CSE4255
Cellular Network

Lecture 6

Interference and System Capacity

Interference

- Interference is anything which alters, modifies, or disrupts a signal.
- It limits capacity and increases the number of dropped calls.
- Sources of interference include
  - Another mobile in the same cell.
  - A call in progress in a neighboring cell.
  - Other base stations operating in the same frequency band.
  - Non-cellular systems leaking energy into cellular frequency band.

- Effects of interference:
  - Interference on voice channels can cause cross-talks and noise in the background.
  - Interference on control channels causes missed calls and blocked calls due to errors in the digital signaling.

- Types of Interference
  - Co-channel Interference (CCI)
  - Adjacent Channel Interference (ACI)

Co-channel Interference (CCI)

- The cells that use the same set of frequencies are called co-channel cells.
- The interference between signals from these cells is called Co-Channel Interference (CCI).
- Cannot be controlled by increasing carrier power of a transmitter. Rather, this will increase CCI.
- To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance.

Reuse Distance Calculation

- D = minimum distance between centers of cells that use the same band of frequencies (called co-channels)
- R = radius of a cell
- d = distance between centers of adjacent cells (d = $\sqrt{3}R$)
- N = number of cells in repetitious pattern
  - Reuse factor
  - Each cell in pattern uses unique band of frequencies
- Hexagonal cell pattern, following values of N possible
  - $N = i^2 + j^2 + ij, \quad i, j = 0, 1, 2, 3, \ldots$
- Possible values of N are 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, …
- D/R= $\sqrt{3N}$
- D/d = $\sqrt{N}$

