Assignment

ASSIGNMENT # 3

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Subject: **Broadband Wireless Communication**

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Code:

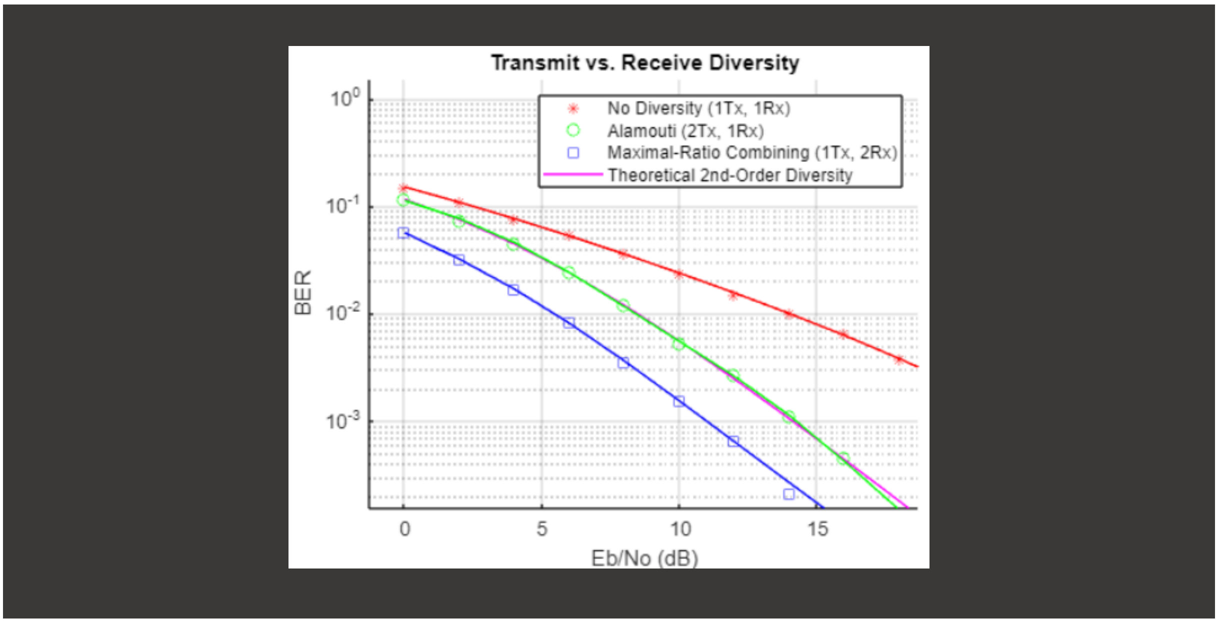
```
frmLen = 100; % frame length
numPackets = 1000; % number of packets
EbNo = 0:2:20; % Eb/No varying to 20 dB
N = 2; % maximum number of Tx antennas
M = 2; % Set up a figure for visualizing BER results
% Create comm.BPSKModulator and comm.BPSKDemodulator System
objects(TM)
P = 2; % modulation order
bpskMod = comm.BPSKModulator;
bpskDemod = comm.BPSKDemodulator('OutputDataType','double');
% Create comm.OSTBCEncoder and comm.OSTBCCombiner System objects
ostbcEnc = comm.OSTBCEncoder;
ostbcComb = comm.OSTBCCombiner;
% Convert Eb/No values to SNR values. The output of the BPSK
modulator
% generates unit power signals.
SNR = convertSNR(EbNo,"ebno","BitsPerSymbol",1);
% Create comm.ErrorRate calculator System objects to evaluate
BER.
errorCalc1 = comm.ErrorRate;
errorCalc2 = comm.ErrorRate;
errorCalc3 = comm.ErrorRate;
% Since the AWGN function as well as the RANDI function use the
default
% random stream, the following commands are executed so that the
results
% will be repeatable, i.e., same results will be obtained for
every run of
% the example. The default stream will be restored at the end
of the
% example.
```

```
s = rng(55408);
% Pre-allocate variables for speed
H = zeros(frmLen, N, M);
ber_noDiver = zeros(3,length(EbNo));
ber_Alamouti = zeros(3,length(EbNo));
ber_MaxRatio = zeros(3,length(EbNo));
ber_thy2 = zeros(1,length(EbNo));
fig = figure;
grid on;
ax = fig.CurrentAxes;
hold(ax,'on');
ax.YScale = 'log';
xlim(ax,[EbNo(1), EbNo(end)]);
ylim(ax,[1e-4 1]);
xlabel(ax,'Eb/No (dB)');
ylabel(ax,'BER');
fig.NumberTitle = 'off';
fig.Renderer = 'zbuffer';
fig.Name = 'Transmit vs. Receive Diversity';
title(ax,'Transmit vs. Receive Diversity');
set(fig, 'DefaultLegendAutoUpdate', 'off');
fig.Position = figposition([15 50 25 30]);
% Loop over several EbNo points
for idx = 1:length(EbNo)
 reset(errorCalc1);
 reset(errorCalc2);
 reset(errorCalc3);
 % Loop over the number of packets
 for packetIdx = 1:numPackets
 % Generate data vector per frame
