Project 3

Space Time Block Coding

CES 544 – Wireless Communication
Sonoma State University
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David Bozarth

Introduction

Combination of path loss, channel fading, noise and interference present special challenges for the wireless receiver. Of particular interest is multipath fading: differential distortion of multiple transmitted signal components. Each such component may be regarded as occupying an independent fading channel, experiencing both constructive and destructive fading as a function of space and time.

Wireless channel methods that exploit the occurrence of constructive fading, forming a processed sum of signals having favorable characteristics, are known as *diversity* methods. Spatial diversity employs multiple transmitting and/or receiving antennae; temporal diversity and frequency diversity methods transmit multiple signals separated in time or frequency.

Space-time block coding (STBC) combines spatial and temporal diversity by using N transmit antennae and one or more (M) receive antennae[1]. N different symbols are transmitted together over L distinct spatial configurations during L distinct time slots[2] [2]. Fading combined with matrix processing at the receiver, yields N symbol representations that can be detected using channel estimation or sequence detection.

In summary, N distinct symbols originally separated in time, become separated in space and are transmitted simultaneously over the STBC link. Each particular symbol is transmitted in various forms (identical, conjugated, inverted) during L time slots. M receiving channels each process L occurrences of $N \times M$ channel transmissions, yielding N detected symbols.

These simulations used orthogonal STBC with N = 2, L = 2, and M = 1, 2. The two transmitted symbols represent two successive bits of a BPSK-modulated stream. The bit error rate of the diversity-enhanced system is compared with that of a flat fading channel with no diversity. Appendix I (Project 3 Procedure) gives details of the theory and procedure.

[1] S. Alamouti, “A Simple Transmit Diversity Technique for Wireless Communications,” in IEEE J. Communications vol. 16 no. 8, Oct. 1999, pp. 1451-1458

[2] T. Gulliver, “Space Time Block Coding for Wireless Communication Systems,” http://www.ece.uvic.ca/~agullive/stbc3.pdf

