# Frequency Allocation for 5G+
# The Magic of Mobile Communications

## LAB1: Cellular Networks and Frequency Planning

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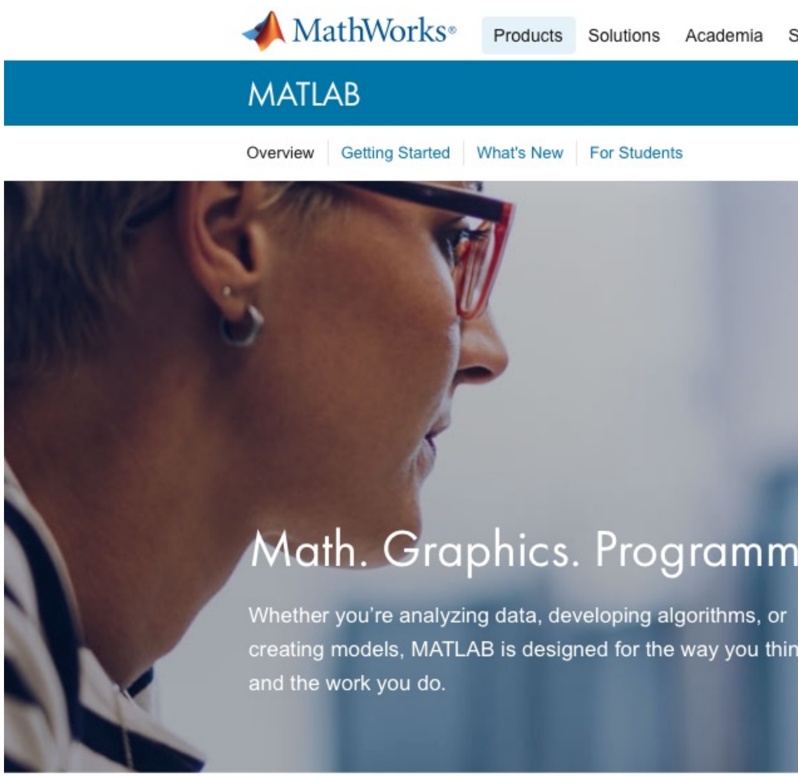
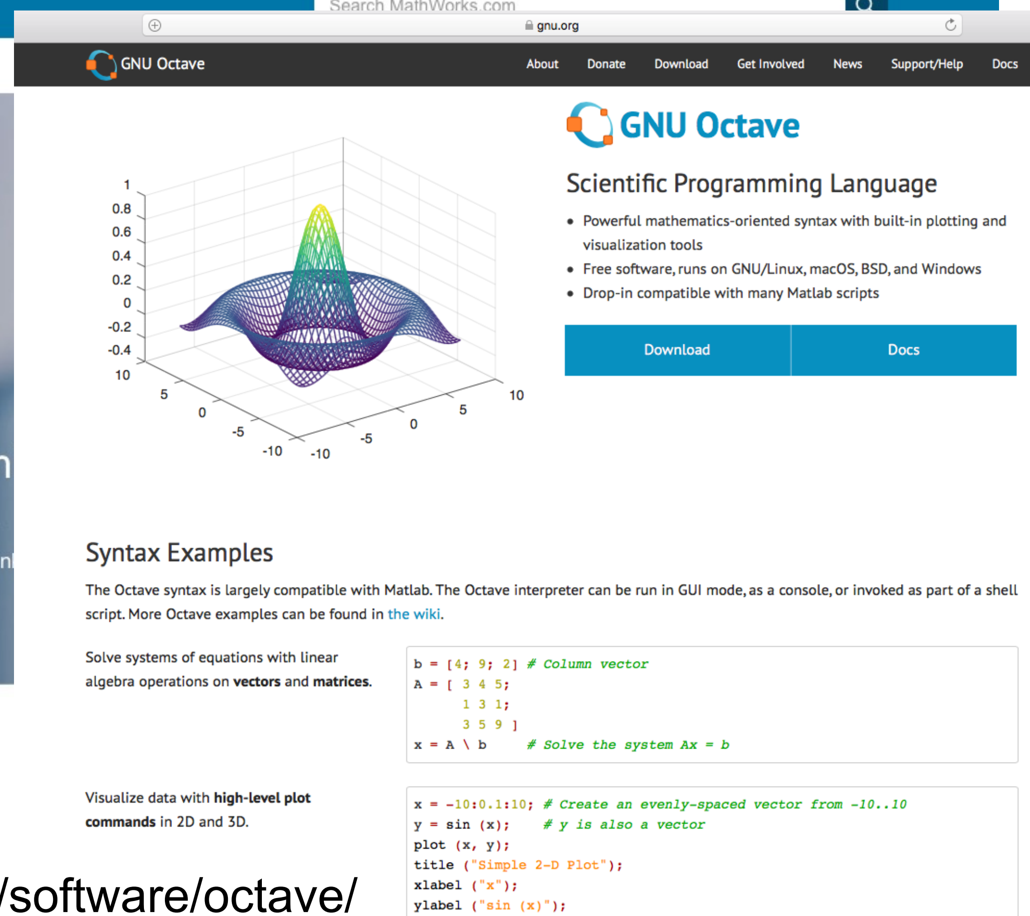
Google Scholar: https://scholar.google.co.uk/citations?user=kVhcY0gAAAAJ

