Technical University of Crete
School of Electrical and Computer Engineering
Course: **Wireless Communications 2022-2023**
Exercise 3
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Part 1 Study of DS-CDMA. Assume communication with M-length packets of dual same-probability symbols from the alphabet $\mathcal{X} = \{+1, -1\}$
Every user uses N-length code with white gaussian noise characteristics.
Each User utilizes an L-length complex impulse response. he response is the same for each packet and changes from packet ot packet.

```
K = 1; % User Number
M = 300; % Sequence lengh
N = 64; % Code Length
L = 3; % Responce Length
Packets = 1000;
X = [1, -1];

%User code
c = (1/sqrt(N))*sign(randn(N,K));

%Channel response
h = (randn(K,L) + 1i*randn(K,L))*sqrt(1/(2*L));
```

We are decoding the fist user with a Rake receiver (the same process is utilized for the other users).

(a) One user in the system

i. By concentrating on the decision for the first symbol (s_1): The system input is described by the following equality:

$$\mathbf{y} = \sum_{l=1}^{L} h_l \mathbf{x}^{(l)} + \mathbf{w}$$

Where $\mathbf{x}^(l) = s_1 \mathbf{c}^{(l)}$
and

$$\mathbf{c}^{(l)} := \begin{bmatrix} \mathbf{0}_l \\ \mathbf{c} \\ \mathbf{0}_{L-l} \end{bmatrix}$$

Assuming that $||\mathbf{c}^{(l)}|| = 1$ and $\mathbf{c}^(l)^T \mathbf{c}^{(m)} = 0$.
Then the $i-th$ finger output for $i = 1, ..., L$ is

$$\frac{|h_i|^2}{||\mathbf{h}||} s + w_i'$$

Where $w_i' \sim \mathcal{CN}(0, \dfrac{|h_i|^2}{||\mathbf{h}||^2} N_0)$
and the Rake output is:

$$r = ||\mathbf{h}|| s + w'',\ w'' \sim \mathcal{CN}(0, N_0)$$

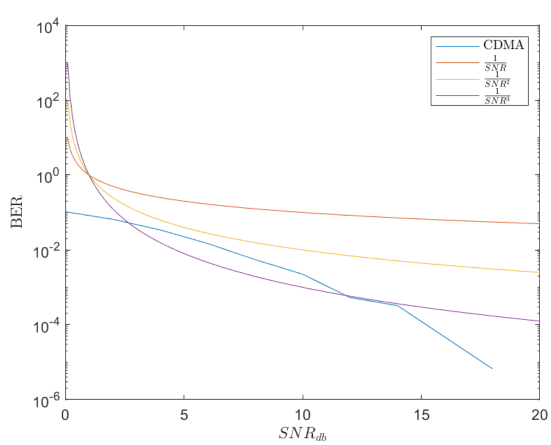


Figure 1: CDMA comparison with $\frac{1}{SNR^i}$ and one user

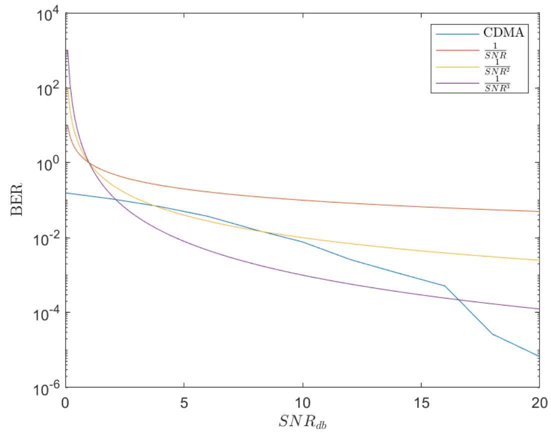


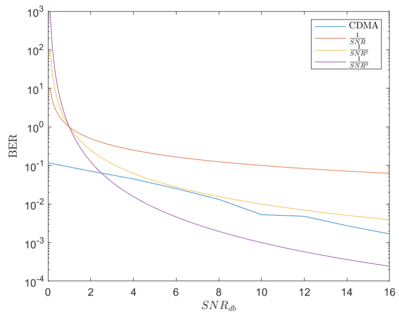
Figure 2: CDMA comparison with $\frac{1}{SNR^i}$ and one user using stronger channel factor

ii. The Rake receiver using only the highest amplitude channel factor
For low SNRs the Rake receiver with one finger achieves order 2 diversity and for high SNRs order 3. While with L fingers the diversity order is always 3.

