Cellular Network Planning and Performance Analysis

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1 System Specification

For the downlink transmission of a cellular mobile network, you are required to complete network planning and performance analysis tasks based on the system settings and assumptions given below.

- The spectrum for downlink operation: 1805 -1880 MHz.
- The channel spacing: 200 kHz.
- Guard band: 100 kHz at both ends of the spectrum.
- The bandwidth allocated for control channels: 5 MHz.
- The area covered by the entire network: 2550 km^2.
- The radius of a cell: 1.5 km.
- The required signal-to-interference ratio is 18 dB.
- The potential intercell interference is considered from the 6 co-channel cells in the first tier of the network only.
- The average holding time per voice channel: 1.5 minutes.
- The average blocking probability: 1.5%.
- Path-loss exponent (distance-power gradient) is 4.3.

2 Tasks

2.1 Determine the frequency reuse ratio, q.

With Intercell Signal to Interference Ratio SIR = 18 dB;

$$SIR = \frac{P_{dir}}{\sum_{i=1}^{n_{co}} P_{int,i}} = \frac{1}{6}q^{\alpha}, \alpha = 4.3 \text{ and } n_{co} = 6 \tag{1}$$

Hence,

$$q = (6 \times SIR)^{1/\alpha} = (6 \times 10^{18/10})^{1/4.3} = 3.97 \tag{2}$$

Where:

- P_{dir}: Distance between the mobile terminal and the desired base station
- $P_{int,i}$: Distance between the mobile terminal and the i-th interfering base station
- q: Frequency reuse ratio
- α: Path-loss exponent
- n_{co}: Number of co-channel cells which could make considerable intercell interference for one cell

2.2 Determine the cluster size (frequency reuse factor), N.

Using the frequency reuse ratio q,

$$q = \frac{D}{R} = \frac{R\sqrt{3N}}{R} = \sqrt{3N} \tag{3}$$

Hence,

$$N = \frac{q^2}{3} = \frac{3.97^2}{3} = 5.273 \approx 7 \tag{4}$$

Where:

- R is radius of the cell.
- D is distance between the two adjacent cochannel cells.
- N is frequency reuse factor and must satisfy $N = I^2 + J^2 + I \times J$, for $I, J = 0, 1, 2, \ldots$

2.3 Determine the distance between two adjacent cochannel cells, D.

$$D = R\sqrt{3N} = 1.5\sqrt{3 * 7} = 6.874 \text{ km} \tag{5}$$

Where R is the radius of the cell and N is the frequency reuse factor.

2.4 Draw a diagram showing the cell structure of this cellular system, indicating the 6 cochannel cells in the first tier.

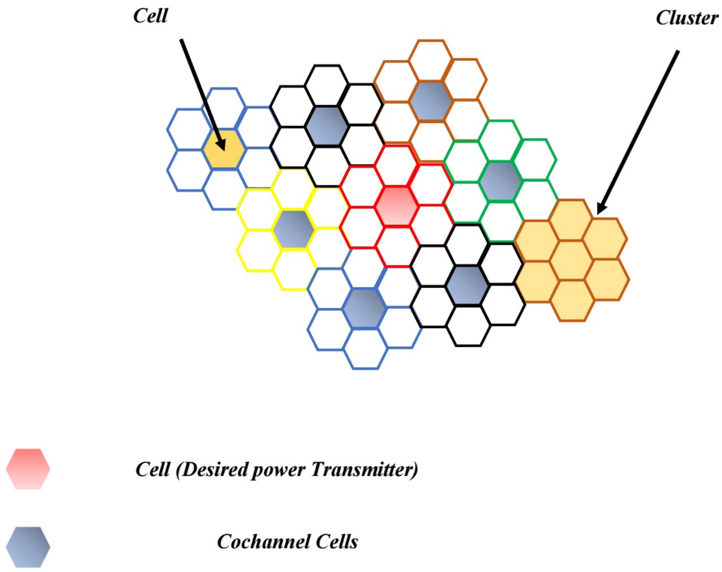


Figure 1: Cell structure showing 6 cochannel cells in the first tier

2.5 Determine the number of control channels, N_{ctl}.

$$N_{ctl} = \frac{W_{ctl}}{B} = \frac{5 \text{ MHz}}{200 \text{ kHz}} = 25 \text{ Channels} \tag{6}$$

Where W_{ctl} is Control Channels Bandwidth and B is Channel Spacing.

2.6 Determine the number of service channels per cluster, N_{clu}.

$W_S = 1880 \text{ MHz} - 1805 \text{ MHz} = 75 \text{ MHz}$

$$N_{clu} = \frac{W_S - W_{ctl} - 2 * W_g}{B} = \frac{75 \text{ MHz} - 5 \text{ MHz} - 2 * 100 \text{ kHz}}{200 \text{ kHz}} = 349 \text{ Channels} \tag{7}$$

Where W_S is Allocated Spectrum, W_g is Guard Band, W_{ctl} is Control Channels Bandwidth, and B is Channel Spacing.