# MATLAB or Octave

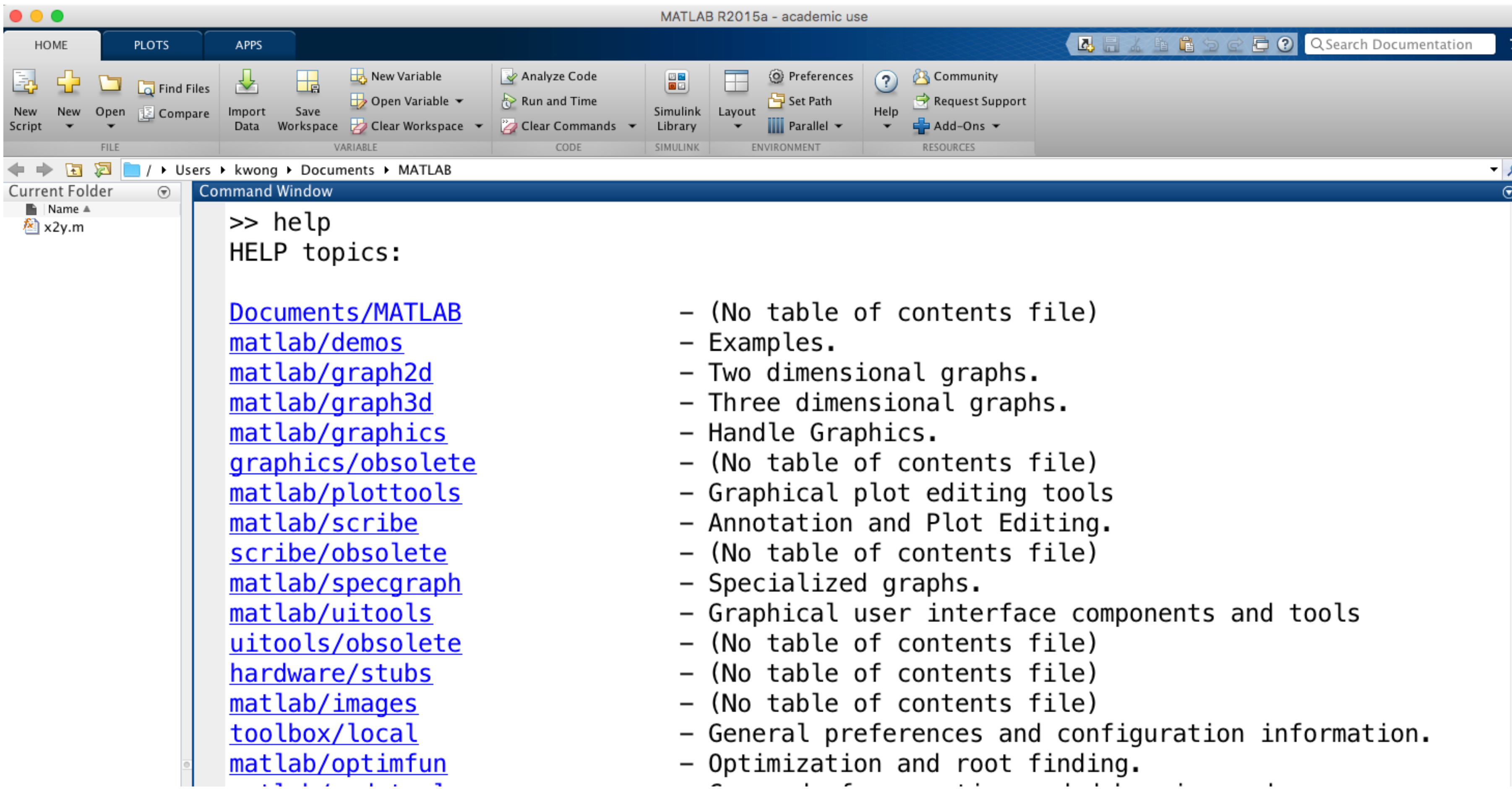



https://www.mathworks.com




https://www.gnu.org/software/octave/

# Basics


MATLAB R2015a - academic use
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>> help
HELP topics:
Documents/MATLAB - (No table of contents file)
matlab/demos - Examples.
matlab/graph2d - Two dimensional graphs.
matlab/graph3d - Three dimensional graphs.
matlab/graphics - Handle Graphics.
graphics/obsolete - (No table of contents file)
matlab/plottools - Graphical plot editing tools
matlab/scribe - Annotation and Plot Editing.
scribe/obsolete - (No table of contents file)
matlab/specgraph - Specialized graphs.
matlab/uitools - Graphical user interface components and tools
uitools/obsolete - (No table of contents file)
hardware/stubs - (No table of contents file)
matlab/images - (No table of contents file)
toolbox/local - General preferences and configuration information.
matlab/optimfun - Optimization and root finding.

# Basic Commands

```
