Frequency Allocation for 5G+
The Magic of Mobile Communications

LT3: Frequency Reuse Algorithms

Professor (Kit) Kai-Kit Wong, 黃繼傑

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

Integer Frequency Reuse (IFR)

Recalling from the **fixed** frequency planning, we have

$$\boxed{N = k^2 + kl + l^2} \qquad \boxed{Q = \frac{D}{R} = \sqrt{3N}}$$

$$\boxed{\mathrm{SIR} = \frac{1}{\frac{2(Q+1)^\alpha + (Q-1)^\alpha}{(Q^2-1)^\alpha} + \frac{(Q+0.5)^\alpha + (Q-0.5)^\alpha}{(Q-0.25)^\alpha} + \frac{1}{Q^\alpha}}}$$

Limitations

- The SIR analysis is based on the worst case
- The frequency channel allocation is predefined and inflexible
- Larger N improves the SIR but reduces the number of available channels in a cell (the number of channels per cell is N_c/(N))

Reuse factor

Total no. of channels

IFR1 $(N = 1)$

The number of channels per cell is maximum at N_c

Interference will be nearest and most severe

Transmit power from BS n

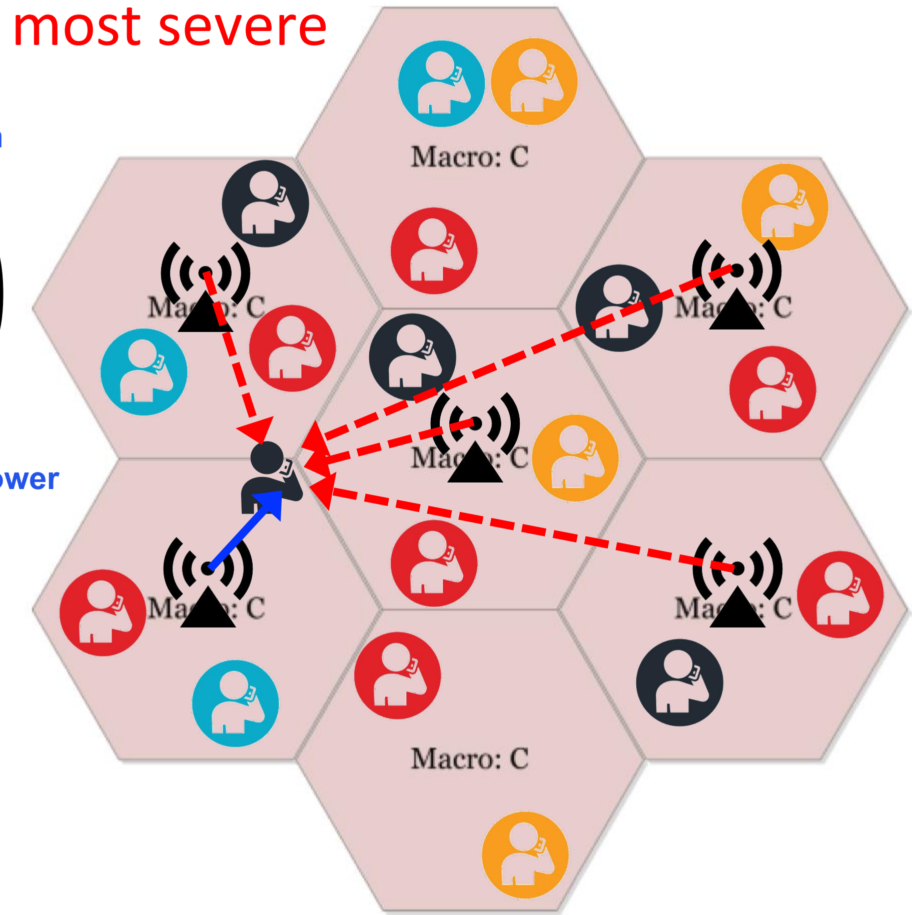
$$C_n = \log_2\left(1 + \frac{|h_{n,n}|^2 P_n}{\sum_{m\neq n} |h_{m,n}|^2 P_m + \sigma^2}\right)$$