2.7 Determine the number of service channels per cell, N_{cell}.

$$N_{cell} = \frac{N_{clu}}{N} = \frac{349}{7} = 49.857 \approx 49 \text{ Channels} \tag{8}$$

Where N_{clu} is the number of service channels per cluster and N is Reuse factor.

2.8 Determine the system capacity (total number of service channels of the network), C.

$$Area_{cell} = \frac{3\sqrt{3}R^2}{2} = \frac{3\sqrt{3}(1.5)^2}{2} = 5.846 \text{ km}^2 \tag{9}$$

$$M = \frac{A_{sys}}{A_{clu}} = \frac{A_{sys}}{NA_{cell}} = \frac{2550}{7 * 5.846} = 62.314 \approx 63 \text{ Clusters} \tag{10}$$

$$C = MN_{clu} = 63 * 349 = 21987 \text{ Channels} \tag{11}$$

2.9 If 3-sector directional antennas are used in each cell, determine the maximum cell capacity that can be achieved under the same SIR requirement.

Step 1: Using 3-sector directional antennas means $n_s = 3$. Hence, the number of adjacent cochannel cells will be: $n_{co} = \frac{6}{n_s} = \frac{6}{3} = 2$.

Step 2: Keeping the same SIR requirement,

$$SIR = \frac{1}{n_{co}}(\sqrt{3N'})^{\alpha} \geq 18 \text{ dB} = 63.096 \tag{12}$$

Giving

$$N' = \frac{1}{3}(SIR * n_{co})^{2/\alpha} = \frac{1}{3}(63.096 * 2)^{2/4.3} \geq 3.183 = 4 \tag{13}$$

Where N' is the smallest frequency reuse factor after sectoring that keeps the same SIR requirement and $\alpha = 4.3$ is Path-loss exponent.

Step 3: Calculating the maximum cell capacity:

$$C_{cell}^{max} = \frac{C_{clu}}{N'} = \frac{349}{4} = 87.25 \approx 87 \text{ Channels} \tag{14}$$

2.10 Plot a diagram of blocking probability B(N_{cell}, A_{cell}) of a cell with the fixed N_{cell} and variable offered traffic A_{cell}.

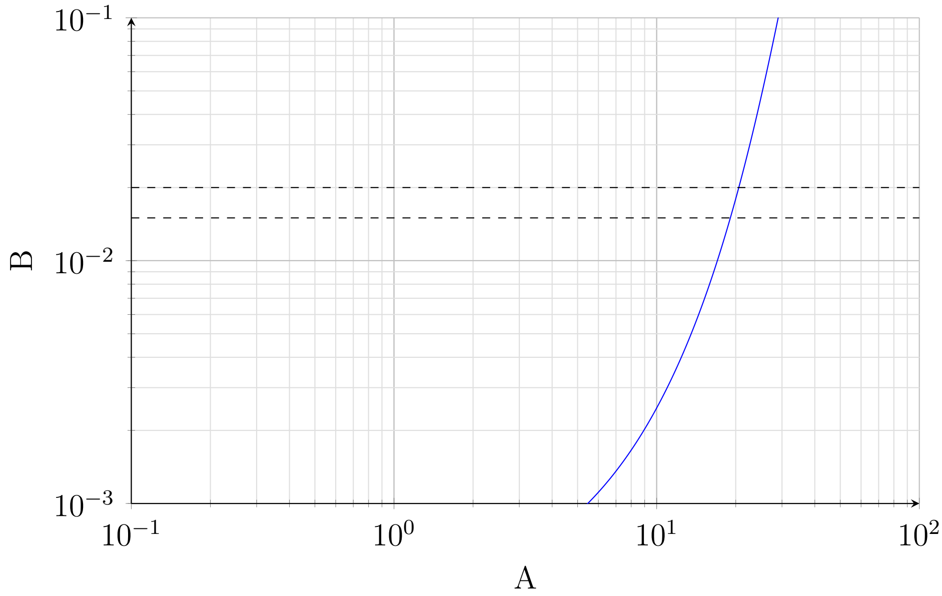
The blocking probability B(N_{cell}, A_{cell}) was plotted using MATLAB® code with $N_{cell} = 50$ channels and A_{cell} varies between 0.1 to 100 Erlangs with a step of 0.1 Erlang.

Based on the blocking probability formula:

$$B(N_{cell}, A_{cell}) = \frac{A^{N_{cell}}/N!}{\sum_{n=0}^{N_{cell}}(A^n/n!)} \tag{15}$$

```
clear
close all
clc
syms k;
N = 50;
A = 0.1:0.1:100;
for i = 1:length(N)
 for j = 1:length(A)

 B(i,j) =
double((A(j)^N(i)/factorial(N(i)))/(symsum(A(j)^
k/factorial(k),k,0,N(i))));

 end

 loglog(A,B)
 xlim([0.1 100])
 ylim([0.001 0.1])
 yline(0.02)
 yline(0.015)
 grid on
 hold on
end
```

Resulting Plot



2.11 Find the total offered traffic per cell A_{cell} for the given blocking probability (1.5%) using the diagram produced

From the plotted diagram, $B(N_{cell}, A_{cell}) = 1.5\%$ for $A_{cell} = 39.3$ Erlangs.