>> 3+4
>> x=[1 2 3 4 5]
>> y=[6;7;8;9;10]
>> y'
>> whos, who
>> clear ans, clear all
>> save filename.mat
>> u=0:8
>> u=0:2:8
>> u(1:3), u(1:2:4)
```

# Basic Commands (cont’d)

```
>> A=[1 2 3;4 5 6;7 8 9]
>> A(2,2), A(:,1), A(2,:), A(1:2,2:3), A′
>> A*A, A.*A, A.^2
>> Some scalar functions: sin, cos, tan,
asin, acos, atan, exp, log, abs, sqrt, rem,
round, floor, ceil
>> Some vector functions: max, min, length,
sort, sum, prod, median, mean, std
>> Some matrix functions: eye, zeros, ones,
diag, triu, tril, rand, size, det, inv, rank,
eig, poly, norm, cond, lu, qr, chol, svd
```

# Basic Commands (cont'd)

```
>> plot(x,y), xlabel, ylabel, title, legend
>> function [a,b]=fname(x,y)
>> for i=1:10
I=i+2;
end
>> Relational operators: <, >, <=, >=, ==,
~=, &, |, ~
>> if, elseif, else, end
>> help, clc, ls, % … and more (please refer
to the MATLAB primer as well)
```

# Frequency Reuse

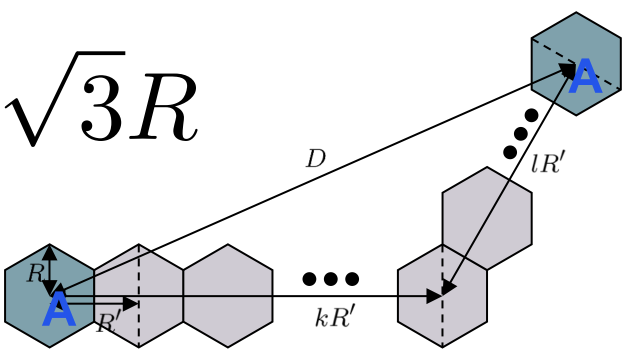
Pick a starting cell with the frequency channel set A.