Channel from BS m to user n

Noise power

Transmit power from BS m

$$\boxed{C_{\text{total}} = \sum_n C_n}$$



IFR3 $(N = 3)$

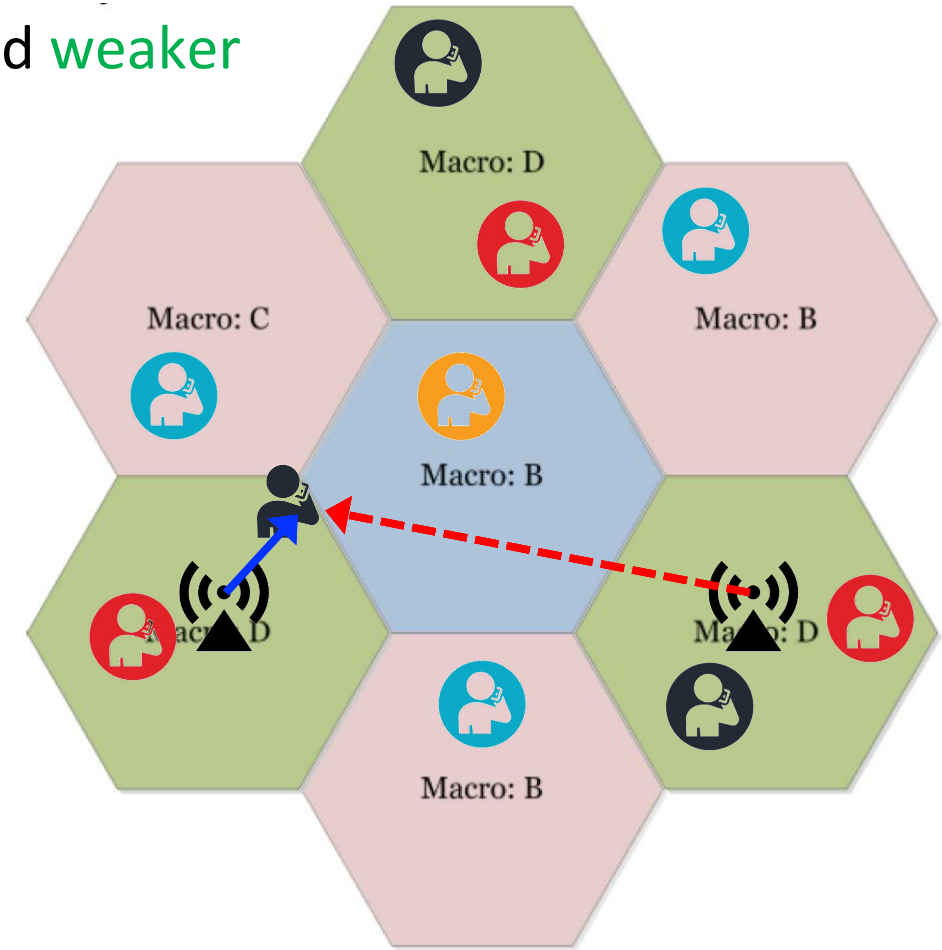
The number of channels per cell is reduced to $N_c/3$

Interference is further away and weaker

$$C_n = \log_2\left(1 + \frac{|h_{m,n}|^2 P_n}{\sum_{m\neq n} \rho_{m,n} |h_{m,n}|^2 P_m + \sigma^2}\right)$$

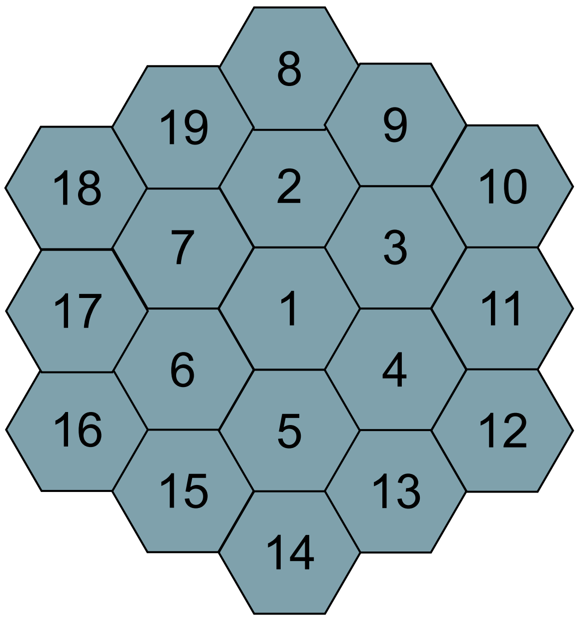
The parameter that adjusts the amount of interference from cell m to cell n

$$\boxed{C_{\text{total}} = \sum_n C_n}$$



Consider a 19-Cell Network

The network cells can be indexed as follows:



