HW4 Tommy Azzino

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PROBLEM 3

$P_{TX} = 15$ dBm ; $B = 18$ MHz $T = -165$ dBm/Hz

(a)

At least 95% of the users are in Rooms: 1, 2, and 3

[SEE MATLAB] The SNR that can be guaranteed to at least 95% of the users is the SNR of Room 3 (i.e. the lowest one) which is 17,4473 dB

(b) Rayleigh fading

Expression for the CDF of the SNR including variation in both location and fading

$$F_\Gamma(\gamma) = P(\Gamma \le \gamma) = \int_{-\infty}^{\gamma} f_\Gamma(\gamma)\, d\gamma = 1 - e^{-\gamma/\bar{\gamma}} \quad / \quad P(\Gamma > \gamma) = e^{-\gamma/\bar{\gamma}}$$

In this case,

$$F_{\Gamma_{RL}}(\gamma) = P(\Gamma_{RL} \le \gamma) = \sum_{i=1}^{4} P(\Gamma \le \gamma \mid Room = i)\, P(Room = i)$$

$$= 0{,}6\left(1 - e^{-\gamma/\bar{\gamma}_1}\right) + 0{,}3\left(1 - e^{-\gamma/\bar{\gamma}_2}\right) + 0{,}06\left(1 - e^{-\gamma/\bar{\gamma}_3}\right) + 0{,}04\left(1 - e^{-\gamma/\bar{\gamma}_4}\right)$$, where $\bar{\gamma}_i$ = avg SNR in Room i

(c) SNR guaranteed to at least 95% of the people with slow fading

$0{,}05 = F_{\Gamma_{RL}}(\gamma) = P(\Gamma_{RL} \le \gamma)$ $\Rightarrow$ [SEE MATLAB]

value we want to find

5% of users will have less than this value / 95% will have greater SNR than this

The SNR value we can guarantee to at least 95% of the users is $\approx 10{,}2086$ dB

PROBLEM 4

(a) Average SNR?

$$h(f,0) = \sqrt{P_1}\, e^{-2\pi j f \tau_1} + \sqrt{P_2}\, e^{-2\pi j f \tau_2} \Rightarrow |h|^2 = P_1 + P_2$$

Hence, $SNR_{avg} = \dfrac{P_1 + P_2}{W N_0}$

(b)

Ergodic Capacity $= E[\log(1+\gamma)]$

In this case, $C = \dfrac{1}{2}\left[\log\left(1 + \dfrac{P_1}{N_0 W}\right) + \log\left(1 + \dfrac{P_2}{N_0 W}\right)\right]$

(c)

$$\frac{P_1}{W N_0} = 8\,dB \xrightarrow{linear} 6{,}31 \quad / \quad \frac{P_2}{W N_0} = 5\,dB \xrightarrow{linear} 3{,}16$$

$$SNR_{avg} = \frac{P_1}{W N_0} + \frac{P_2}{W N_0} = 8 + 5 = 13\,dB \quad / \quad C = \frac{1}{2}\left[\log(7{,}31) + \log(4{,}16)\right] = 2{,}4632$$

PROBLEM 5

$$L(r) = \log \frac{p(r|c=1)}{p(r|c=0)}$$

(a) Real-valued binary channel with fading

$$r = A x + w, \quad w \sim N\left(0, \frac{N_0}{2}\right), \quad x = \begin{cases} \sqrt{E_x/2} & \text{if } c=1 \\ -\sqrt{E_x/2} & \text{if } c=0 \end{cases}$$

$$Ax = \begin{cases} A\sqrt{\frac{E_x}{2}} & \text{if } c=1 \\ -A\sqrt{\frac{E_x}{2}} & \text{if } c=0 \end{cases} \quad w \sim N\left(0, \frac{N_0}{2}\right)$$

$$p(r|c=1) = \frac{1}{\sqrt{\pi N_0}} e^{-\frac{\left(r - A\sqrt{\frac{E_x}{2}}\right)^2}{N_0}}$$

$$p(r|c=0) = \frac{1}{\sqrt{\pi N_0}} e^{-\frac{\left(r + A\sqrt{\frac{E_x}{2}}\right)^2}{N_0}}$$

