

# Frequency Allocation for 5G+


## The Magic of Mobile Communications



### LAB1: Cellular Networks and Frequency Planning

Professor (Kit) Kai-Kit Wong, 黃繼傑

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

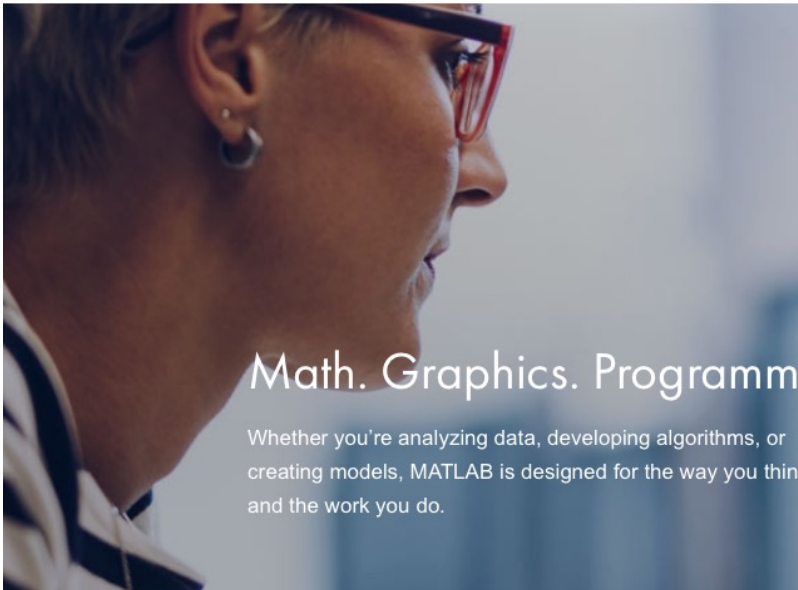
# MATLAB or Octave


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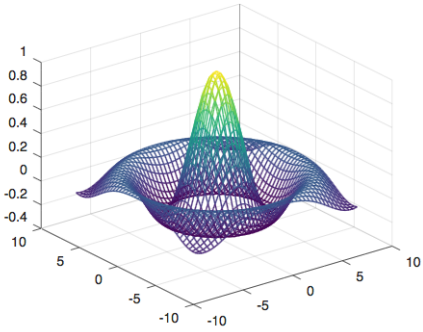
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## Scientific Programming Language

- Powerful mathematics-oriented syntax with built-in plotting and visualization tools
- Free software, runs on GNU/Linux, macOS, BSD, and Windows
- Drop-in compatible with many Matlab scripts

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<https://www.mathworks.com>

## Syntax Examples

The Octave syntax is largely compatible with Matlab. The Octave interpreter can be run in GUI mode, as a console, or invoked as part of a shell script. More Octave examples can be found in [the wiki](#).

Solve systems of equations with linear algebra operations on **vectors** and **matrices**.