Given **18** frequency channels

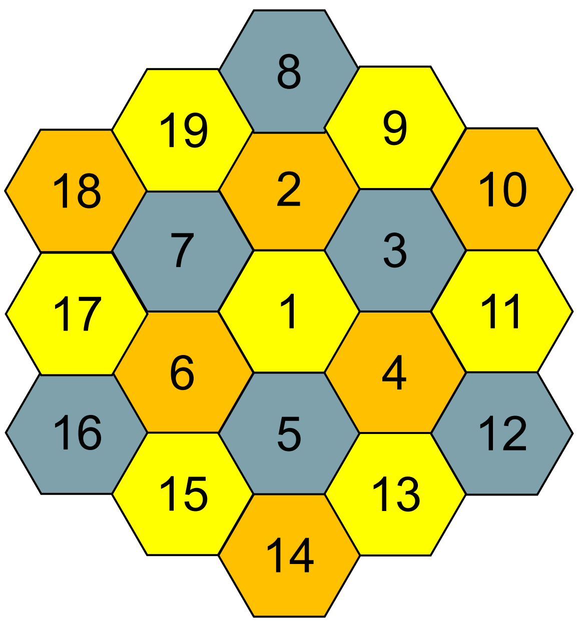
If IFR1 is used, then

$$\begin{cases} f_1 = [1\ 2\ \cdots\ 18] \\ f_2 = [1\ 2\ \cdots\ 18] \\ \quad \vdots \\ f_{19} = [1\ 2\ \cdots\ 18] \end{cases}$$

Every cell is given all the frequencies

The 19-Cell Network (cont'd)

If IFR3 (i=1, j=1) is used, then each cell is given **6** frequencies



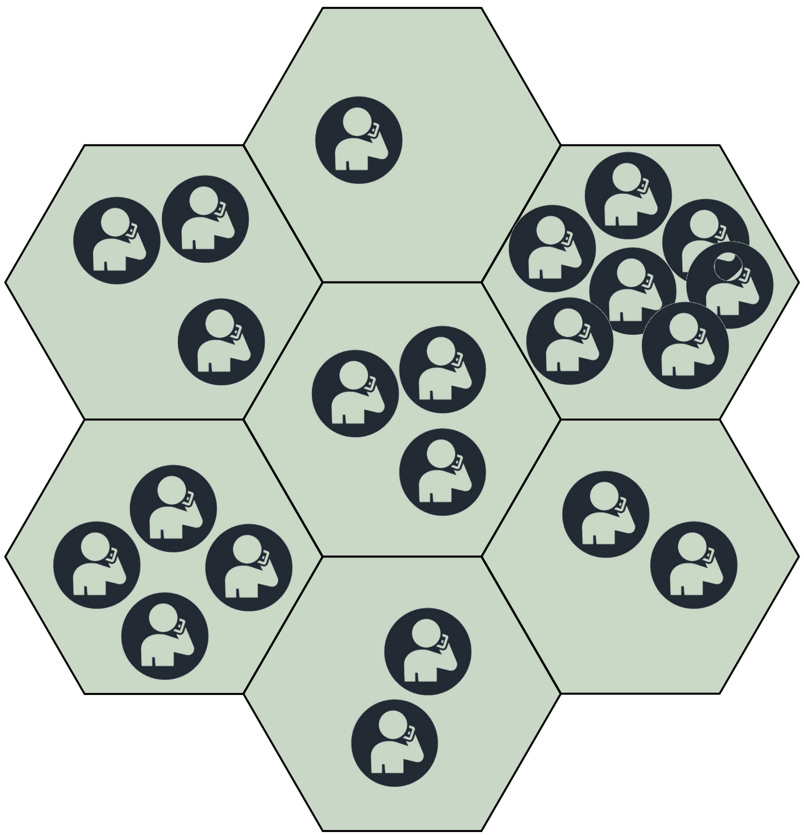
$$
\begin{cases}
f_1 = [1\ 2\ 3\ 4\ 5\ 6] \\
f_2 = [7\ 8\ 9\ 10\ 11\ 12] \\
f_3 = [13\ 14\ 15\ 16\ 17\ 18] \\
f_4 = [7\ 8\ 9\ 10\ 11\ 12] \\
f_5 = [13\ 14\ 15\ 16\ 17\ 18] \\
f_6 = [7\ 8\ 9\ 10\ 11\ 12] \\
f_7 = [13\ 14\ 15\ 16\ 17\ 18] \\
\quad\vdots \\
f_{19} = [1\ 2\ 3\ 4\ 5\ 6]
\end{cases}
$$