Move $k$ cells along any of the 6 directions perpendicular to the sides of the hexagons.

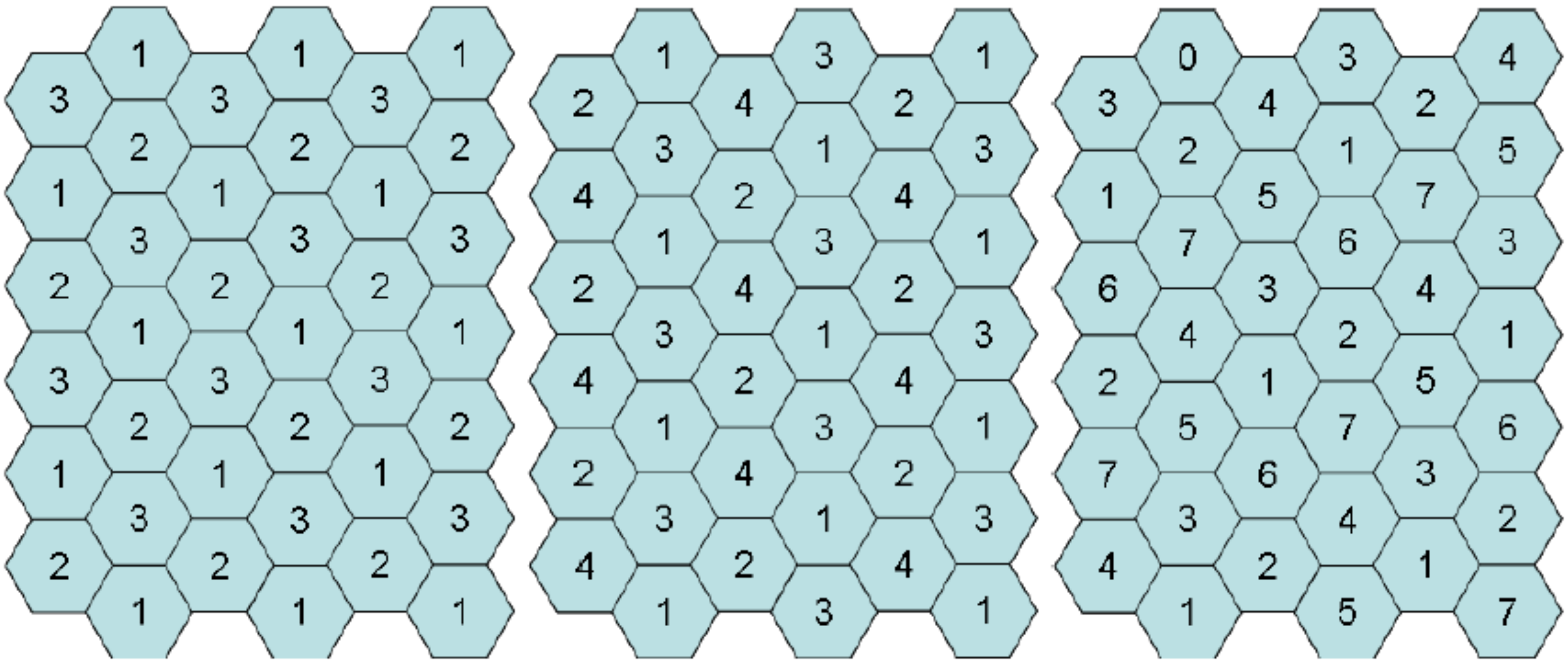
Then turn clockwise 120º and move $l$ cells. The resulting cell is a cell that reuses the same channel set A as the starting cell.

