Mobile Communications

TCS 455

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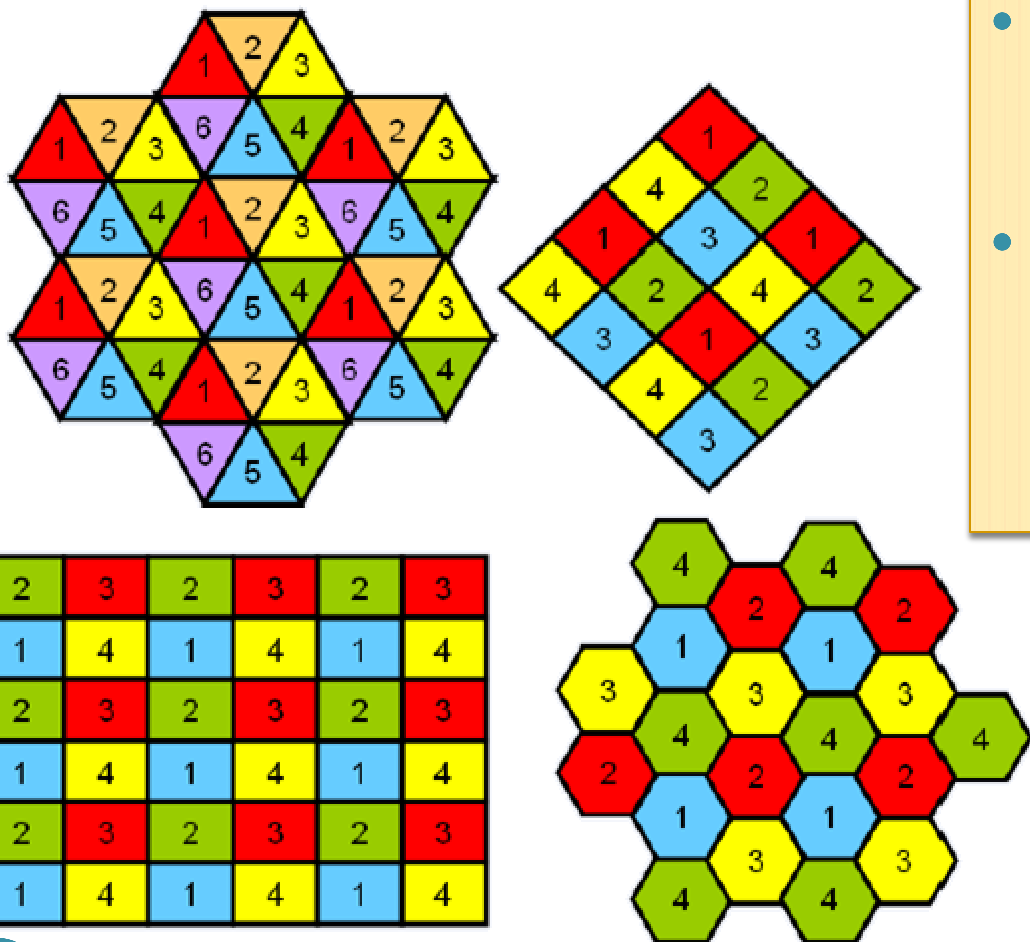
Lecture 6

Office Hours:
BKD 3601-7
Tuesday 14:00-16:00
Thursday 9:30-11:30

Announcements

- Read
  - Chapter 3: 3.1 – 3.2, 3.5.1, 3.6, 3.7.2
    - Posted on the web
- Due date for HW2: Nov 27
  - Official version available on Thursday.
  - Draft already been posted.
- All *graduate* students should send an email to me (prapun@siit.tu.ac.th). I need to somehow add ***your id*** into the SIIT online lecture note system. In the case that there is some delay to this, I might need to send the files to you via ***email***.