Core implementation (Matlab)

```
% project3.m
% Simulate a wireless channel using 8PSK.
% Find BER for various Eb/No
% D.Bozarth, CES 544, Sonoma State University
% Adapted 05-06-07 from project2.m
% Mod 05-12-07
%
debugFlg     = 0;
graphBiasFlg = 1;   % 0 => Allow (#bit errors) == 0.
                    % 1 => Ensure min (#bit errors) == 1.
ni  = 32000000;   % number of iterations used to determine BER
if debugFlg
    ni = 1;
    graphBiasFlg = 0;
end

bsz = 2;        % length of binary sequence (one frame)
Es  = 1;        % energy per symbol
Rs  = 24e3;     % symbol rate, baud
fD  = 10;       % max Doppler frequency, Hz
K   = 2;        % modulation index (Currently limited to 2 or 8. May 2007)
M   = 2;        % number of receive antennas used for STBC
%
EbN = [0  5 10 15 20 25]; % bit energy per noise, dB
ben = [0  0  0  0  0  0]; % counted Bit Errors
ber = [0  0  0  0  0  0]; % calculated Bit Error Rates

format short e;
t1 = cputime;

if debugFlg
    lim = 1;
else
    lim = size(ber, 2);
end

for i = 1 : lim
    be = 0 ; % number of bit errors detected

    for j = 1:ni
        % Generate a random binary sequence.
        [Bt] = zeros(1, bsz);
        for k = 1:bsz ; Bt(k) = (rand(1, 1) > 0.5); end

        if debugFlg
            Bt
        end

        % Transmit & receive the frame.
        %[Br] = frameLink_PSK( Bt, Es, Rs, fD, EbN(i), K );
        [Br] = frameLink_PSK_STBC( Bt, Es, Rs, fD, EbN(i), K, M );

        if debugFlg
            Br
        end

        % Compare with original sequence and find BER.
        dif = abs(Bt - Br);
        be = be + sum(dif);
    end

    if (graphBiasFlg == 1)
        if be == 0; be = 1; end
    end
    ben(i) = be;
    ber(i) = be ./ (bsz * ni);
end
t2 = cputime;
elapsed = t2 - t1

ben
ber

if ~debugFlg
    %semilogy(EbN, ber, 'r-.');
    semilogy(EbN, ber, 'b');
end
% End of program.
```

```
function [Br] = frameLink_PSK_STBC(Bt, Es, Rs, fD, EbN, K, M)
% Simulate one frame PSK link with Space-Time Block Code diversity.
% Br: 2 x n vector: Received bit streams after compensation & demodulation.
% Bt: 1 x 2 vector: Bit streams to be transmitted.
%   Precondition: Length of Bt corresponds to exactly one frame.
% Es: Energy per symbol (no dimension)
% Rs: Desired symbol rate, baud
% fD: Max Doppler frequency, Hz
% EbN: Bit energy per noise, dB
% K: Modulation index (Currently handles only 2 and 8. May 2007)
% M: Number of receive antennas.
%
% CES 544, Sonoma State University
% D.Bozarth
% Adapted 05-12-07 from frameLink_PSK.m
% Mod
%
debugFlg    = 0;
noiseFlg    = 1;
RayIndepFlg = 1;
    % 0 => Rayleigh fadings are correlated.
    % 1 => Rayleigh fadings are completely uncorrelated.

bsy = log2(K);      % #bits per symbol
%bsz = size(Bt(1, :), 2);  % length of binary sequence
%bsz = size(Bt, 2);  % length of binary sequence
bsz = 2;  % length of binary sequence
ssz = bsz / bsy;    % length of symbol sequence