Repeat the same procedure for each of the other 5 sides of the starting hexagonal cell to identify all the 6 closest co-channel cells. Repeat each of the co-channel cells on the entire region.

$$R' = \sqrt{3}R$$



# Reuse Examples



(a) Reuse factor = 3 (b) Reuse factor = 4 (c) Reuse factor = 7

$$(k,l) = (1,1) \quad (k,l) = (2,0) \quad (k,l) = (1,2)$$

# Reuse Factor

The frequency reuse factor $N$ is defined as the number of channel sets in the reuse pattern, depending on $(k, l)$

Derive $N$:

$$A = 6\left(\frac{1}{2}\left(\frac{D}{\sqrt{3}}\right)^2 \sin 60^\circ\right) = \frac{\sqrt{3}D^2}{2}$$

$$a = 6\left(\frac{1}{2}R^2 \sin 60^\circ\right) = \frac{3\sqrt{3}R^2}{2}$$

$$N = \frac{\text{Area of the group}}{\text{Area of the cell}} \equiv \frac{A}{a}$$

$$= \frac{D^2}{3R^2}$$

$$\boxed{\frac{D}{R} = \sqrt{3N}}$$

Also, from the geometry, we have

$$D^2 = \left(kR' + \frac{lR'}{2}\right)^2 + \left(\frac{lR'\sqrt{3}}{2}\right)^2$$

$$= (k^2 + kl + l^2){R'}^2 = 3R^2(k^2 + kl + l^2)$$

$$\boxed{N = k^2 + kl + l^2}$$

The allowable reuse pattern is 1, 3, 4, 7, 9, 12, 13, …

# Class Practice 1.1

List out the possible values of frequency reuse factor and their configurations

| $k$ | $l$ | $N$ |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

# Pathloss Formula

The received power can be expressed as

Transmit antenna gain

Transmit power

Receive antenna gain

Wavelength

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

$$= P_0 d^{-2}$$

Distance

More generally,

Pathloss exponent

$$\boxed{P_r = P_0 d^{-\alpha}}$$

# Choosing the Reuse Factor

A smaller $N$ implies the frequency channels are reused more quickly. If $N$ = 1, it means channels are reused everywhere!

A suitable $N$ is chosen by considering the signal-to-interference ratio (SIR), i.e.,

$$\mathrm{SIR} = \frac{S}{\sum_\ell I_\ell} = \frac{P_0 R^{-\alpha}}{\sum_\ell P_0 D_\ell^{-\alpha}}$$

$$\boxed{\mathrm{SIR} \approx \frac{\left(\sqrt{3N}\right)^\alpha}{6}}$$

# Signal-to-Interference Ratio (SIR) Analysis

$$Q \triangleq \frac{D}{R}$$

$$\begin{aligned}
\mathrm{SIR} &= \frac{R^{-\alpha}}{\sum_\ell D_\ell^{-\alpha}} \\
&= \frac{R^{-\alpha}}{(D+R)^{-\alpha} + \left(D+\frac{R}{2}\right)^{-\alpha} + D^{-\alpha} + 2(D-R)^{-\alpha} + \left(D-\frac{R}{2}\right)^{-\alpha}} \\
&= \frac{1}{\frac{2(Q+1)^\alpha + (Q-1)^\alpha}{(Q^2-1)^\alpha} + \frac{(Q+0.5)^\alpha + (Q-0.5)^\alpha}{(Q^2-0.25)^\alpha} + \frac{1}{Q^\alpha}}
\end{aligned}$$

