Massive Notes 1.4

Key Points : NLoS

1. Increase the Transmit Power(3): NLoS case

1. Similar to the LoS case, suppose the BS in cell 0 knows the channel responses. An achievable UL SE for the desired UE in the NLoS case is

$$\mathrm{SE}_0^{\mathrm{NLoS}} = \mathbb{E}\big\{ \log_2\big(1 + \frac{p|h_0^0|^2}{p|h_1^0|^2 + \sigma^2}\big)\big\} \tag{1}$$

2. From the previous notes we have already known that $\bar{\beta} = \beta_1^0/\beta_0^0$ and $\mathrm{SNR}_0 = \frac{p}{\sigma^2}\beta_0^0$, so (1) can be rewritten as

$$\mathrm{SE}_0^{\mathrm{NLoS}} = \frac{e^{\frac{1}{\mathrm{SNR}_0}} E_1(\frac{1}{\mathrm{SNR}_0}) - e^{\frac{1}{\mathrm{SNR}_0\bar{\beta}}} E_1(\frac{1}{\mathrm{SNR}_0\bar{\beta}})}{\log_e(2)(1-\bar{\beta})} \tag{2}$$

where $E_1(x) = \int_1^\infty \frac{e^{-xu}}{u} du$ and $\bar{\beta} \neq 1$. In fact when $\bar{\beta} = 1$ represents a cell-edge scenario where the desired and interfering signals are equally strong, and it does not provide any further insights.

3. So we can have

$$\mathrm{SE}_0^{\mathrm{NLoS}} \to \frac{1}{1-\bar{\beta}} \log_2\big(\frac{1}{\bar{\beta}}\big) \quad \text{as} \quad p \to \infty \tag{3}$$

4. We now prove (3). Firstly, since $\bar{\beta} = \beta_1^0/\beta_0^0$ and $\mathrm{SNR}_0 = \frac{p}{\sigma^2}\beta_0^0$, the equation (2) can be rewritten as

$$\mathrm{SE}_0^{\mathrm{NLoS}} = \frac{1}{1-\bar{\beta}} \cdot \frac{1}{\log_e(2)} \cdot \left\{ e^{\frac{\sigma^2}{p\beta_0^0}} E_1(\frac{\sigma^2}{p\beta_0^0}) - e^{\frac{\sigma^2}{p\beta_1^0}} E_1(\frac{\sigma^2}{p\beta_1^0}) \right\} \tag{4}$$

when $p \to \infty$, we have

$$\left\{ e^{\frac{\sigma^2}{p\beta_0^0}} E_1(\frac{\sigma^2}{p\beta_0^0}) - e^{\frac{\sigma^2}{p\beta_1^0}} E_1(\frac{\sigma^2}{p\beta_1^0}) \right\} \to E_1(\frac{\sigma^2}{p\beta_0^0}) - E_1(\frac{\sigma^2}{p\beta_1^0}) \tag{5}$$

because $E_1(z) = -\gamma - \log_e z - \sum_{n=1}^{\infty} \frac{(-1)^n z^n}{nn!}$ when $|\arg z| < \pi$, and γ is *Euler's constant*, then (5) can be rewritten as (6)

$$E_1(\frac{\sigma^2}{p\beta_0^0}) - E_1(\frac{\sigma^2}{p\beta_1^0}) = \log_e(\frac{\sigma^2}{p\beta_1^0}) - \log_e(\frac{\sigma^2}{p\beta_0^0}) = \log_e(\frac{\beta_0^0}{\beta_1^0}) = \log_e(\frac{1}{\bar{\bar{\beta}}}) \quad \text{as} \quad p \to \infty$$

therefore, when $p \to \infty$, (4) can be

$$\mathrm{SE}_0^{\mathrm{NLoS}} \to \frac{1}{1-\bar{\beta}} \cdot \frac{1}{\log_e(2)} \cdot \log_e(\frac{1}{\bar{\bar{\beta}}}) \quad \text{as} \quad p \to \infty \tag{7}$$

since $\log_a b = \log_c b / \log_c a$, so

$$\frac{1}{\log_e(2)} \cdot \log_e(\frac{1}{\bar{\bar{\beta}}}) = \log_2(\frac{1}{\bar{\bar{\beta}}}) \tag{8}$$

from (7) and (8), finally we obtain (3).