Ts  = 1 / Rs;       % symbol period, s

x = zeros(1, 2); % row vector
y = zeros(2 * M, 1); % column vector
n = y;
s = y;

% Convert to complex baseband.
switch K
    case 2
        x = BPSK_mod(Bt, Es);
    case 8
        x = EightPSK_mod(Bt, Es);
    otherwise
        error('K must be 2 or 8.');
end

x = x ./ sqrt(2);
x = x.'; % column vector

if debugFlg
    x
end

% Transmit with flat Rayleigh fading.
h = zeros(1, 2 * M);
H = zeros(2 * M, 2);

for k = 0 : (M - 1)
    thisRow = 2 * k + 1;
    nextRow = thisRow + 1;

    if RayIndepFlg == 0
        [R] = Rayleigh(2, fD, Ts);
    else
        [R] = [Rayleigh(1, fD, Ts), Rayleigh(1, fD, Ts)];
    end

    h(thisRow)    =  R(2, 1);
    h(nextRow)    =  R(2, 2);
    H(thisRow, :) =  R(2, :);
    H(nextRow, 1) =  conj(H(thisRow, 2));
    H(nextRow, 2) = -conj(H(thisRow, 1));
end

if debugFlg
    h
    H
end

% Add noise and form the received signal.
na = 0;
if noiseFlg
```

```
    na = sqrt( Es / (bsy * 2 * 10 .^ (EbN / 10)) ); % noise amplitude
end

for k = 1 : (2 * M)
    a = randn(1, 1);
    b = randn(1, 1);

    if (k / 2) ~= fix(k / 2) % odd
        n(k) = na * (a + b*i);
    else
        n(k) = na * conj(a + b*i);
    end
end

if debugFlg
    n
end

y = H * x + n;

if debugFlg
    y
end

r = H' * y;

if debugFlg
    r
end

% Receiver fading compensation.
div = 0;

for k = 1 : (2 * M)
    div = div + abs(h(k))^2;
end

s = r;
s(2) = conj(s(2));
s = s ./ div; % Estimate value of the original symbols.

if debugFlg
    s
end

% Demodulation -> binary sequence at receiver.
switch K
    case 2
        Br = BPSK_demod((s.'), Es);
    case 8
        Br = EightPSK_demod((s.'), Es);
    otherwise
        error('K must be 2 or 8.');
end
% End of program.
```

```
function [X] = BPSK_mod(B, e)
% Returns a vector of complex numbers representing the complex baseband
% BPSK symbols derived from a bit stream.
% Arguments:
%   B is a vector of binary digits.
%   e is the energy per symbol.
%
% CES 544, Sonoma State University
% D.Bozarth 05-06-07 adapted from EightPSK_mod.m
%
n_B = size(B);  % B is a (1 x n) vector.
n_B = n_B(2);   % Second element is the #columns in B.
X = zeros(1, n_B);

for k = 1:n_B
    a = B(k);
    if (a == 0)
        a = -1;
    end
    X(k) = a * e;
end

% end of program
```

```
function [B] = BPSK_demod(X, e)
% Returns a bit stream derived from BPSK demodulation.
% Arguments:
%   B is a vector of complex numbers representing complex baseband symbols.
%   e is the energy per symbol. (Only for compatibility with other modules.)
%
% CES 544, Sonoma State University
% D.Bozarth 05-06-07 adapted from EightPSK_demod.m
%
n_X = size(X);  % X is a (1 x n) vector.
n_X = n_X(2);   % Second element is the #columns in B.
B = zeros(1, n_X);
ptr = 0;

for k = 1:n_X
    if real(X(k)) < 0
        B(k) = 0;
    else
        B(k) = 1;
    end
end

% end of program
```

