# 数字通信基础第一次作业

Cantjie

## 1)

### a)

$$P_e = 2Q\left(\frac{d_{min}}{2\sigma}\right) - Q^2\left(\frac{d_{min}}{2\,\sigma}\right),$$

where $\sigma = \sqrt{\frac{N_0}{2}}$, $d_{min} = 2\sqrt{E} = 2\sqrt{E_b}$ and $Q(\cdot)$ is the Gaussian Q function. Thus, we have

$$P_e = 2Q\left(\sqrt{\frac{2E}{N_0}}\right) - Q^2\left(\sqrt{\frac{2E}{N_0}}\right).$$

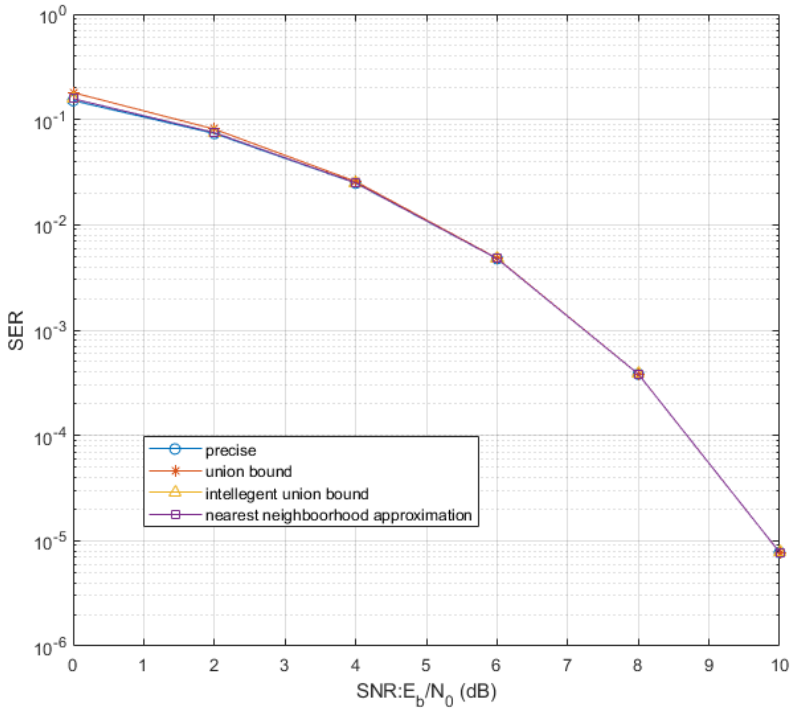
$$P_e \le 2Q\left(\sqrt{\frac{2E}{N_0}}\right) + Q\left(\sqrt{\frac{4E}{N_0}}\right). \quad \text{(Union Bound)}$$

$$P_e \le 2Q\left(\sqrt{\frac{2E}{N_0}}\right). \quad \text{(Intelligent Union Bound)}$$

$$P_e \approx 2Q\left(\sqrt{\frac{2E}{N_0}}\right).$$

(Nearest Neighborhood Approximation)