Tessellating Cell Shapes

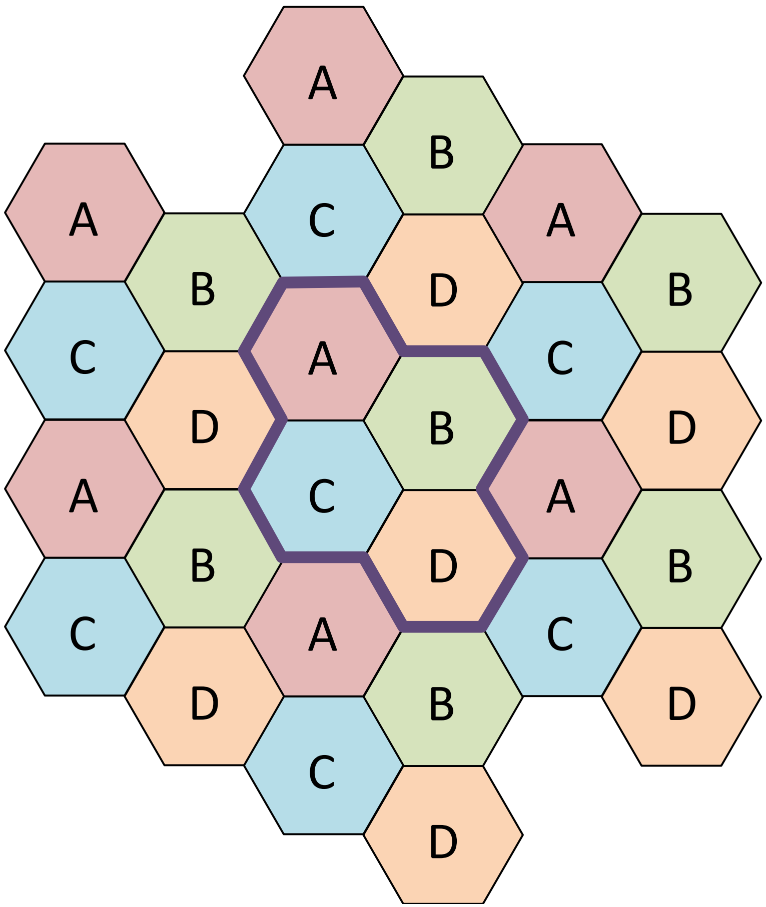


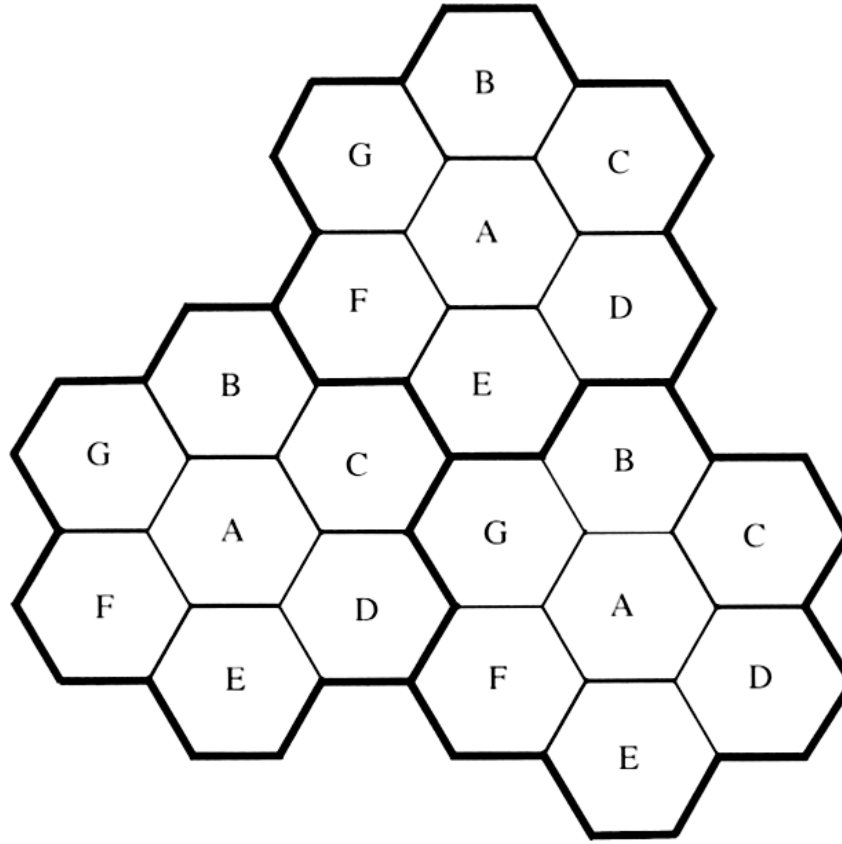
Hexagonal cells:

- Having largest area for a given distance between the center of a polygon and its farthest perimeter points
- Approximating a circular radiation pattern for an omnidirectional base station antenna and free space propagation

Frequency Reuse (N = 4, N = 7)

- **Cluster**: a group of N cells use the complete set of available frequencies

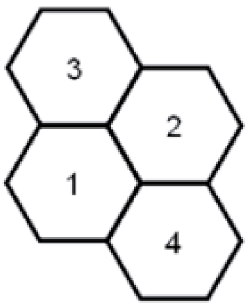




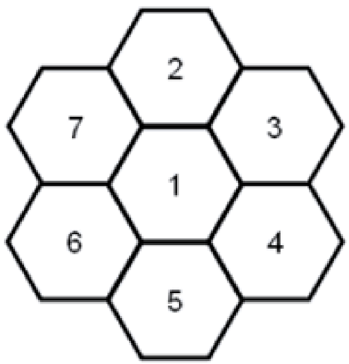
Frequency Reuse

- **Cluster**: a group of ***N*** cells using the complete set of available frequencies