2. Simulation Results

Program 2: NLoS

Listing 1: NLoS.m

```
%Empty workspace and close figures
close all;
clear;

%Define the SNR range for analytical curves
SNRdB = -10 : 0.1 : 30;
SNR = 10 .^ (SNRdB/10);

%Define the SNR range for Monte Carlo simulations
SNRdB_montecarlo = -10 : 5 : 30;
SNR_montecarlo = 10 .^ (SNRdB_montecarlo/10);
%SNR_montecarlo = \frac{p}{\sigma^2}

%Define the different beta_bar values (strength of inter-cell interference)
betabar = [1e-1, 1e-3]';

%Preallocate matrices for storing the simulation results
SE_LoS = zeros(length(betabar), length(SNR));
SE_NLoS = zeros(length(betabar), length(SNR));
SE_NLoS_montecarlo = zeros(length(betabar), length(SNR_montecarlo));

%Select number of Monte Carlo realizations of the Rayleigh fading
numberOfFadingRealizations = 100000;

%% Go through different strengths of the interference
for b = 1 : length(betabar)

    %Compute SE under line-of-sight (LoS) propagation as in (1.17)
    SE_LoS(b, :) = log2(1 + 1 ./ (betabar(b) + 1 ./ SNR));

    %Generate uncorrelated Rayleigh fading channel realizations
    fadingRealizationsDesired = (randn(numberOfFadingRealizations,1) + 1i *
       randn(numberOfFadingRealizations, 1)) / sqrt(2);%h_0^0
    fadingRealizationsInterference = (randn(numberOfFadingRealizations, 1)
       +1i * randn(numberOfFadingRealizations, 1)) / sqrt(2);%h_1^0

    %Compute SE under non-line-of-sight (NLoS) propagation from the first
    %line in (1.18), using Monte Carlo simulations
    %for the channel realizations
```

```
    SE_NLoS_montecarlo(b, :) = mean(log2(1 + abs(fadingRealizationsDesired) .^ 2 * SNR_montecarlo ./ (abs(fadingRealizationsInterference) .^ 2 * SNR_montecarlo*betabar(b) +1)),1);
    %note that SNR_montecarlo = \frac{p}{\sigma^2}

    %Compute SE under non-line-of-sight (NLoS) propagation
    %as in (1.18)
    SE_NLoS(b,:) = (exp(1 ./ SNR) .* expint(1 ./ SNR) - exp(1 ./ (betabar(b) * SNR)) .* expint(1 ./ (betabar(b) * SNR)))/((1 - betabar(b)) * log(2));

end


%% Plot the simulation results
figure;
hold on; box on;

for b = 1 : length(betabar)

    plot(SNRdB, SE_LoS(b, :), 'k-', 'LineWidth', 1);
    plot(SNRdB_montecarlo, SE_NLoS_montecarlo(b, :), 'rd', 'LineWidth', 1);
    plot(SNRdB, SE_NLoS(b, :), 'b-.', 'LineWidth', 1);

end

xlabel('SNR [dB]');
ylabel('Average SE [bit/s/Hz]');

legend('beta = 0.1 and 0.001, Analytical LoS', 'beta = 0.1 and 0.001, Montecarlo NLoS', 'beta = 0.1 and 0.001, Analytical NLoS', 'Location','NorthWest');
ylim([0 10]);
```

Output 2:

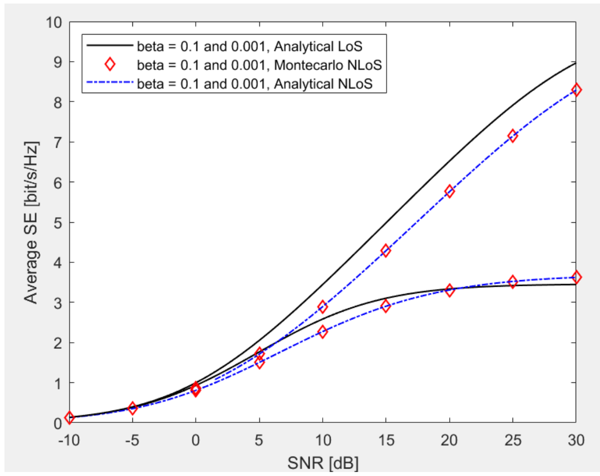

Figure 1: Average UL SE as a function of the SNR for different cases of inter-cell interference strength and different channel models.

3. Results Analysis

5. We notice that going from $\mathrm{SNR}_0 = 10\mathrm{dB}$ to $\mathrm{SNR}_0 = 30\mathrm{dB}$ only doubles the SE, though 100 times more transmit power is required. The NLoS case provides slightly lower SE than the LoS case for most SNRs, due to **the random fluctuations** of the squared magnitude $|h_0^0|^2$ of the channel. However, the randomness turns into a small advantage at high SNR, where the limit is slightly higher in NLoS because **the interference can be much weaker than signal for some channel realizations**. This behavior is seen for $\bar{\beta} = -10\mathrm{dB}$ in Figure 1(when $\mathrm{SNR}_0 = 20\mathrm{dB}$), while it occurs at higher SNRs for $\bar{\beta} = -30\mathrm{dB}$. (END)