```

```
data = randi([0 P-1], frmLen, 1);
% Modulate data
modData = bpskMod(data);
% Alamouti Space-Time Block Encoder
encData = ostbcEnc(modData);
% Create the Rayleigh distributed channel response matrix
% for two transmit and two receive antennas
H(1:N:end, :, :) = (randn(frmLen/2, N, M) + ...
1i*randn(frmLen/2, N, M))/sqrt(2);
% assume held constant for 2 symbol periods
H(2:N:end, :, :) = H(1:N:end, :, :);
% Extract part of H to represent the 1x1, 2x1 and 1x2 channels
H11 = H(:,1,1);
H21 = H(:,:,1)/sqrt(2);
H12 = squeeze(H(:,1,:));
% Pass through the channels
chanOut11 = H11 .* modData;
chanOut21 = sum(H21.* encData, 2);
chanOut12 = H12 .* repmat(modData, 1, 2);
% Add AWGN
rxSig11 = awgn(chanOut11,SNR(idx));
rxSig21 = awgn(chanOut21,SNR(idx));
rxSig12 = awgn(chanOut12,SNR(idx));
% Alamouti Space-Time Block Combiner
decData = ostbcComb(rxSig21, H21);
% ML Detector (minimum Euclidean distance)
demod11 = bpskDemod(rxSig11.*conj(H11));
demod21 = bpskDemod(decData);
demod12 = bpskDemod(sum(rxSig12.*conj(H12), 2));
% Calculate and update BER for current EbNo value
```

```
% for uncoded 1x1 system
ber_noDiver(:,idx) = errorCalc1(data, demod11);
% for Alamouti coded 2x1 system
ber_Alamouti(:,idx) = errorCalc2(data, demod21);
% for Maximal-ratio combined 1x2 system
ber_MaxRatio(:,idx) = errorCalc3(data, demod12);
end % end of FOR loop for numPackets
% Calculate theoretical second-order diversity BER for current
EbNo
ber_thy2(idx) = berfading(EbNo(idx), 'psk', 2, 2);
% Plot results
semilogy(ax,EbNo(1:idx), ber_noDiver(1,1:idx), 'r*', ...
EbNo(1:idx), ber_Alamouti(1,1:idx), 'go', ...
EbNo(1:idx), ber_MaxRatio(1,1:idx), 'bs', ...
EbNo(1:idx), ber_thy2(1:idx), 'm');
legend(ax,'No Diversity (1Tx, 1Rx)', 'Alamouti (2Tx, 1Rx)',...
'Maximal-Ratio Combining (1Tx, 2Rx)', ...
'Theoretical 2nd-Order Diversity');
drawnow;

end % end of for loop for EbNo
% Perform curve fitting and replot the results
fitBER11 = berfit(EbNo, ber_noDiver(1,:));
fitBER21 = berfit(EbNo, ber_Alamouti(1,:));
fitBER12 = berfit(EbNo, ber_MaxRatio(1,:));

semilogy(ax,EbNo, fitBER11, 'r', EbNo, fitBER21, 'g', EbNo,
fitBER12, 'b');
hold(ax,'off');
% Restore default stream
rng(s);
```