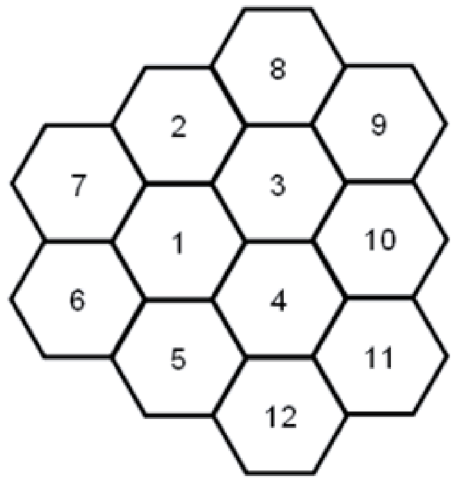
4-cell reuse



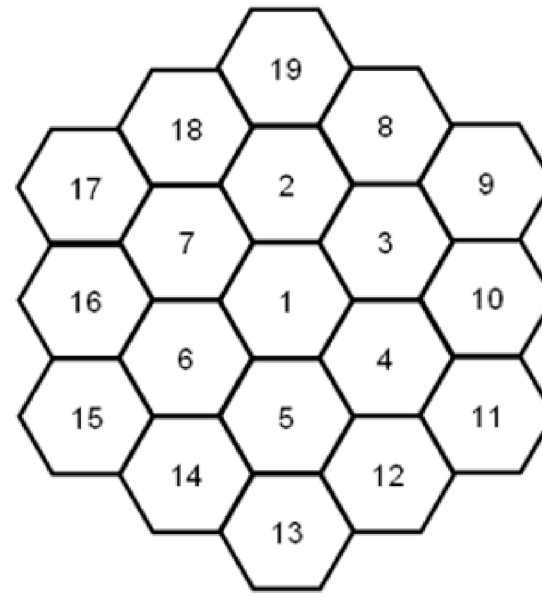
7-cell reuse



12-cell reuse

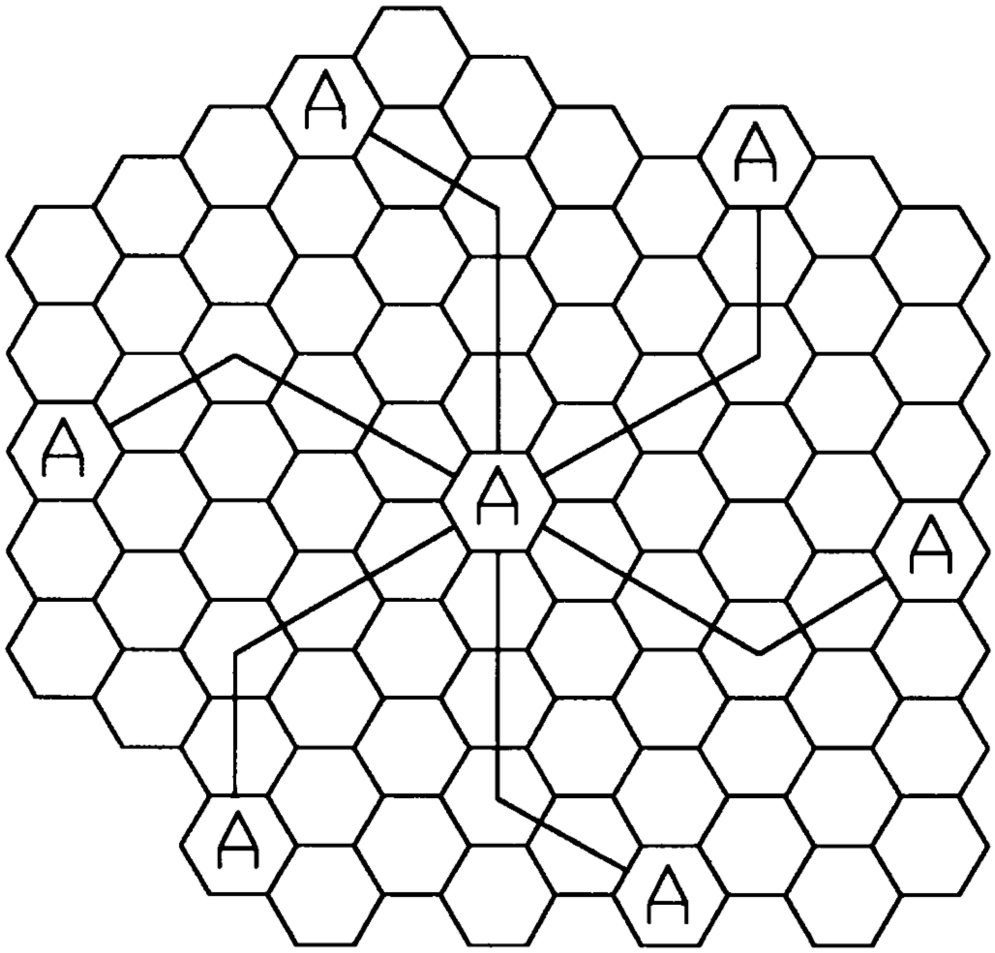


19-cell reuse



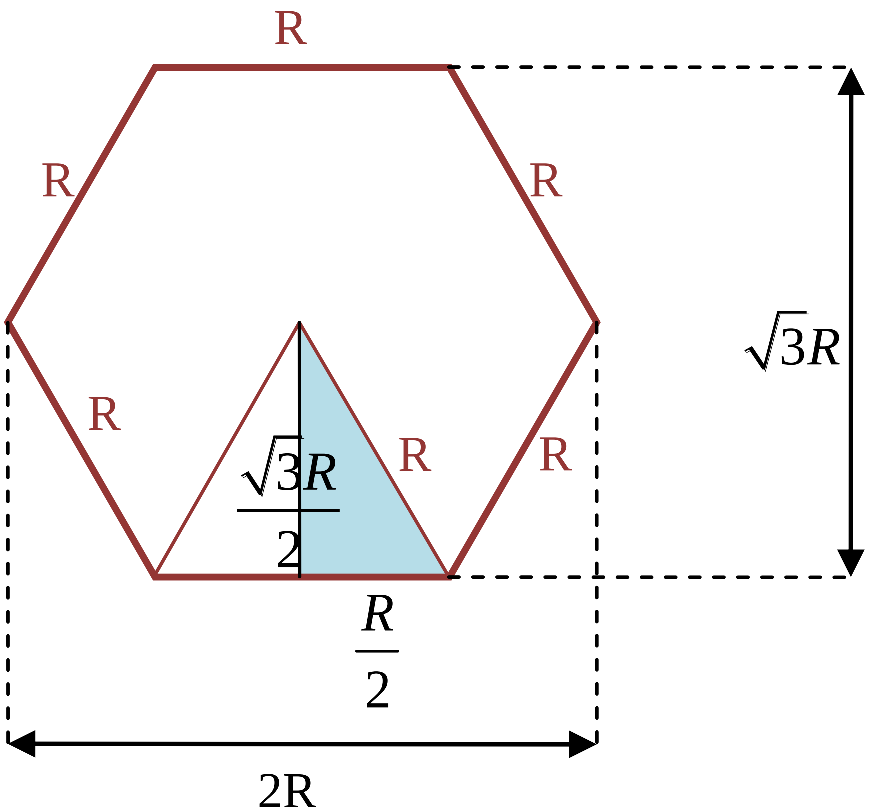