$\left| -A\sqrt{\frac{E_x}{2}} \text{ if } c=0 \right.$ $\qquad$ $\left| \; p(r|c=0) = \frac{1}{\sqrt{\pi N_0}} e^{-\frac{\left(r+A\sqrt{\frac{E_x}{2}}\right)^2}{N_0}} \right.$

$$L(r) = \log\frac{p(r|c=1)}{p(r|c=0)} = \frac{-\left(r-A\sqrt{\frac{E_x}{2}}\right)^2}{N_0} + \frac{\left(r+A\sqrt{\frac{E_x}{2}}\right)^2}{N_0}$$

$$= \frac{\cancel{-r^2} + 2rA\sqrt{\frac{E_x}{2}} - \cancel{\left(A\sqrt{\frac{E_x}{2}}\right)^2} \cancel{+r^2} + 2rA\sqrt{\frac{E_x}{2}} + \cancel{\left(A\sqrt{\frac{E_x}{2}}\right)^2}}{N_0}$$

$$= \frac{4rA\frac{\sqrt{E_x}}{\sqrt{2}}}{N_0} = \frac{2\sqrt{2}\,rA\sqrt{E_x}}{N_0} = \frac{2rA\sqrt{2E_x}}{N_0}$$

(b) Binary Simmetric Channel

$r = c + w \pmod 2$ $\qquad$ $w = \begin{cases} 1 & \text{with probablity } p \\ 0 & \text{with probablity } 1-p \end{cases}$

r can be $0, 1$

$$L(r) = \log\frac{p(r|c=1)}{p(r|c=0)} \Rightarrow L(1) = \log\frac{1-p}{p} \;\Big/\; L(0) = \log\frac{p}{1-p}$$

Which can be written as: $L(r) = (2r-1)\log\frac{1-p}{p}$, for $r = 0, 1$

(c) Non-coherent channel

$r = \begin{cases} h+n & \text{when } c=1 \\ n & \text{when } c=0 \end{cases}$ $\qquad$ $h \sim CN(0, E_s)$, $n \sim CN(0, N_0)$

$$L(r) = \log\frac{p(r|c=1)}{p(r|c=0)} \qquad p(r|c=0) = \frac{1}{\sqrt{2\pi N_0}} e^{-|r|^2/2N_0} \qquad r = n \sim CN(0, N_0)$$

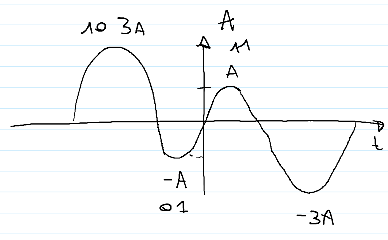
$$P(r|c=1) = \frac{1}{\sqrt{2\pi(N_0+E_s)}} e^{-|r|^2/2(N_0+E_s)}, \quad r = h+n \sim CN(0, E_s+N_0)$$

assuming h and n are independent

$$L(r) = \log\frac{\frac{1}{\sqrt{2\pi(N_0+E_s)}} e^{-|r|^2/2(N_0+E_s)}}{\frac{1}{\sqrt{2\pi N_0}} e^{-|r|^2/2N_0}} = \frac{1}{2}\log\frac{N_0}{E_s+N_0} + \frac{-|r|^2}{2(N_0+E_s)} + \frac{|r|^2}{2N_0} = \frac{1}{2}\log\frac{N_0}{E_s+N_0} + \frac{|r|^2}{2}\left(\frac{1}{N_0} - \frac{1}{E_s+N_0}\right)$$

PROBLEM 6

$r = x + n \qquad n \sim \left(0, \frac{N_0}{2}\right) \qquad x = \begin{cases} -3A & \text{if } c_0, c_1 = 00 \\ -A & \text{if } c_0, c_1 = 01 \\ A & \text{if } c_0, c_1 = 11 \\ 3A & \text{if } c_0, c_1 = 10 \end{cases}$



(a) average symbol energy

$$E|X|^2 = \frac{9A^2 + A^2 + A^2 + 9A^2}{4} = 5A^2$$

$$5A^2 = \frac{E_s}{2} \Rightarrow A = \sqrt{\frac{E_s}{10}}$$

(b) Bitwise LLR for c_0:

$$L_0(r) = \log \frac{p(r|c_0=1)}{p(r|c_0=0)} \qquad p(r|c_0) = \frac{1}{2}\left[p(r|c_0, c_1=1) + p(r|c_0, c_1=0)\right]$$

$$L_0(r) = \log\left[\frac{\overbrace{p(r|c_0,c_1=1,0)}^{N(3A,N_0/2)} + \overbrace{p(r|c_0,c_1=1,1)}^{N(A,N_0/2)}}{\underbrace{p(r|c_0,c_1=0,0)}_{N(-3A,N_0/2)} + \underbrace{p(r|c_0,c_1=0,1)}_{N(-A,N_0/2)}}\right]$$