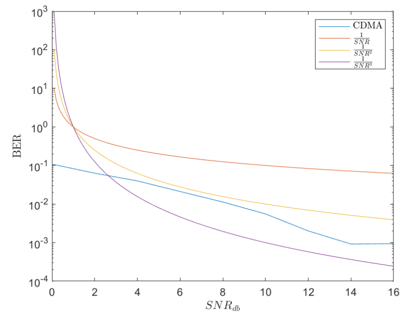
Compared to using all the channel factor the performance is comparable but in the highest SNRs using all channel factor achieves the lowest BER.

(b) Multiple users in the system

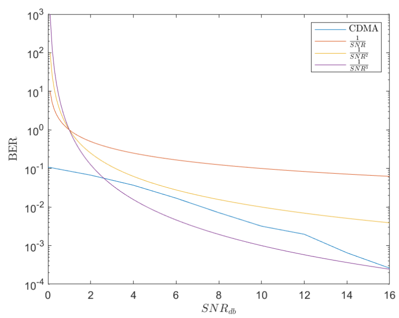
i. Two Users



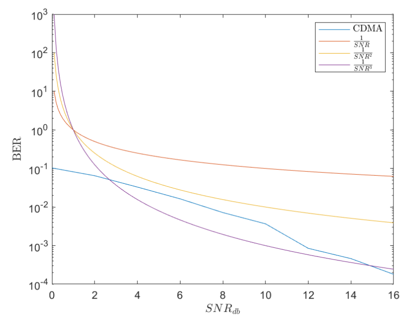
(a) N=16



(b) N=32



(c) N=64

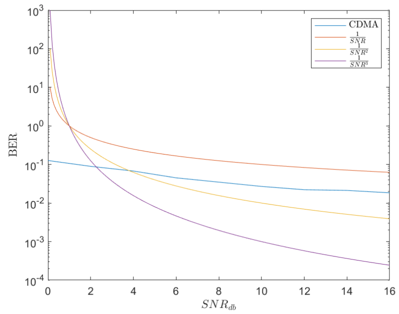


(d) N=128

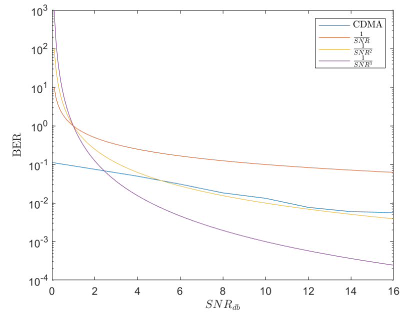
Figure 3: CDMA comparison with $\frac{1}{SNR^i}$ and two users

As seen from Figure 3 when $N = 16$ the Rake receiver achieves order 2 diversity and as N goes to $N = 128$ it achieves order 3 diversity.