Capacity Evaluation

$$C_{\text{total}} = \sum_n C_n$$

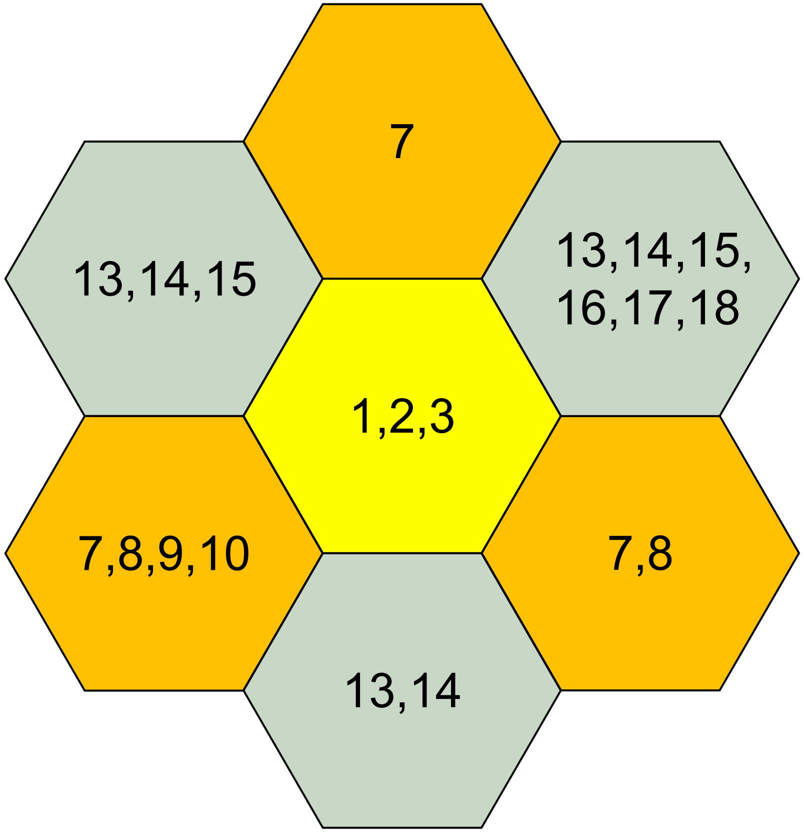
First, we need to have users in the cell

>> Generate a random number to decide on the number of users for each cell



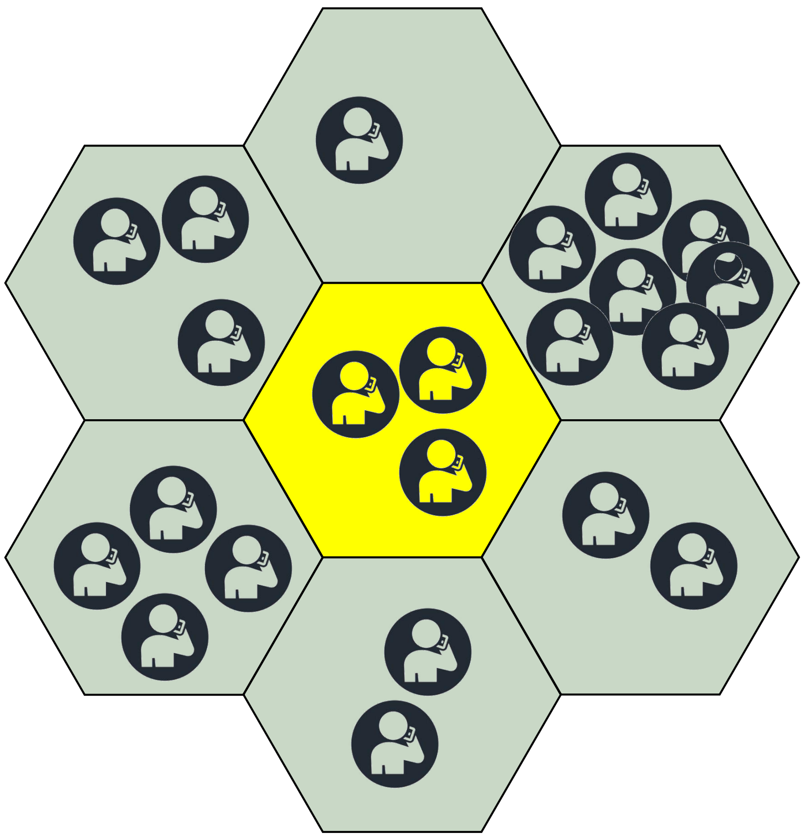
Capacity Evaluation (cont'd)