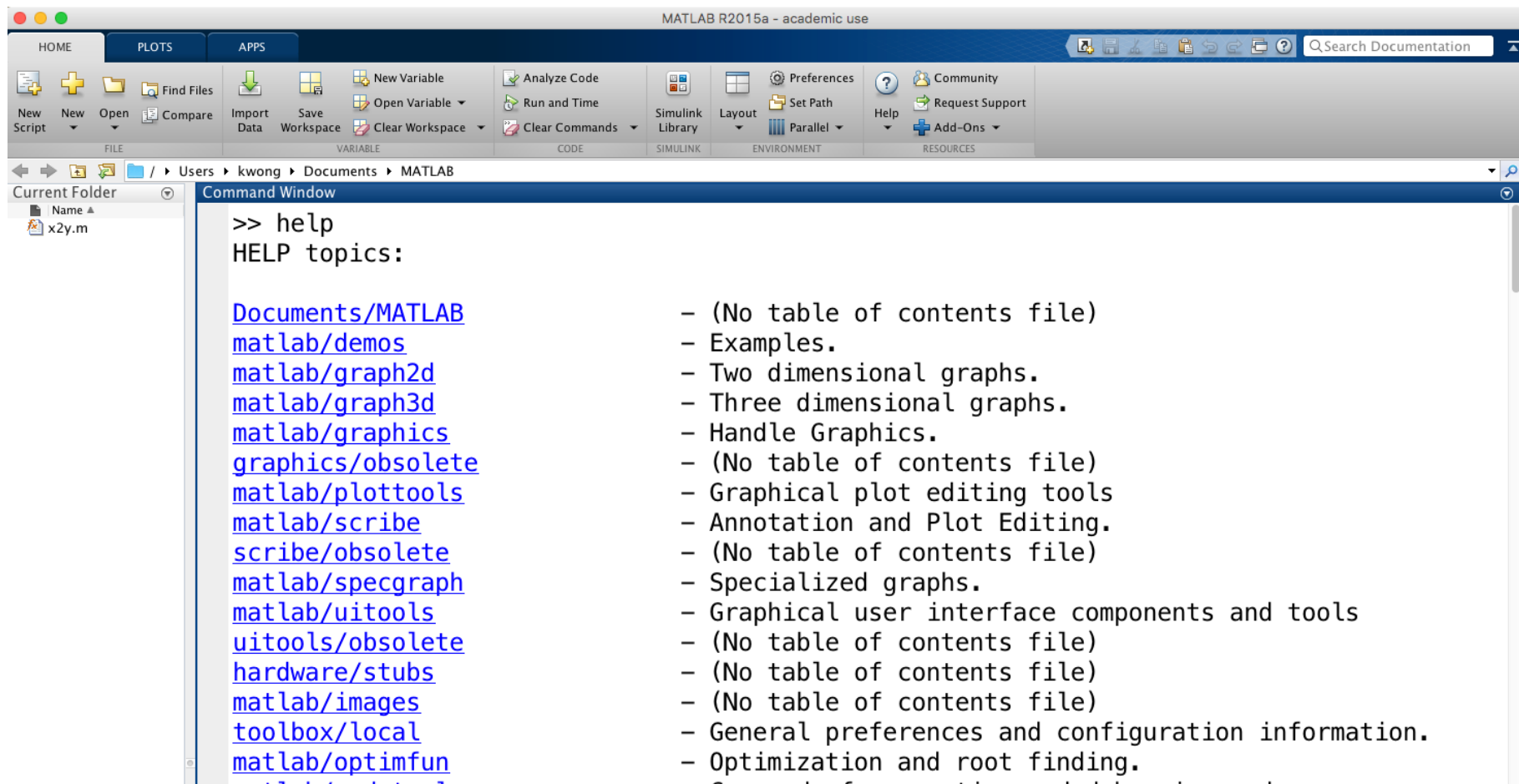
```
b = [4; 9; 2] # Column vector
A = [ 3 4 5;
      1 3 1;
      3 5 9 ]
x = A \ b # Solve the system Ax = b
```

Visualize data with **high-level plot commands** in 2D and 3D.

```
x = -10:0.1:10; # Create an evenly-spaced vector from -10..10
y = sin(x); # y is also a vector
plot(x, y);
title("Simple 2-D Plot");
xlabel("x");
ylabel("sin(x)");
```

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

# Basics



The image shows the MATLAB R2015a - academic use interface. The top menu bar includes HOME, PLOTS, and APPS. The main toolbar contains icons for New Script, New, Open, Find Files, Compare, Import Data, Save Workspace, New Variable, Open Variable, Clear Workspace, Analyze Code, Run and Time, Clear Commands, Simulink Library, Layout, Parallel, Preferences, Set Path, Help, Community, Request Support, and Add-Ons. The Command Window displays the following text:

```
>> help
HELP topics:

Documents/MATLAB
matlab/demos
matlab/graph2d
matlab/graph3d
matlab/graphics
graphics/obsolete
matlab/plottools
matlab/scribe
scribe/obsolete
matlab/specgraph
matlab/uitools
uitools/obsolete
hardware/stubs
matlab/images
toolbox/local
matlab/optimfun
```

- (No table of contents file)
- Examples.
- Two dimensional graphs.
- Three dimensional graphs.
- Handle Graphics.
- (No table of contents file)
- Graphical plot editing tools
- Annotation and Plot Editing.
- (No table of contents file)
- Specialized graphs.
- Graphical user interface components and tools
- (No table of contents file)
- (No table of contents file)
- (No table of contents file)
- General preferences and configuration information.
- 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

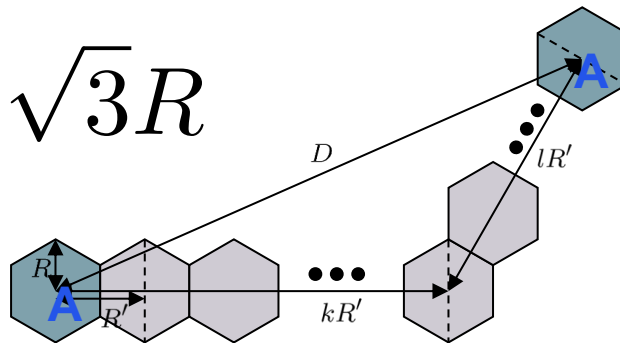
Pick a starting cell with the frequency **channel set A**.