$$= \log\left[\frac{\cancel{\frac{1}{\sqrt{\pi N_0}}}\, e^{-(r-3A)^2/N_0} + \cancel{\frac{1}{\sqrt{\pi N_0}}}\, e^{-(r-A)^2/N_0}}{\cancel{\frac{1}{\sqrt{\pi N_0}}}\, e^{-(r+3A)^2/N_0} + \cancel{\frac{1}{\sqrt{\pi N_0}}}\, e^{-(r+A)^2/N_0}}\right]$$

$$= \log\left[\frac{e^{-(r-3A)^2/N_0} + e^{-(r-A)^2/N_0}}{e^{-(r+3A)^2/N_0} + e^{-(r+A)^2/N_0}}\right]$$

$$L_1(r) = \log\left[\frac{p(r|c_0,c_1=0,1) + p(r|c_0,c_1=1,1)}{p(r|c_0,c_1=0,0) + p(r|c_0,c_1)=1,0)}\right]$$

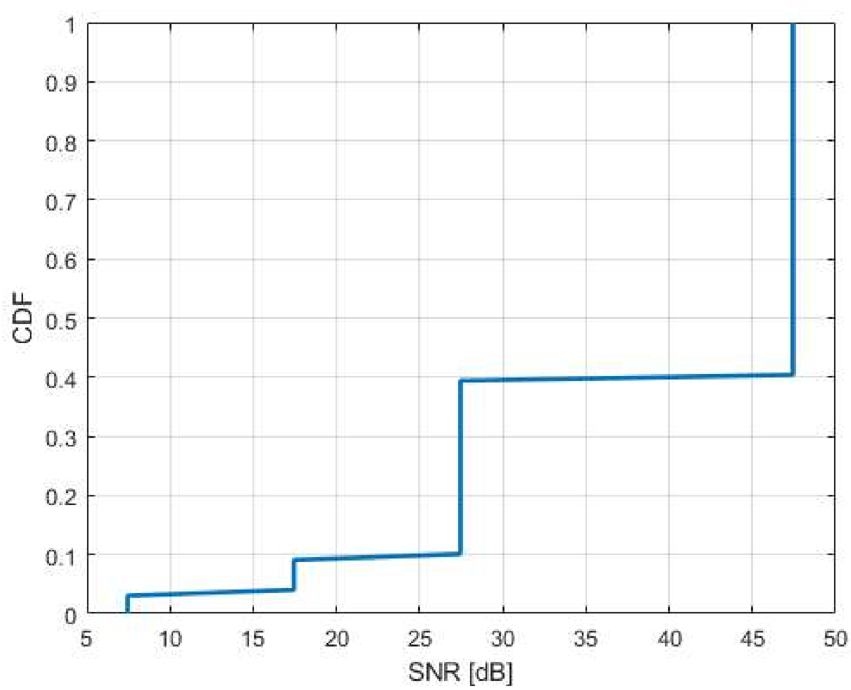
$$= \log\left[\frac{e^{-(r+A)^2/N_0} + e^{-(r-A)^2/N_0}}{e^{-(r+3A)^2/N_0} + e^{-(r-3A)^2/N_0}}\right]$$

Wireless Communications EL-GY 6023

Homework 4 - Tommy Azzino (ta1731)

Problem 3

```
path_losses = [60, 80, 90, 100];
Ptx = 15; % dBm
B = 18e6;
N0 = -165;
N0_lin = db2pow(N0-30);
Ptx_lin = db2pow(Ptx-30);
Prx = Ptx - path_losses;
Prx_lin = db2pow(Prx-30);
SNRs_dB = pow2db(Prx_lin/(N0_lin*B));
user_distribution = [0.6, 0.3, 0.06, 0.04];
snr_cdf = [];
for i=1:length(SNRs_dB)
    snr_cdf = [snr_cdf, repelem(SNRs_dB(i), user_distribution(i)*100)];
end
figure;
plot(sort(snr_cdf), linspace(0,1,length(snr_cdf)), "LineWidth",2);
grid on;
xlabel("SNR [dB]"); ylabel("CDF");
```




```
disp(SNRs_dB(3));
```

```
17.4473
```

(a)

As we can see from the plot above, we have that 95 % of the users will experience an SNR value of at least 17.4473 dB.

(c)

```
npoints = 10000;
snrs = linspace(-10,60,npoints);
F = zeros(npoints,1);
```

```
for i=1:npoints
    F(i) = dot((1-exp(-db2pow(snrs(i))./db2pow(SNRs_dB))), user_distribution);
end
snr_t = interp1(F,snrs,0.05);
fprintf(1, 'SNR that can be guaranteed to at least 95 perc of the users with fading [dB] = %f\n', snr_t);
```

```
SNR that can be guaranteed to at least 95 perc of the users with fading [dB] = 10.208600
```