Output:



Code:

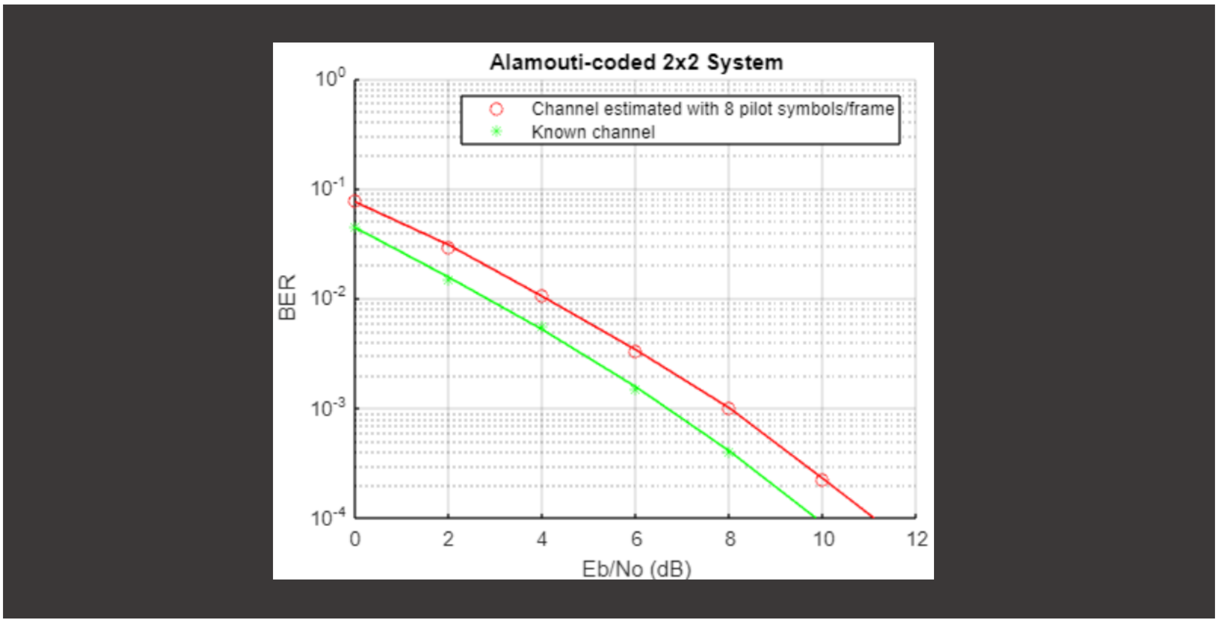
```
frmLen = 100; % frame length
maxNumErrs = 300; % maximum number of errors
maxNumPackets = 3000; % maximum number of packets
EbNo = 0:2:12; % Eb/No varying to 12 dB
N = 2; % number of Tx antennas
M = 2; % number of Rx antennas
pLen = 8; % number of pilot symbols per frame
W = hadamard(pLen);
pilots = W(:, 1:N); % orthogonal set per transmit antenna
% Create a comm.MIMOChannel System object to simulate the 2x2
spatially
% independent flat-fading Rayleigh channel
chan = comm.MIMOChannel( ...
 'MaximumDopplerShift', 0, ...
 'SpatialCorrelationSpecification', 'None', ...
 'NumTransmitAntennas', N, ...
```

```
 'NumReceiveAntennas', M, ...
 'PathGainsOutputPort', true);
%  Change  the  NumReceiveAntennas  property  value  of  the
hAlamoutiDec System
% object to M that is 2
release(ostbcComb);
ostbcComb.NumReceiveAntennas = M;
% Set the global random stream for repeatability
s = rng(55408);
% Pre-allocate variables for speed
HEst = zeros(frmLen, N, M);
ber_Estimate = zeros(3,length(EbNo));
ber_Known = zeros(3,length(EbNo));
% Set up a figure for visualizing BER results
fig = figure;
grid on;
ax = fig.CurrentAxes;
hold(ax,'on');
ax.YScale = 'log';
xlim(ax,[EbNo(1), EbNo(end)]);
ylim(ax,[1e-4 1]);
xlabel(ax,'Eb/No (dB)');
ylabel(ax,'BER');
fig.NumberTitle = 'off';
fig.Name = 'Orthogonal Space-Time Block Coding';
fig.Renderer = 'zbuffer';
title(ax,'Alamouti-coded 2x2 System');
set(fig,'DefaultLegendAutoUpdate','off');
fig.Position = figposition([41 50 25 30]);
% Loop over several EbNo points
```

```
for idx = 1:length(EbNo)
 reset(errorCalc1);
 reset(errorCalc2);
% Loop till the number of errors exceed 'maxNumErrs'
 % or the maximum number of packets have been simulated
 while (ber_Estimate(2,idx) < maxNumErrs) && ...
 (ber_Known(2,idx) < maxNumErrs) && ...