Then work out the frequency for each user (e.g., IFR3)



Capacity Evaluation (cont'd)

Then for a given user, identify the other users who occupy the same frequency (their BS are the sources of interference)



For Cell 1, users do not suffer any interference

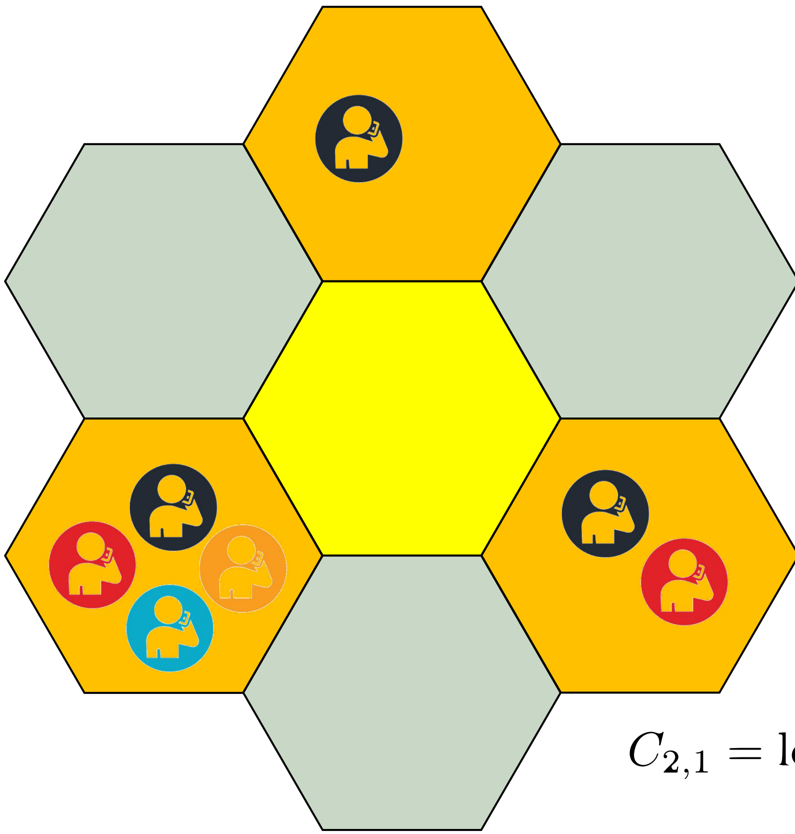
For each user, we simulate the channels $h_{1,1}, h_{1,2}, h_{1,3}$

For each user, we compute

$$C_{1,u} = \log_2\left(1 + \frac{P|h_{1,u}|^2}{\sigma^2}\right)$$

Capacity Evaluation (cont'd)