Reuse Distance Calculation

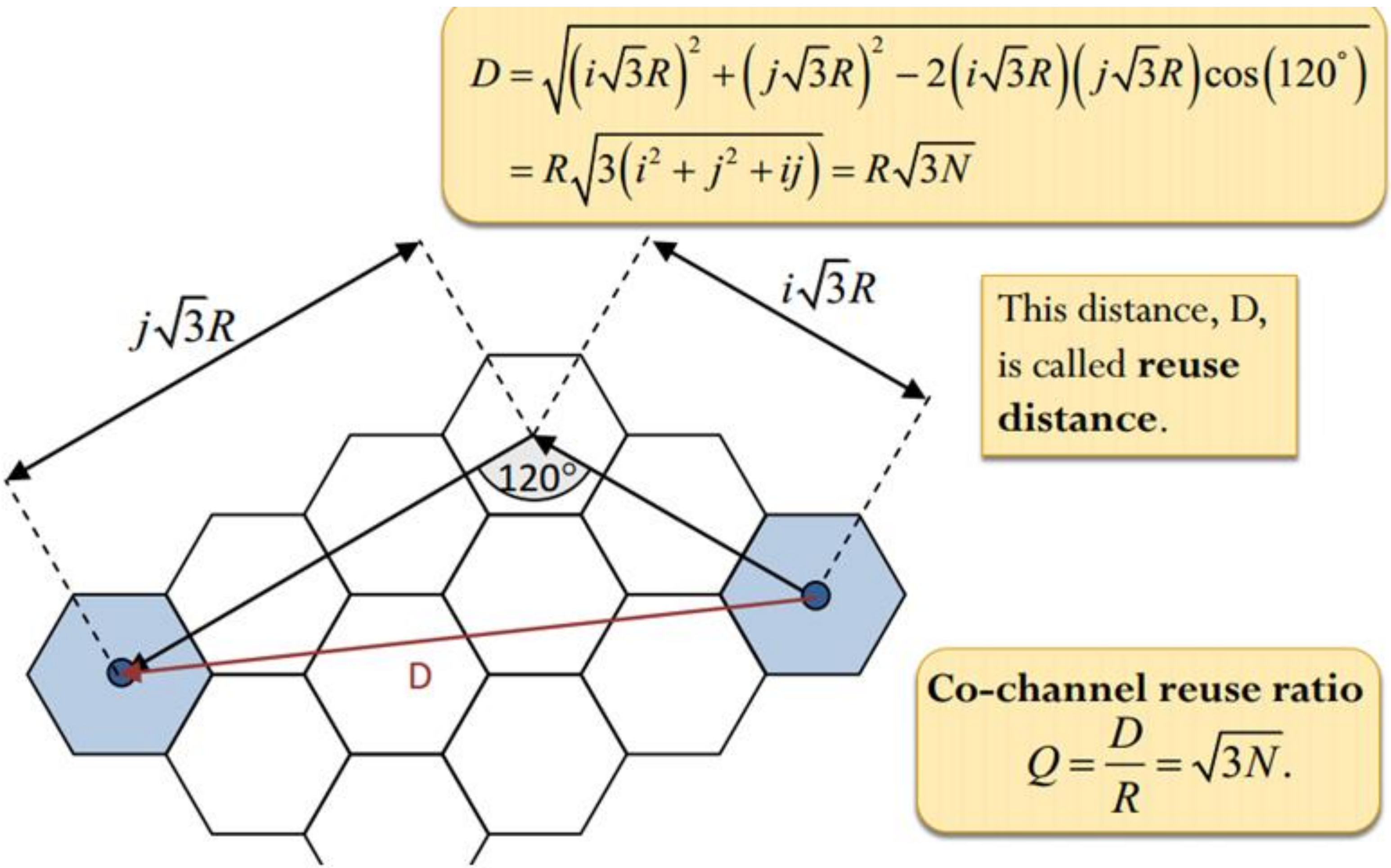


Figure 3: Resue Distance Calculation

Co-channel Reuse Ratio

- Q = D/R = co channel reuse ratio = the spatial separation between co-channel cells relative to the coverage distance of a cell.
- Q is related to the cluster size(N) for a hexagonal geometry, $Q = D/R = \sqrt{3N}$
- A smaller value of Q provides a larger capacity but a higher co-channel interference.

I	J	Cluster Size (N)	Co-Channel Reuse Ratio (Q)
1	1	3	3
1	2	7	4.58
2	2	12	6
1	3	13	6.24

Example: 1

You are trying to design a cellular network that will cover an area of at least 2800 km^2. There are K=300 available voice channels. Your design is required to support at least 100 concurrent calls in each cell. If the co-channel cell centre distance is required to be 9 km, how many base stations will you need in this network?

Solution:

If 100 concurrent voice calls must be supported in each cell, each cell must be allocated 100 voice channels.

This necessitates the frequency re-use factor, N, to be 300/100=3.

The distance between co-channel cell centers D is related to R and N via the formula:

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

D = 9 km, then, R = 3 km

cell area is $\frac{3 \cdot \sqrt{3}}{2} \cdot R^2 = 23.38$

2800/23.38 = 120 base stations are required

Signal to Interference Ratio/SIR

- Signal to Interference Ratio is the ratio between the desired signal power (S) from desired base station and the interference power (I_i) caused by i^{th} interfering co-channel cell base station.

$$\textbf{SIR = S/ I}$$

$$= \frac{S}{\sum_{i=1}^{i_0} I_i}$$

i_o = number of co-channel interfering cells

SIR for BS/ MS at the center:

When the transmit power of each base station is equal and the path loss exponent is the same throughout the coverage area, S/I for a mobile can be approximated as

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}}$$

Considering only the first layer of interfering cells, if all the interfering base stations are equidistant from the desired base station and if this distance is equal to the distance D between cell centers, then Equation simplifies to

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0}$$

Example-2:

- If a SIR of 15 dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is (a) n = 4, (b) n = 3? Assume that there are six co-channel cells in the first tier, and all of them are at the same distance from the mobile. Use suitable approximation.

Solution

(a) $n = 4$

First, let us consider a seven-cell reuse pattern.

Using Equation (3.4), the co-channel reuse ratio $D/R = 4.583$.

Using Equation (3.9), the signal-to-noise interference ratio is given by

$$S/I = (1/6) \times (4.583)^4 = 75.3 = 18.66 \text{ dB}$$

Since this is greater than the minimum required S/I, $N = 7$ can be used.