 (ber_Estimate(3,idx)/frmLen < maxNumPackets)
 % Generate data vector per frame
 data = randi([0 P-1], frmLen, 1);

 % Modulate data
 modData = bpskMod(data);
 % Alamouti Space-Time Block Encoder
 encData = ostbcEnc(modData);
 % Prepend pilot symbols for each frame
 txSig = [pilots; encData];
 % Pass through the 2x2 channel
 reset(chan);
 [chanOut, H] = chan(txSig);

 % Add AWGN
 rxSig = awgn(chanOut,SNR(idx));
 % Channel Estimation
 % For each link => N*M estimates
 HEst(1,:,:) = pilots(:,:).' * rxSig(1:pLen, :) / pLen;

 % assume held constant for the whole frame
 HEst = HEst(ones(frmLen, 1), :, :);
 % Combiner using estimated channel
```

```
 decDataEst = ostbcComb(rxSig(pLen+1:end,:), HEst);
 % Combiner using known channel
 decDataKnown = ostbcComb(rxSig(pLen+1:end,:), ...
 squeeze(H(pLen+1:end,:,:,:)));
 % ML Detector (minimum Euclidean distance)
 demodEst = bpskDemod(decDataEst); % estimated
 demodKnown = bpskDemod(decDataKnown); % known
 % Calculate and update BER for current EbNo value
 % for estimated channel
 ber_Estimate(:,idx) = errorCalc1(data, demodEst);

 % for known channel
 ber_Known(:,idx) = errorCalc2(data, demodKnown);
 end % end of FOR loop for numPackets

 % Plot results
 semilogy(ax,EbNo(1:idx), ber_Estimate(1,1:idx), 'ro');
 semilogy(ax,EbNo(1:idx), ber_Known(1,1:idx), 'g*');
 legend(ax,['Channel estimated with ' num2str(pLen) ' pilot
symbols/frame'],...
 'Known channel');
 drawnow;
end % end of for loop for EbNo
% Perform curve fitting and replot the results
fitBEREst = berfit(EbNo, ber_Estimate(1,:));
fitBERKnown = berfit(EbNo, ber_Known(1,:));
semilogy(ax,EbNo, fitBEREst, 'r', EbNo, fitBERKnown, 'g');
hold(ax,'off');
% Restore default stream
rng(s)
```

Output:



Alamouti-coded 2x2 System
Channel estimated with 8 pilot symbols/frame
Known channel
BER
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
Eb/No (dB)