For Cell 2, interference comes from Cell 4 & Cell 6



We need to simulate the channel $h_{2,(\mathbf{2},1)}$

Also, the interference channels

$$h_{4,(\mathbf{2},1)}, h_{6,(\mathbf{2},1)}$$

from Cell 4

to Cell 2

User 1 in Cell 2

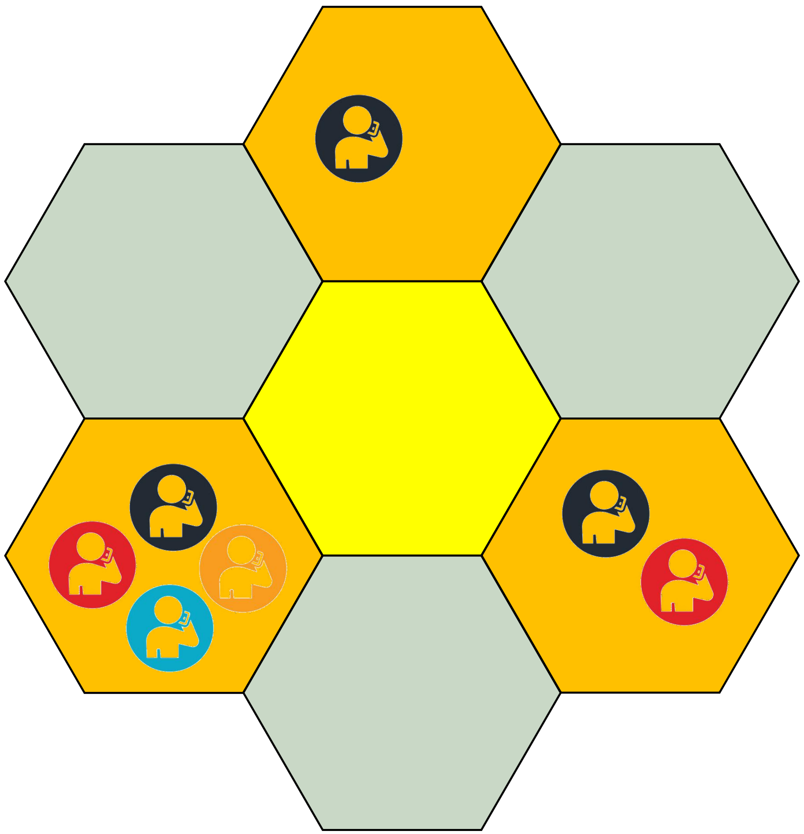
We also need to set $\rho_{4,\mathbf{2}}, \rho_{6,\mathbf{2}}$

Thus,

$$C_{2,1} = \log_2\left(1 + \frac{P|h_{2,(2,1)}|^2}{P(\rho_{4,2}|h_{4,(2,1)}|^2 + \rho_{6,2}|h_{6,(2,1)}|^2) + \sigma^2}\right)$$

Capacity Evaluation (cont'd)

For Cell 4, interference comes from Cell 2 & Cell 6

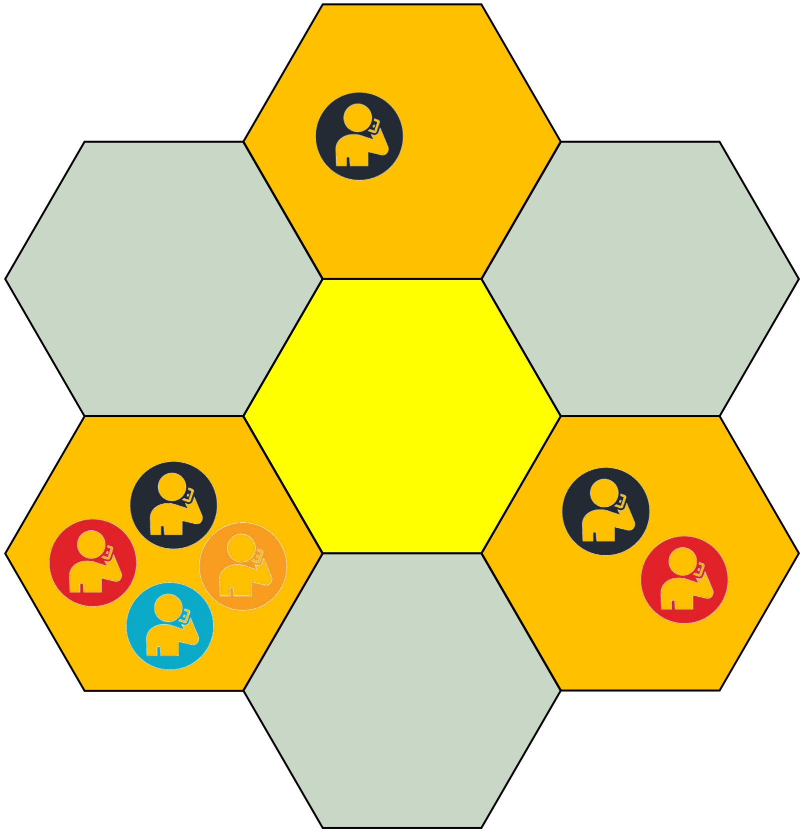


$$C_{4,1} = \log_2\left(1 + \frac{P|h_{4,(4,1)}|^2}{P(\rho_{2,4}|h_{2,(4,1)}|^2 + \rho_{6,4}|h_{6,(4,1)}|^2) + \sigma^2}\right)$$

$$C_{4,2} = \log_2\left(1 + \frac{P|h_{4,(4,2)}|^2}{P\rho_{6,4}|h_{6,(4,2)}|^2 + \sigma^2}\right)$$