(b) $n = 3$

First, let us consider a seven-cell reuse pattern.

Using Equation (3.9), the signal-to-interference ratio is given by

$$S/I = (1/6) \times (4.583)^3 = 16.04 = 12.05 \text{ dB}$$

Since this is less than the minimum required S/I, we need to use a larger N.

Using Equation (3.3), the next possible value of N is 12, ($i = j = 2$).

The corresponding co-channel ratio is given by Equation (3.4) as

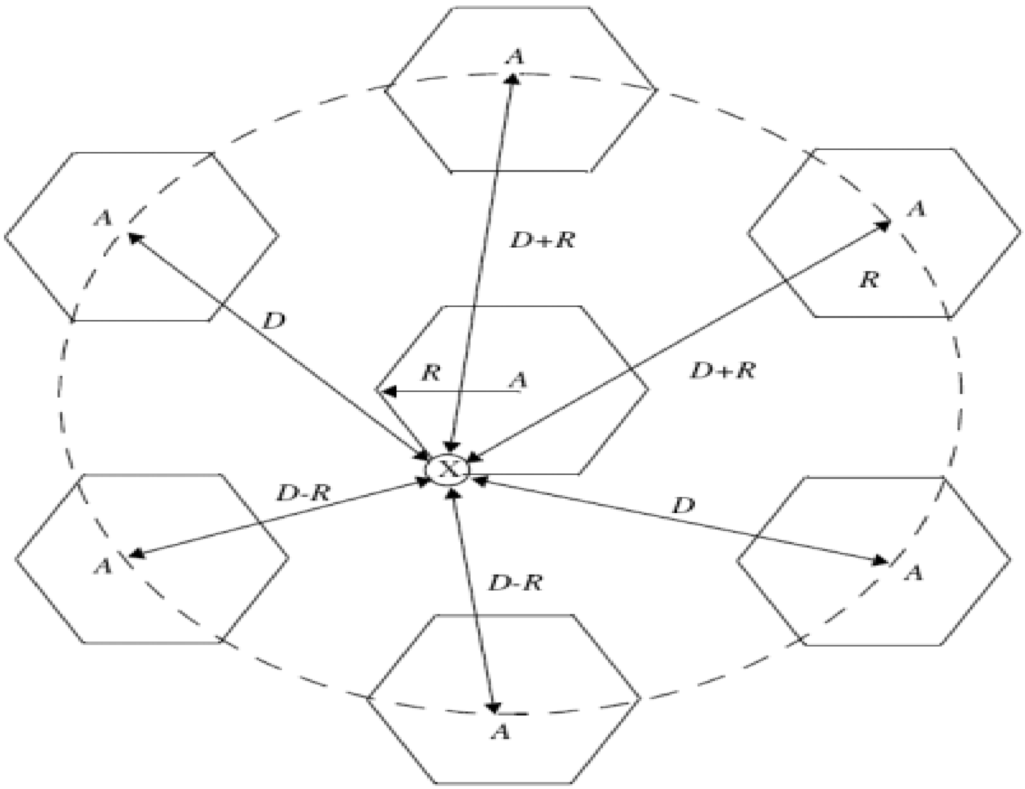
$$D/R = 6.0$$

Using Equation (3.3), the signal-to-interference ratio is given by

$$S/I = (1/6) \times (6)^3 = 36 = 15.56 \text{ dB}$$

Since this is greater than the minimum required S/I, $N = 12$ is used.