2.12 Determine the trunking efficiency of the system.

$$\eta_{Trunking} = \left(\frac{A_{cell}}{N_{cell}}\right) \times 100\% = \left(\frac{39.3}{50}\right) \times 100\% = 78.6\% \tag{16}$$

Where A_{cell} is the Offered traffic and N_{cell} is the number of channels.

2.13 Determine the number of calls per cell per day

The offered traffic is given by:

$$A = \sigma h \tag{17}$$

Where σ is the mean rate of calls attempted per unit time and h is the mean holding time per successful call.

Hence,

$$\sigma = \frac{A_{channel}}{h} = \frac{A_{cell}/N_{channel}}{h} = \frac{39.3/50}{1.5 \text{ minutes}} = 0.524 \text{ calls/minute/Channel} \tag{18}$$

Finally, $\sigma = 37728$ calls/day/cell

2.14 Determine the spectral efficiency of the system in Erlang/MHz/km^2.

For one cell, it's known that:

- The offered traffic is: $A_{cell} = 39.3$ Erlang
- The allocated spectrum is: $B_{cell} = N_{cell} \times B = 50 \times 200$ kHz $= 10$ MHz
- The area is: $Area_{cell} = 5.846$ km^2

Hence,

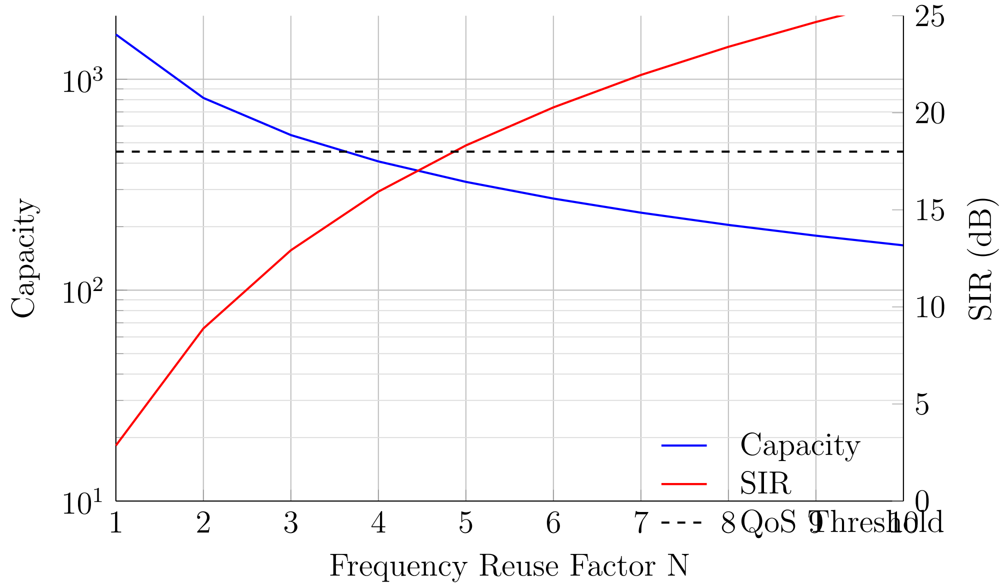
$$\eta = \frac{A_{cell}}{B_{cell} \times Area_{cell}} = \frac{39.3}{10 \times 5.846} = 0.67 \text{ Erlang/MHz/km}^2 \tag{19}$$

2.15 Explain how the cluster size or frequency reuse factor (N) affects the system capacity and the intercell signal-to-interference ratio, and how to choose a suitable N in order to meet the QoS requirements of the system.

```
clear
close
clc

N = 1:10;
alpha = 4.3;
R=1.5;
B_Sys=69.8*10^6;
B=200*10^3;
A_Sys = 2550;
A_Cell=(3*sqrt(3)*R^2)/2;
C_Clu=B_Sys/B;
C = (A_Sys*C_Clu)./(N.*A_Cell);
SIR = 10*log10(((sqrt(3*N)).^alpha)/6);

a=semilogy(N,C);
hold on
yyaxis left
```

```
ylabel('Capacity')
xlabel('Frequency Reuse Factor N')

grid on

yyaxis right
ylabel('SIR (dB)')
b=plot(N,SIR);
c=yline(18)
legend([a;b;c],'Capacity', 'SIR','QoS Threshold')
```

3 Resulting Plot



3.1 Discuss the techniques or schemes that can improve system spectral efficiency.

- Decrease cell area by splitting and sectoring.
- Obtain more spectrum.
- Change channel allocation and increase frequency reuse factor.
- Communication techniques.