Capacity Evaluation (cont'd)

For Cell 6, interference comes from Cell 2 & Cell 4



$$C_{6,1} = \log_2\left(1 + \frac{P|h_{6,(6,1)}|^2}{P(\rho_{2,6}|h_{2,(6,1)}|^2 + \rho_{4,6}|h_{4,(6,1)}|^2) + \sigma^2}\right)$$

$$C_{6,2} = \log_2\left(1 + \frac{P|h_{6,(6,2)}|^2}{P\rho_{4,6}|h_{4,(6,2)}|^2 + \sigma^2}\right)$$

$$C_{6,3} = \log_2\left(1 + \frac{P|h_{6,(6,3)}|^2}{\sigma^2}\right)$$

$$C_{6,4} = \log_2\left(1 + \frac{P|h_{6,(6,4)}|^2}{\sigma^2}\right)$$

Class Practice 3.1

Using the approaches mentioned, consider a 7-cell network and simulate the frequency allocation algorithms IFR1 & IFR3

Compute the capacity for each user and the total capacity

Repeat the simulations for a 19-cell network

The simulations should be generalisable for different N_c

Also, you should try different values of $\{\rho_{m,n}\}$

Key Steps

Generate random number of users (for each cell)

```
>> U=poissrnd(3)

U =

     3
```

Obtain a frequency allocation table

```
>> f=[1:6;7:12;13:18;7:12;13:18;7:12;13:18]

f =

     1     2     3     4     5     6
     7     8     9    10    11    12
    13    14    15    16    17    18
     7     8     9    10    11    12
    13    14    15    16    17    18
     7     8     9    10    11    12
    13    14    15    16    17    18
```

frequency bands for Cell 1

frequency bands for Cell 5

frequency bands for Cell 7

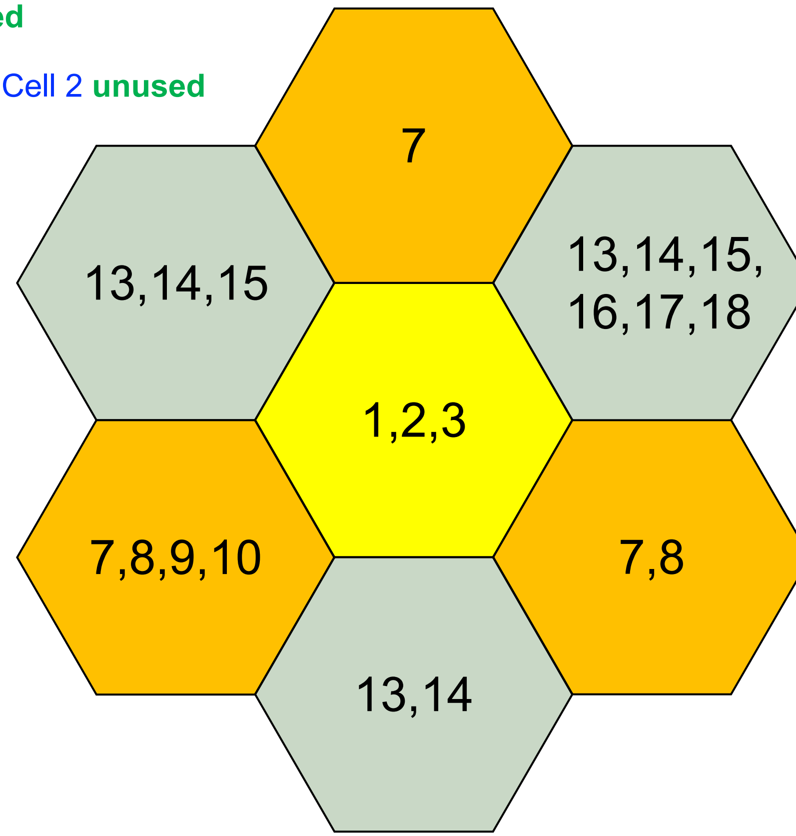
Key Steps (cont'd)