SIR for MS at the boundary of the cell:



$$SIR = \frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4}+2(D+R)^{-4}+2(D)^{-4}}$$

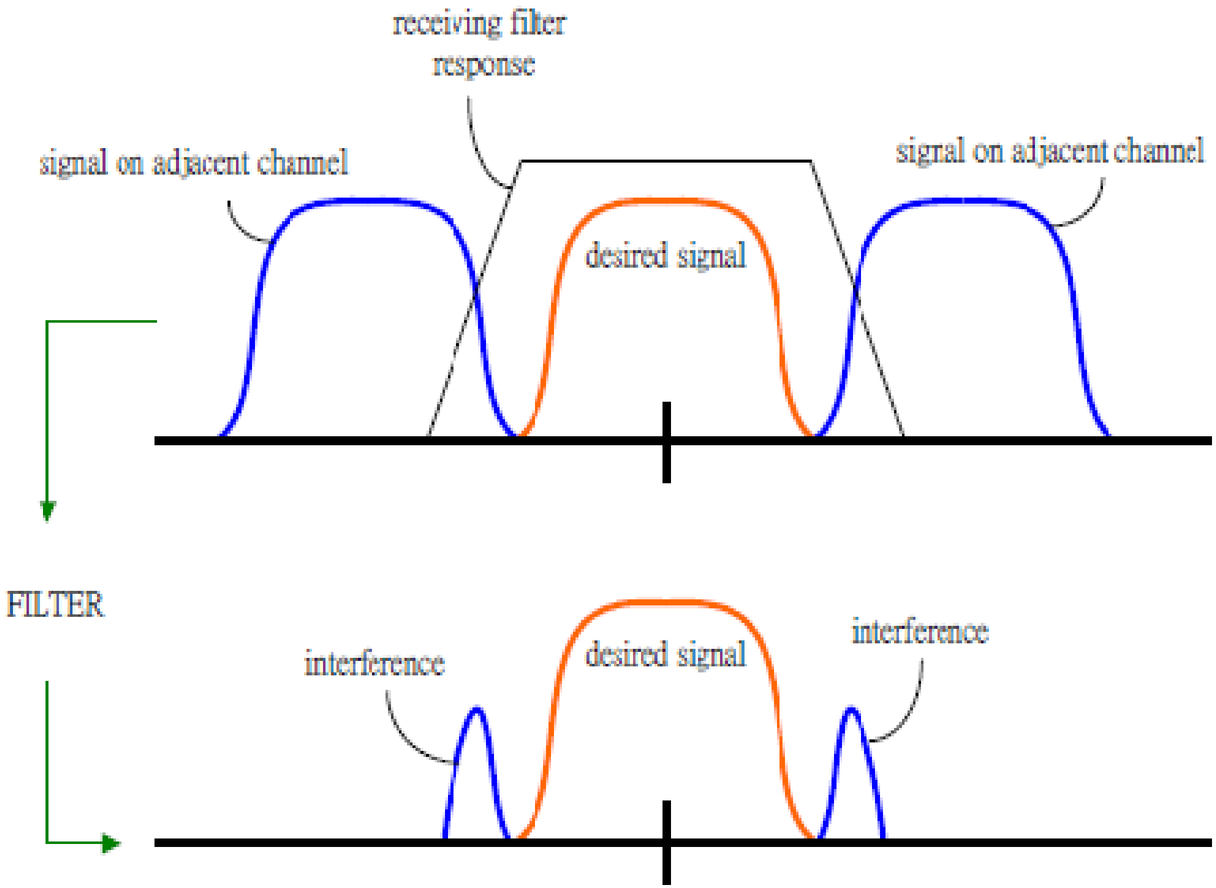
$$\frac{S}{I} \approx \frac{1}{2(Q-1)^{-4}+2(Q+1)^{-4}+2Q^{-4}}$$

Adjacent Channel Interference (ACI)

- Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference.
- It occurs when mobile phones in the same cell transmitting signals at different but close (adjacent) frequencies.
- Adjacent Channel interference is only a reverse channel problem.

Reason for ACI

- Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the passband.