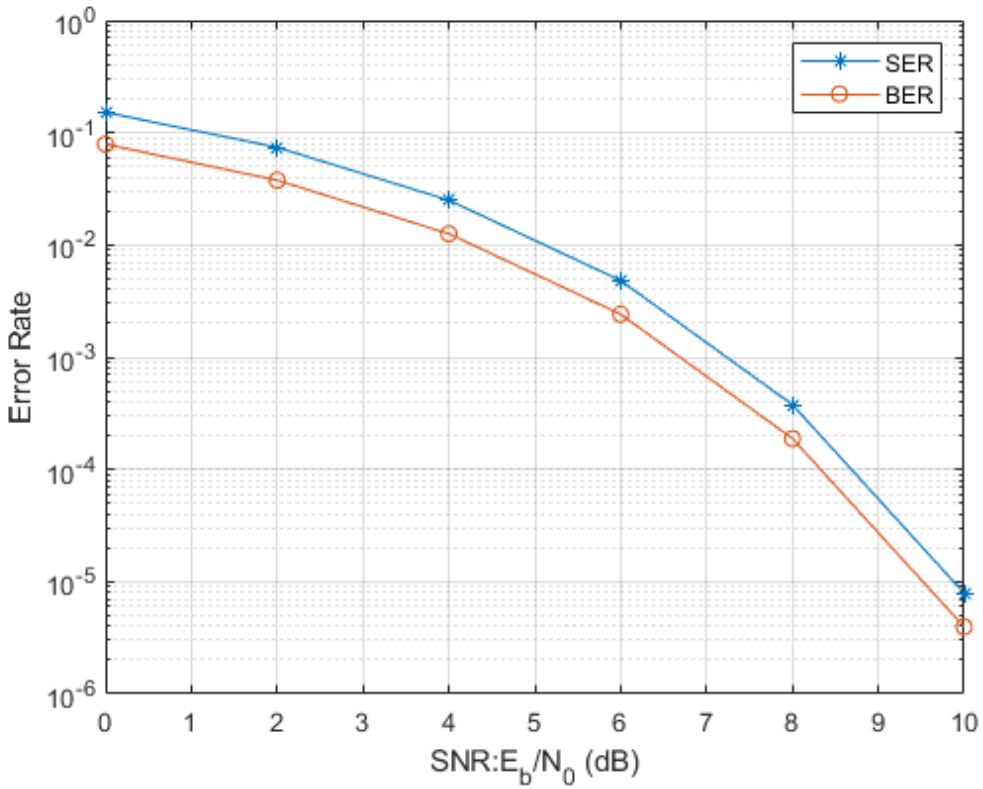
### b)



**c)** 注意到最近邻近似和智能联合界表达式一样，因此在图中是重合的曲线。
在低信噪比时，联合界与精确值误差较大，随着信噪比的增加，联合界与精确值逐渐趋近，在信噪比大于 4dB 时，几乎看不出联合界与精确值的差距。
智能联合界与精确值几乎重合，且差距也随着信噪比的增加而减小。

$Q$函数是小于 1 的减函数。联合界与精确值相差$Q\left(\sqrt{\frac{4E}{N_0}}\right)+Q^2\left(\sqrt{\frac{2E}{N_0}}\right)$，Q 函数的平方项远小于 Q 的一次项，因此 Q 的一次项是主导项，在信噪比较小时，精确值与联合界的差距较大。智能联合界与精确值相差$Q^2\left(\sqrt{\frac{2E}{N_0}}\right)$，因为 Q 小于 1，因此该值一直很小。

**d)**




**代码：**

```
clc,clear
clf,

SNR_min = 0;
SNR_max = 10;
SNR_step = 2;

%1.b)

SNR_db = SNR_min:SNR_step:SNR_max;
```

```
SNR = 10 .^ (SNR_db/10);

Q = qfunc(sqrt(2 .* SNR));
P_e_precise = 2 .* Q - Q .^ 2;
P_e_ub = 2 .* Q + qfunc(sqrt(4 .* SNR));
P_e_iub = 2 .* Q;
P_e_nna = 2 .* Q;

semilogy(SNR_db,P_e_precise,'Marker','o');
hold on;
grid on;
semilogy(SNR_db,P_e_ub,'Marker','*');
semilogy(SNR_db,P_e_iub,'Marker','^');
semilogy(SNR_db,P_e_nna,'Marker','s');
xlabel("SNR:E_b/N_0 (dB)");
ylabel("SER");
legend("precise","union bound","intellegent union bound","nearest
neighboorhood approximation");

% 1.d)

figure

M = 4;
symbol_num = 1e7;
data = randi([0 M-1],symbol_num,1);
txSig = pskmod(data,M,pi/M,'gray');
SNR_db = SNR_min:SNR_step:SNR_max;
SER = zeros(size(SNR_db));
BER = zeros(size(SNR_db));
for SNR_idx = 1:length(SNR_db);
    % pay attentation to E_bit and E_symbol
    rxSig = awgn(txSig,SNR_db(SNR_idx) + 3,'measured');
    rxdata = pskdemod(rxSig,M,pi/M,'gray');
    [~,SER(SNR_idx)] = symerr(data,rxdata);
    [~,BER(SNR_idx)] = biterr(data,rxdata);
end
semilogy(SNR_db,SER,'Marker','*');
hold on
grid on
semilogy(SNR_db,BER,'Marker','o');
xlabel("SNR:E_b/N_0 (dB)");
ylabel("Error Rate");
legend("SER","BER");
```