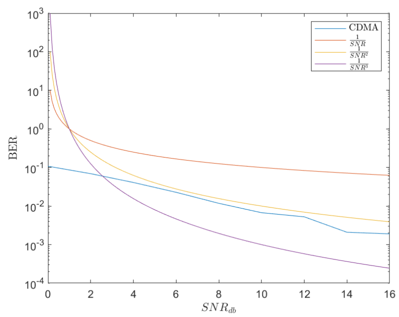
ii. Five Users



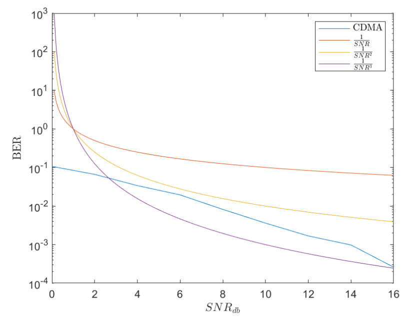
(a) N=16



(b) N=32



(c) N=64



(d) N=128

Figure 4: CDMA comparison with $\frac{1}{SNR^i}$ and five users

In the case of five users the performance seems to also achieve better diversity a N increases but for low N the BER does not decreace significantly as SNR increases.

Part 2 (a) i. Creation of a random complex channel h_l, $l =, 0, .., L$ where h_i i.i.d $h_i \sim \mathcal{CN}(0, \frac{1}{L})$

```
% Channel response
h = (randn(L,1) + 1i*randn(L,1))*sqrt(1/(2*L));
```

ii. Creation of 4-QAM input $\tilde{d}$, $k = 1, ...N$ with values $\pm 1 \pm j$

```
% 4-QAM data block
d = sign(-1+2*rand(N,1)) + 1i*sign(-1+2*rand(N,1));
d_tilde = (1/sqrt(N))*fft(d,N);
```

iii. In order to be convinced that the frequency selective channel is equal to N parallel channels the two equalities mast produce the same output.

Equality 1:

$$y[m] = \sum_{l=0}^{L-1} h_l x[m-l], m = 1, ..., N+L-1$$

Where,

$$\mathbf{x} = \begin{bmatrix} d[N-L+2] \\ \vdots \\ d[N] \\ d[1] \\ \vdots \\ d[N] \end{bmatrix}$$

Ignoring the first $L-1$ elements we get y' the channel output.

Equality 2:

$$\tilde{y} = \tilde{h}\tilde{d}$$

Where

$$\tilde{h} = DFT(h)$$
$$\tilde{d} = DFT(d)$$

In order for the claim to be true then it must be true that:

$$y' = IDFT(\tilde{y})$$

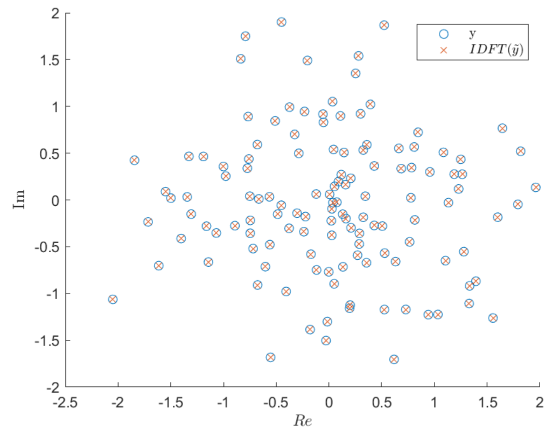


Figure 5: Frequency Selective to N-Parallel channel output comparison

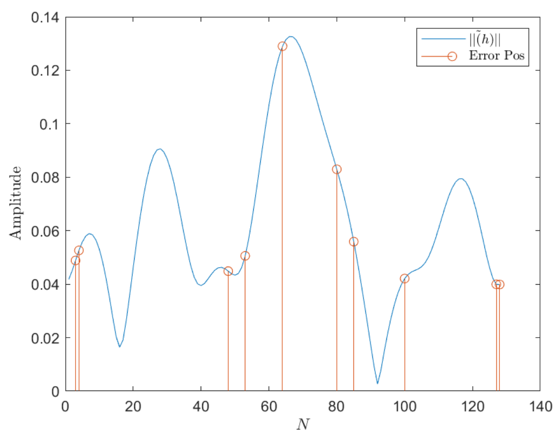


Figure 6: Channel Amplitude compared to decision error

iv. There is no obvious correlation to the channel response amplitude and when the mistakes happen.

(b)