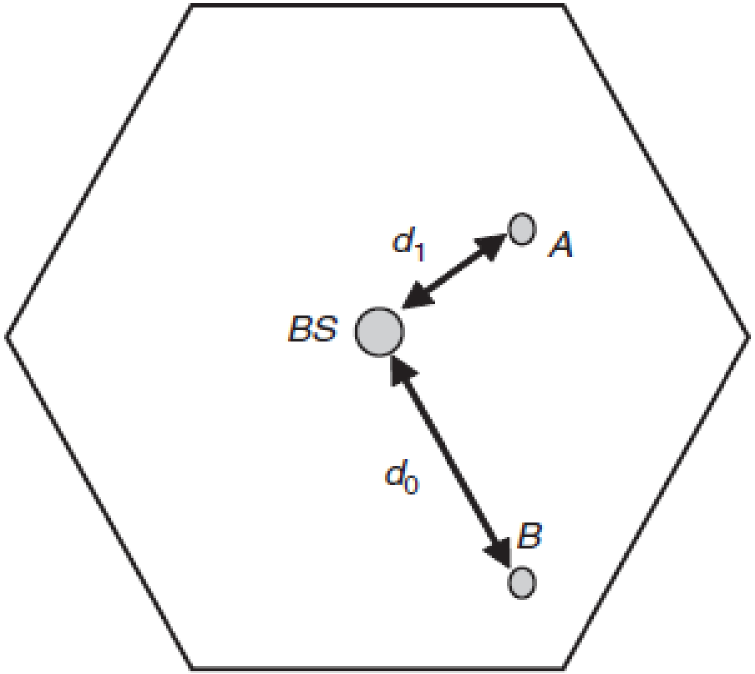


ACI Problem: **Near-Far Effect:**

- When an interferer close to the base station radiates in the adjacent channel while the subscriber is actually far away from the base station.

- If a subscriber is at a distance d_o and the interferer is at a distance d_1, then the signal to interference ratio prior to filtering is given by

$$\frac{S}{I} = \left(\frac{d_0}{d_1}\right)^{-n}$$



- Example-3:

- Suppose the subscriber is at a distance of 1000 m from the BS and another mobile which is using an adjacent channel is unfortunately at a distance of only 100 m from the base station.