Record the used frequencies for all the cells

```
>> fstatus

fstatus =

     1     1     1     0     0     0
     1     0     0     0     0     0
     1     1     1     1     1     1
     1     1     0     0     0     0
     1     1     0     0     0     0
     1     1     1     1     0     0
     1     1     1     0     0     0
```

3rd frequency band of Cell 1 **used**

4th frequency band of Cell 2 **unused**



Key Steps (cont'd)

Set the parameters $\{\rho_{m,n}\}$

```
>> rho

rho =

    1.0000         0         0         0         0         0         0
         0    1.0000         0    0.5000         0    0.5000         0
         0         0    1.0000         0    0.5000         0    0.5000
         0    0.5000         0    1.0000         0    0.5000         0
         0         0    0.5000         0    1.0000         0    0.5000
         0    0.5000         0    0.5000         0    1.0000         0
         0         0    0.5000         0    0.5000         0    1.0000
```

Cell 1 to Cell 2 **no interference**

Cell 2 to Cell 4 **has interference**

Cell 7 to Cell 3 **has interference**

Key Steps (cont'd)

For each user u in Cell b, identify the cells that cause interference to Cell b

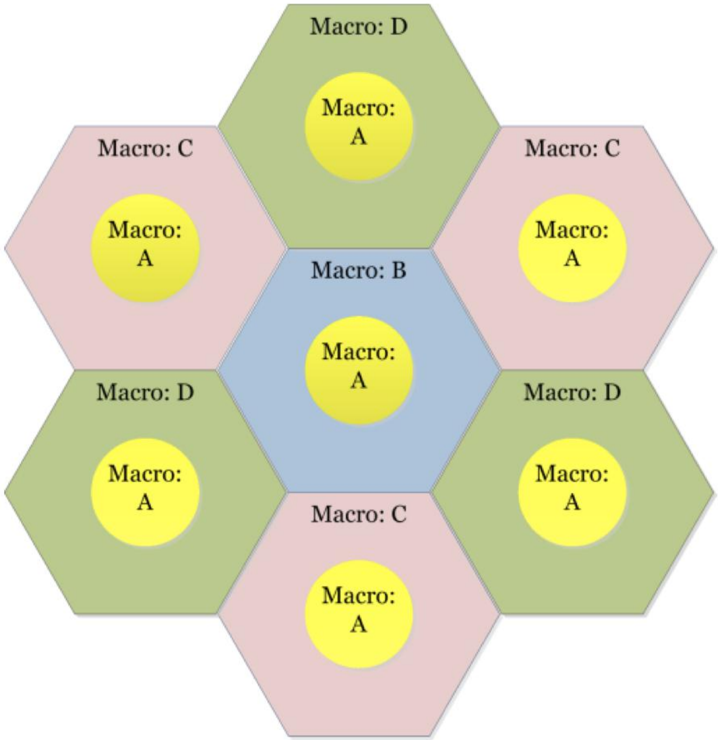
```
>> b

b =

     3

>> ind=find(rho(3,:)~=0&rho(3,:)~=1)

ind =

     5     7
```

Interference exists if

```
u =

     2

>> fstatus(ind,u)

ans =

     1
     1
```

Fractional Frequency Reuse (FFR)

Frequency planning can be improved by



Frequencies for all inner-cells

$$
\begin{cases}
f_0 = [1\ 2\ 3] \\
f_1 = [4\ 5\ 6\ 7\ 8] \\
f_2 = [9\ 10\ 11\ 12\ 13] \\
f_3 = [14\ 15\ 16\ 17\ 18] \\
f_4 = [9\ 10\ 11\ 12\ 13] \\
f_5 = [14\ 15\ 16\ 17\ 18] \\
f_6 = [9\ 10\ 11\ 12\ 13] \\
f_7 = [14\ 15\ 16\ 17\ 18]
\end{cases}
$$

Each cell now has 8 frequencies

FFR (cont'd)

Different transmit power is used to serve users in the inner area of the cell and outer area of the cell

Smaller power P_1 to serve the inner area of the cell helps reduce the interference to the other cells

Larger power P_2 to serve the outer area of the cell is needed because of longer distance