Results

To achieve significant diversity gain, the separate channels must have uncorrelated fading. To this end, there is a minimum separation required between transmit antennae. If the transmit antennae are too close, a supposition of uncorrelated fading is not warranted. The gain of STBC using both correlated and uncorrelated fading is demonstrated in the following simulation result. Both transmitters were using full power. One receiver was used. [Fig. 1]

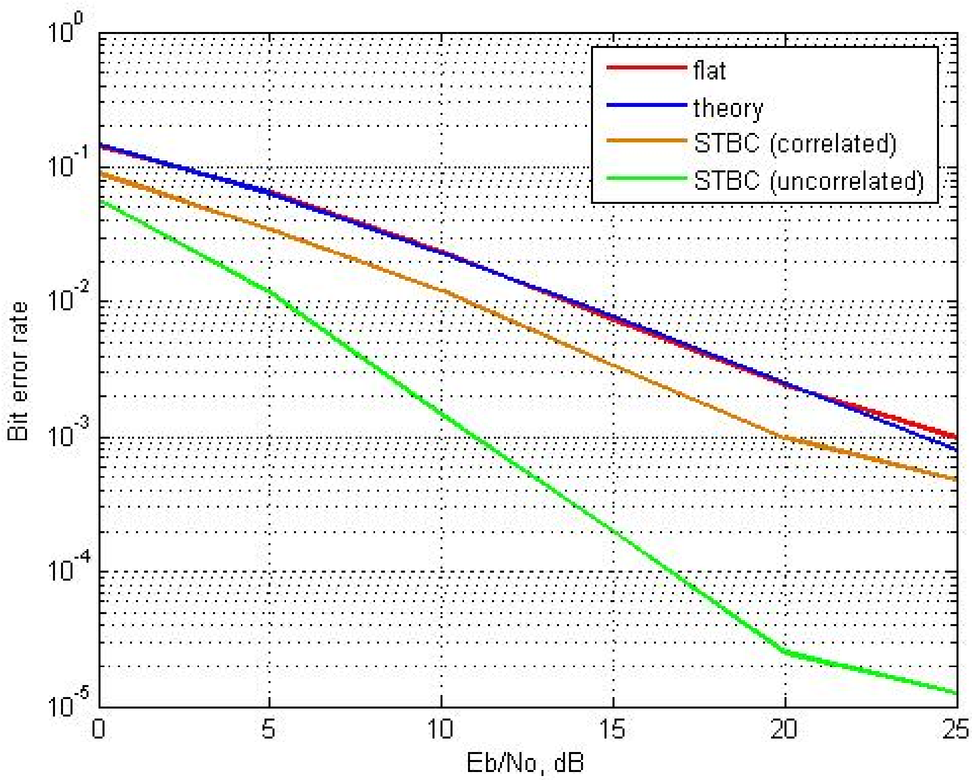
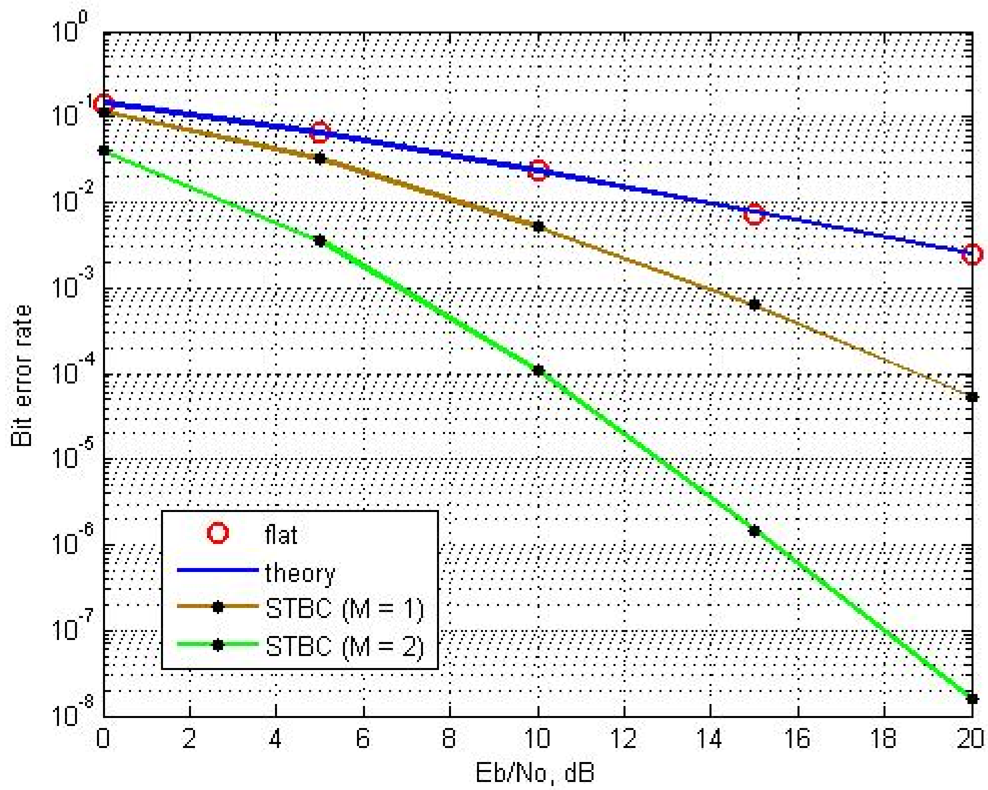


Fig. 1: Space-time block coding with one receiver, compared with non-diversity system.

Since the STBC algorithm calls for reception of two simultaneous copies of the signal, it may be necessary or desirable to reduce the signal level from each transmitting antenna[1]. Doing so will reduce error performance and diversity gain. These performance measures may be improved, though, by using multiple receivers (M > 1). The realized diversity order using STBC is twice that achievable using Maximal Ratio Combining with the same number of receivers.

In the following simulation, the power level from each transmitter is reduced by 3 dB, and uncorrelated Rayleigh fading is used. [Fig. 2]. Note the noise performance effect of using more receivers. Note also the effect of power reduction using uncorrelated fading with one receiver ([Fig. 1 green curve] vs. [Fig. 2 gold curve]).



Conclusion

An example of transmit diversity was shown in the form of space-time block coding, using one receiver and two receivers. The significance of uncorrelated fading and of transmit power reduction was demonstrated.