$$\frac{S}{I} = -40\text{dB}$$

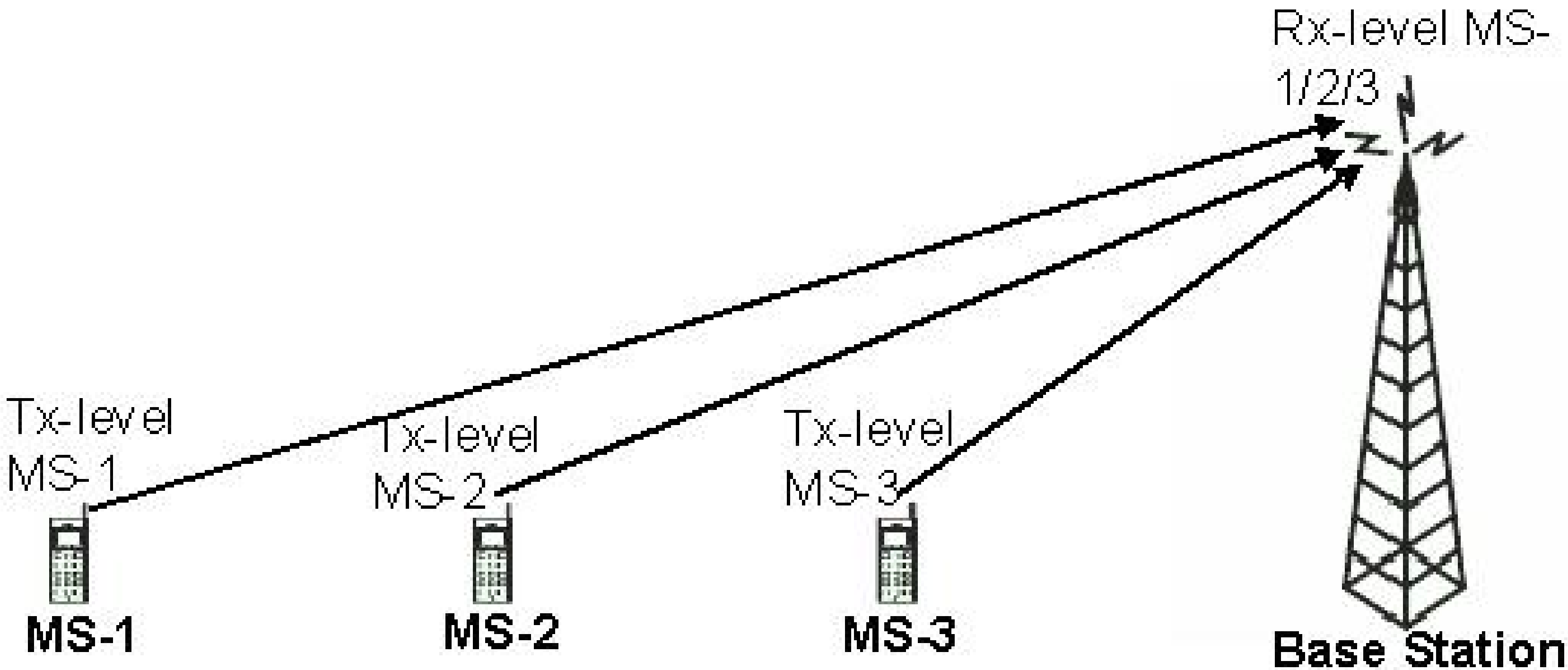
Solving ACI: Channel Assignment

- The solution to the problem of ACI is to insure that non of the channels assigned to a specific cell are adjacent.
- For a cluster size of N = 7 , for example, distribute the channels of the system among different cells in the cluster such that the following channels are allocated to the different cells:
  - Cell 1 gets Channels 1, 8, 15, 22, 29, 36, …
  - Cell 2 gets Channels 2, 9, 16, 23, 30, 37, …
  - Cell 3 gets Channels 3, 10, 17, 24, 31, 38, …
  - Cell 4 gets Channels 4, 11, 18, 25, 32, 39, …
  - Cell 5 gets Channels 5, 12, 19, 26, 33, 40, …
  - Cell 6 gets Channels 6, 13, 20, 27, 34, 41, …
  - Cell 7 gets Channels 7, 14, 21, 28, 35, 42, …

Power Control for Reducing Interference

- Ensure each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel
  - – long battery life
  - – increase SIR
  - – solve the near-far problem

- Types of Power Control:
  - Closed Loop Power Control
  - Open Loop Power Control



Without Power Control:

Tx level MS-1 = Tx level MS-2 = Tx level MS-3 →

Rx level MS-1 < Rx level MS-2 < Rx level MS-3

With Power Control:

Tx level MS-1 > Tx level MS-2 > Tx level MS-3 →

Rx level MS-1 = Rx level MS-2 = Rx level MS-3

Closed-loop Power Control

- Adjusts signal strength in reverse channel (MU to BS) based on some metric of performance in that reverse channel, such as
  - Received signal power level
  - Received signal-to-noise ratio, or
  - Received bit error rate
- BS makes power adjustment decision and communicates to MU on control channel
- Closed loop power control is also used to adjust power in the forward channel.

Open-loop Power Control

- Depends solely on mobile unit with no feedback from BS
- Use spread spectrum systems (SSS) where the BS continuously transmits an un modulated signal known as a **pilot**.
- The MU monitors the RSS of the pilot and sets the transmitted power in the reverse (mobile to BS) channel.
- Not as accurate as closed-loop, but can react quicker to fluctuations in signal strength

Problem 1:

Consider two different cellular systems that share the following characteristics. The frequency bands are 825 to 845 MHz for mobile unit transmission and 870 to 890 MHz for base station transmission. A duplex circuit consists of one 30-kHz channel in each direction. The systems are distinguished by the reuse factor, which is 4, and 19, respectively.

a) Suppose that in each of the systems, the cluster of cells (4, 19) is duplicated 16 times. Find the number of simultaneous communications that can be supported by each system.
b) Find the number of simultaneous communications that can be supported by a single cell in each system.
c) What is the area covered, in cells, by each system?
d) Suppose the cell size is the same in all two systems and a fixed area of 100 cells is covered by each system. Find the number of simultaneous communications that can be supported by each system.