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

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

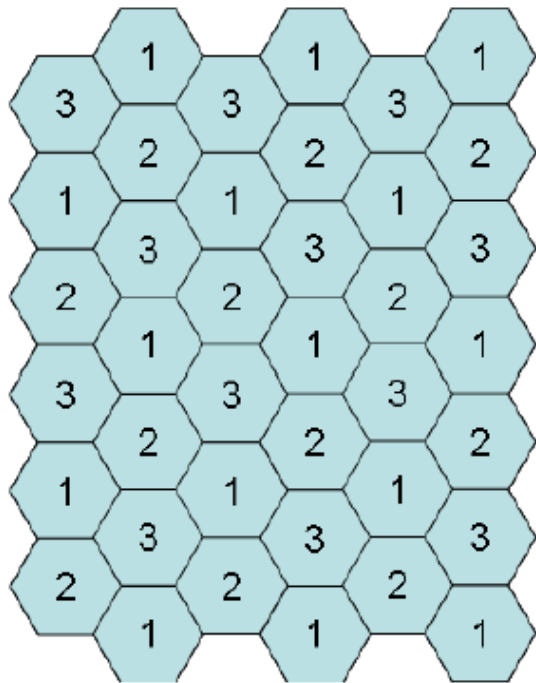
Repeat the same procedure for each of the other 5 sides of the starting hexagonal cell to identify all the 6 closest co-channel cells. Repeat each of the co-channel cells on the entire region.

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

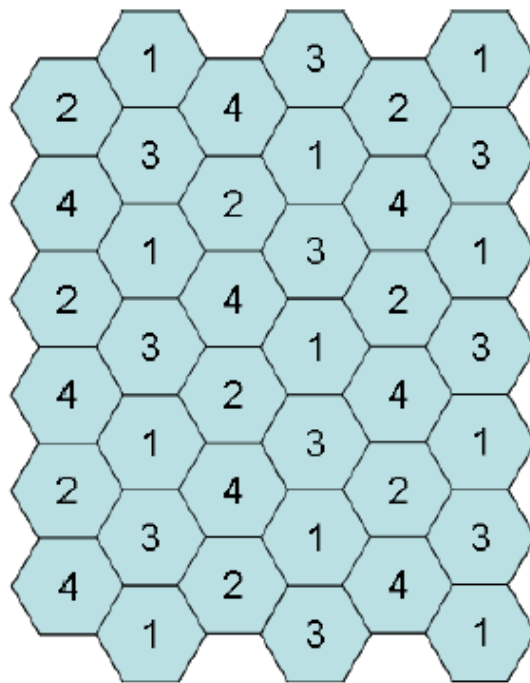




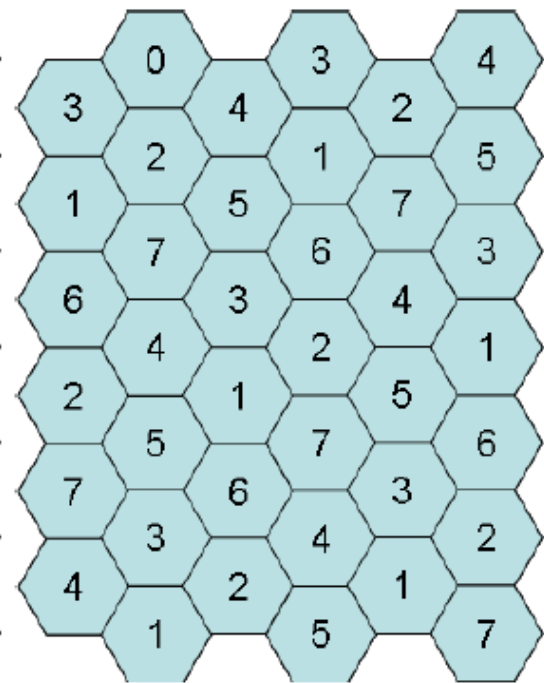
# Reuse Examples



(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  $N$ :

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

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

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

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

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

Also, from the geometry, we have

$$\begin{aligned} D^2 &= \left( kR' + \frac{lR'}{2} \right)^2 + \left( \frac{lR'\sqrt{3}}{2} \right)^2 \\ &= (k^2 + kl + l^2)R'^2 = 3R^2(k^2 + kl + l^2) \end{aligned}$$

$$N = k^2 + kl + l^2$$

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

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

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

Labels for the first equation:

- Transmit power (points to  $P_t$ )
- Transmit antenna gain (points to  $G_t$ )
- Receive antenna gain (points to  $G_r$ )
- Wavelength (points to  $\lambda^2$ )
- Distance (points to  $d$ )

More generally,

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

Labels for the second equation:

- Pathloss exponent (points to  $\alpha$ )