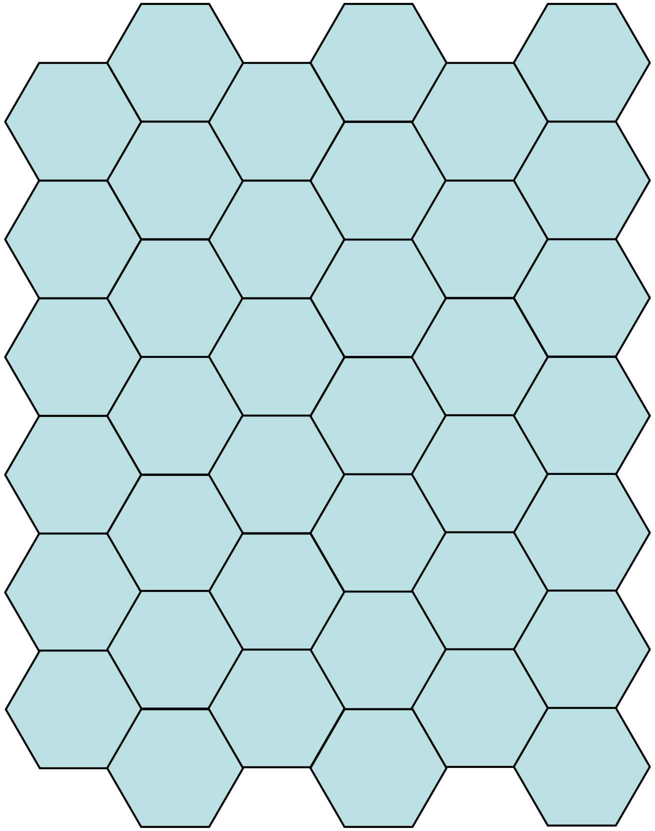
For $\alpha = 4$, to achieve SIR ≥ 10dB, we need to have Q ≥ 3.325 and therefore N ≥ 3.7, or the minimum reuse factor is 4

Similarly, if we need SIR ≥ 20dB, then N ≥ 9.58 and the minimum reuse factor should be 12

# Class Practice 1.2

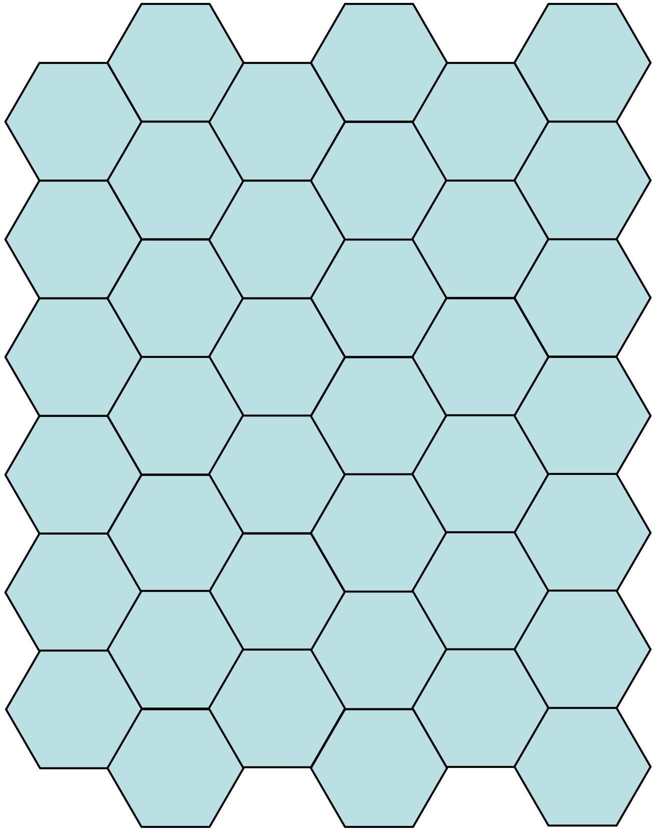
$N = 7$

$\mathrm{SIR} =$



$N = 12$

$\mathrm{SIR} =$



# Class Practice 1.3

Frequency reuse factor vs the SIR

| $k$ | $l$ | $N$ | $\approx \mathrm{SIR}$ | $\mathrm{SIR}$ |
|---|---|---|---|---|
| | | | | |
| | | | | |
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