Wireless Communications
Exercise 3: Fundamentals of Cellular Communications

Module Representative: Prof. Dr.-Ing. Hans D. Schotten
schotten@eit.uni-kl.de

Lecturer: Dr. Vincenzo Sciancalepore
vincenzo.sciancalepore@neclab.eu

Institute of Wireless Communication (WiCon)
Department of Electrical and Computer Engineering
TU Kaiserslautern

SS 2020
Problem 1

A cellular network is based on a multicarrier TDMA system with 18 carriers wherein each carrier consists of 4 channels.

1. What is the minimum cluster size (in terms of number of cells) so as to provide a minimum Signal-to-Interference-Ratio equal to 13.5 dB and assuming a cluster model with a propagation factor equal to 3?
Problem 1

We use the following formula \( K_{min} = \frac{(6 SIR)^2}{3} \eta \)

where \( SIR_{min} = 13.5 \text{ dB} = 10^{\frac{13.5}{10}} \approx 22.39 \)

and \( \eta = 3 \)

\( K_{min} = 8.74 \) that leads to \( K = 9 \)

Note that only some \( K \) values are admitted [3, 4, 7, 9, 12, 13, ...]
Problem 1

A cellular network is based on a multicarrier TDMA system with 18 carriers wherein each carrier consists of 4 channels.

2. How to dimension the cell radius so as to have a blocking probability equal to 0.02 while considering in the cells an offered traffic with an uniform distribution in the area equal to 15 Erlang/km$^2$?
Problem 1

Assuming cluster size of $K = 9$ each cell has $18/9 = 2$ carriers and $4 \times 2 = 8$ channels.

$$B(N, A) = \frac{A^N}{N!} \sum_{k=0}^{N} \frac{A^k}{k!}$$

- Blocking probability
- Number of channels
- Offered load

Traffic Intensity in Erlangs

<table>
<thead>
<tr>
<th>Traffic Intensity in Erlangs</th>
<th>Probability of Blocking</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.001</td>
</tr>
<tr>
<td>1.0</td>
<td>0.002</td>
</tr>
<tr>
<td>10.0</td>
<td>0.010</td>
</tr>
<tr>
<td>3.5 Erlang</td>
<td>0.020</td>
</tr>
</tbody>
</table>

3.5 Erlang
Problem 1

Considering a maximum offered traffic of 3.5 Erlang as well as traffic density of 15 Erlang/km², we get the following area

\[
\frac{3.5}{15} = 0.233 \text{ km}^2
\]

Recalling that the area of an hexagon is \( A = \frac{r^2 \sqrt{3}}{2} \), we get the optimal radius \( r = 299 \text{ m} \)
Problem 1

A cellular network is based on a multicarrier TDMA system with 18 carriers wherein each carrier consists of 4 channels.

3. What is the channel utilization factor?
Problem 1

Recalling the formula of the offered traffic

\[ A_o = \frac{A_s}{(1 - P_b)} \]

we can derive the served traffic as

\[ A_s = A_o (1 - P_b) = 3.5(1 - 0.02) = 3.43 \]

The channels utilization factor is

\[ \rho = \frac{A_s}{N} = \frac{3.43}{8} \approx 0.43 \]
Problem 1

A cellular network is based on a multicarrier TDMA system with 18 carriers wherein each carrier consists of 4 channels.

4. What are the offered traffic and the blocking probability considering after one year a served traffic amount equal to 4.65 Erlang?
Problem 1

Using the Erlang-B formula we can derive

\[ A_s = x(1 - B(8, x)) = 4.65 \]

\[ x = 5; \quad B(8,5) = 0.07 \]

\[ A_s = A_o(1 - B(8,5)) = 4.65 \]
Problem 2
Let us consider a cellular system with 2 base stations and 4 user terminals with the following attenuation matrix $M$

$$
M = \begin{bmatrix}
4 & 8 \\
4 & 8 \\
8 & 2 \\
8 & 4 \\
\end{bmatrix}
$$

wherein each element $m_{i,j} = \frac{1}{g_{i,j}}$ whereas $i$ and $j$ indicate the user terminal index and the base station index, respectively. Assuming a power control mechanism based on a closed loop control that keeps $\frac{E_b}{N_0} = 10$ dB, a processing gain $G_p$ equal to 80 and a noise power $N = 0.25$, calculate the emitted power value $p_i$ of each terminal $i$. 
Problem 2

We need to recall the following formula
\[
\frac{p_{i}g_{i,j}}{\sum_{k \neq i} p_{k}g_{k,j} + N} = \frac{E_{b}}{N_{0}} \frac{1}{G_{p}}
\]
and derive the following system equations based on the given matrix \( M \)

\[
\frac{p_{1}g_{1,1}}{\sum_{k \neq 1} p_{k}g_{k,1} + N} = \frac{E_{b}}{N_{0}} \frac{1}{G_{p}}
\]

\[
\frac{p_{2}g_{2,1}}{\sum_{k \neq 2} p_{k}g_{k,1} + N} = \frac{E_{b}}{N_{0}} \frac{1}{G_{p}}
\]

\[
\frac{p_{3}g_{3,2}}{\sum_{k \neq 3} p_{k}g_{k,2} + N} = \frac{E_{b}}{N_{0}} \frac{1}{G_{p}}
\]

\[
\frac{p_{4}g_{4,2}}{\sum_{k \neq 4} p_{k}g_{k,2} + N} = \frac{E_{b}}{N_{0}} \frac{1}{G_{p}}
\]

\[
p_{1} \approx 0.160
\]

\[
p_{2} \approx 0.160
\]

\[
p_{3} \approx 0.083
\]

\[
p_{4} \approx 0.166
\]
Problem 3

Let us assume the following configuration during a planning phase. There are 7 candidate sites and 15 test points. Let us considering the following propagation matrix $V$

$$V = \begin{bmatrix}
1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 \\
0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\
1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\
0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1
\end{bmatrix}$$
Problem 3

where each binary value \( v_{i,j} \in \{0; 1\} \) indicates whether a potential base station installed into a candidate site \( j \) may cover the test point \( i \) (1) or not (0). For each candidate site an installation cost \( c_j \) is defined as follows

\[
C = \begin{bmatrix}
9 \\
10 \\
11 \\
7 \\
5 \\
2 \\
8
\end{bmatrix}
\]
Problem 3

Calculate a sub-optimal solution on how to place base stations into candidate sites such that each test point $i$ is covered and the overall installation cost is minimized.

We will place BSs into candidate site 6; 1 and 5.