## 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.,

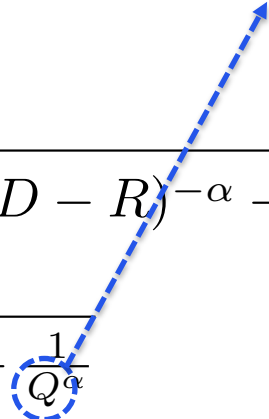
$$\text{SIR} = \frac{S}{\sum_{\ell} I_{\ell}} = \frac{P_0 R^{-\alpha}}{\sum_{\ell} P_0 D_{\ell}^{-\alpha}}$$

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

## Signal-to-Interference Ratio (SIR) Analysis

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

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



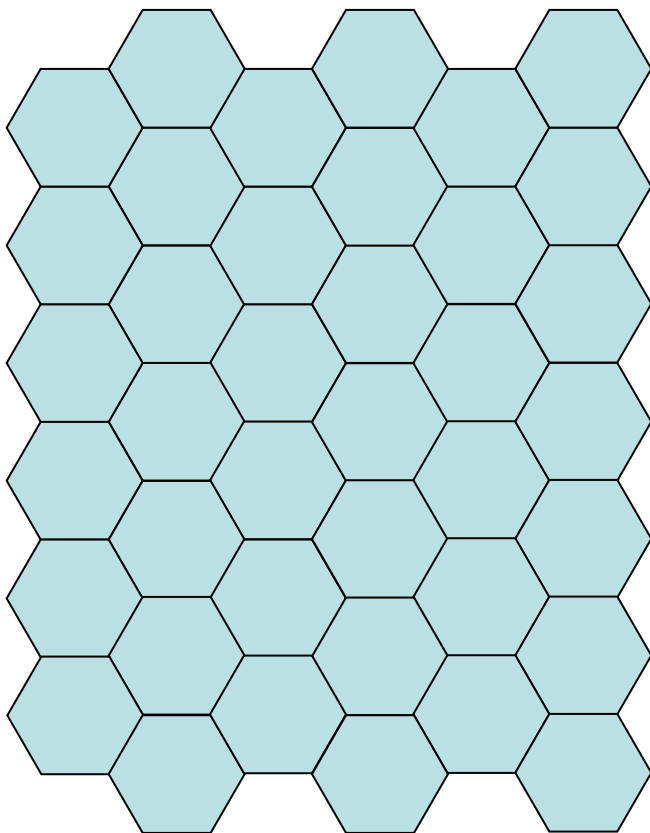
For  $\alpha = 4$ , to achieve  $\text{SIR} \geq 10\text{dB}$ , we need to have  $Q \geq 3.325$  and therefore  $N \geq 3.7$ , or the minimum reuse factor is 4

Similarly, if we need  $\text{SIR} \geq 20\text{dB}$ , then  $N \geq 9.58$  and the minimum reuse factor should be 12

## Class Practice 1.2

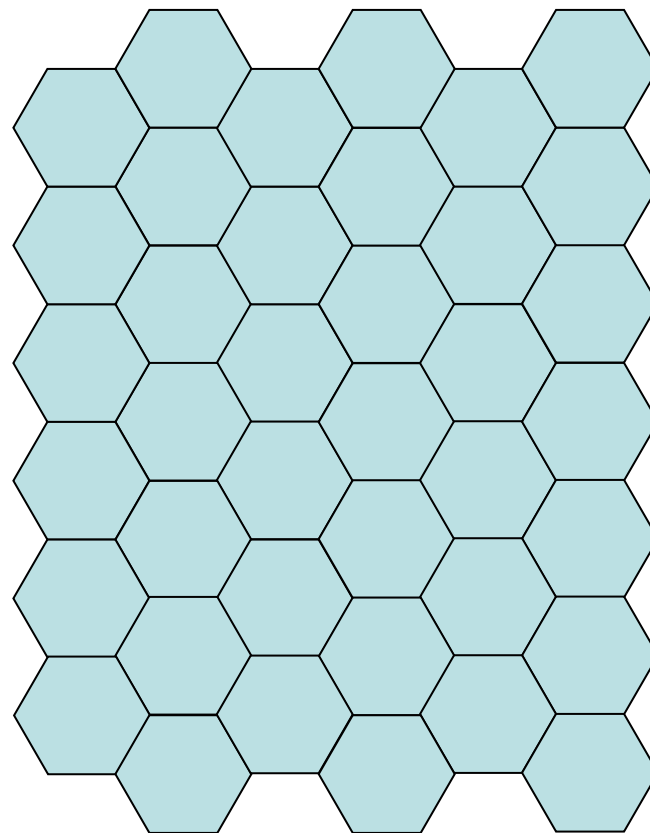
$$N = 7$$

SIR =



$$N = 12$$

SIR =





## Class Practice 1.3

Frequency reuse factor vs the SIR

$k$	$l$	$N$	$\approx$ SIR	SIR