians) per chip, or -45.5861 (degrees) total
- Message: Be Sure To Drink Your Ovaltine.
>> this message comes from a scene from 'A Christmas Story' movie in which Ralphie gets hi
s decoder ring and learns something about the world.
```



Utility Class Definitions / Functions

```
classdef bpsk

    methods(Static)
        function [result] = modBPSK(data)
```

```
            % modulates binary bits to BPSK
            % such that 1 -> 1, 0 -> -1

            % make column vector
            if size(data,2) > 1
                data = data';
            end


            % initialize modulator
            bpskModulator = comm.BPSKModulator;
            bpskModulator.PhaseOffset = 0;

            % make column vector
            if size(data,2) > 1
                data = data';
            end

            % BPSK modulation, but reverse
            result = real(-1*bpskModulator(data));

        end

        function [result] = demodBPSK(data)

            % demodulates BPSK to binary bits
            % such that 1 -> 1, -1 -> 0

            % make column vector
            if size(data,2) > 1
                data = data';
            end

            result = double(data > 0);

        end


    end

end



function [PNsequence] = LFSR(poly, initial_state)

    % feedback taps of order m
    % An LFSR of any given size m (number of register)
    % is capable of producing every possible state during
    % the period N = 2^m - 1 shifts
    % --> maximal length sequance (m-sequence)
    m = max(poly); % highest order

    % initialize PNsequence (binary) to the initial state
    states = zeros([m, 1]);
    states(initial_state) = 1;

    % m-bit register produces an m-sequence of period N (=2^m - 1)
    N = 2^m - 1;    % total sequence length
    PNsequence = zeros([N 1]);
    for i = 1:N
        PNsequence(i) = states(end);
```

```matlab
        temp = mod(sum(states(poly)),2);
        states(2:end) = states(1:end-1);
        states(1) = temp;
    end

end


function [result] = decodePilot(pilot_hadamard, PNsequence)

    % decodes pilot using Walsh channel 0

    % Walsh code
    Hadamard = pilot_hadamard(1:length(PNsequence));
    % BPSK demodulate
    Hadamard_demod = bpsk.demodBPSK(Hadamard);
    % despread
    result = xor(Hadamard_demod, PNsequence);

end


function [result] = decodeData(data)

    % takes data signal only (w/o pilot symbols) and demodulates

    % make column vector
    if size(data,2) > 1
        data = data';
    end

    % decodes BPSK modulated signal into -1, 0, 1
    % such that fo reach bit,
    % -1 if x < -0.5, 0 if -0.5 <= x <= 0.5, and 1 if x > 0.5
    result = zeros(size(data));
    for i = 1:length(data)
        if data(i) > 0.5
            result(i) = 1;
        elseif data(i) >= -0.5 && data(i) <= 0.5
            result(i) = 0;
        elseif data(i) < -0.5
            result(i) = -1;
        end
    end

end


function [result] = translate(data, PNsequence, Hchan)

    % converts decoded BPSK signal to ASCII code

    % 1. divide data into frame chunks
    % - frames1 : frames from 2nd to 2nd to last
    % - frames2 : last frame, without zeros
    frames = reshape(data, length(PNsequence), []);
    frames2 = frames(:, end); % in case last frame has fewer than 3 characters
    frames1 = frames(:, 1:end-1);

    % 2. despread using the PN sequence
    % - data1 : take 3 character-long chips (cpf: 64, # char: 3)
    cpf = 64; num_char = 3;
    data1 = zeros(cpf*num_char, size(frames1,2));
    for i = 1:size(frames1,2)
        frames1_demod = bpsk.demodBPSK( frames1(frames1(:,i)~=0,i) );
        % check sizes for xor operation
        % [size(frames1_demod), size(PNsequence(1:length(frames1_demod')))]
        data1(:,i) = xor( frames1_demod, PNsequence(1:cpf*num_char) );
    end
    % - data2 : only take nonzero symbols
    frames2_demod = bpsk.demodBPSK(frames2(frames2~=0));
    data2 = xor(frames2_demod, PNsequence(1:length(frames2_demod)));
    % concatenate data1 and data2
    data = [data1(:); data2(:)];

    % Walsh decode
    WalshDecoded = Hchan * reshape(bpsk.modBPSK(data),8,[]) / 8;
    % BPSK demodulate
    decoded = bpsk.demodBPSK(WalshDecoded);
    % convert to ASCII characters
    ascii_dec = bi2de(reshape(decoded,8,[]).');
    result = char(ascii_dec.');

end
```

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