$$C = \frac{A_{\text{total}}}{A_{\text{cell}}} \times \frac{S}{N}$$

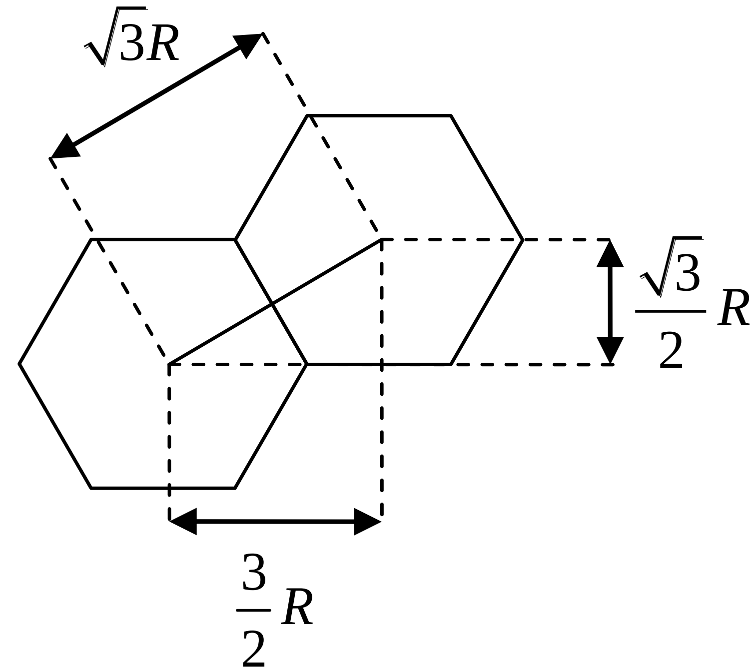
Co-channel Interference (N=19)



Method of locating co-channel cells in a cellular system. In this example, $N = 19$ (i.e., $I = 3$, $j = 2$). (Adapted from [Oet83] © IEEE.)

Hexagon

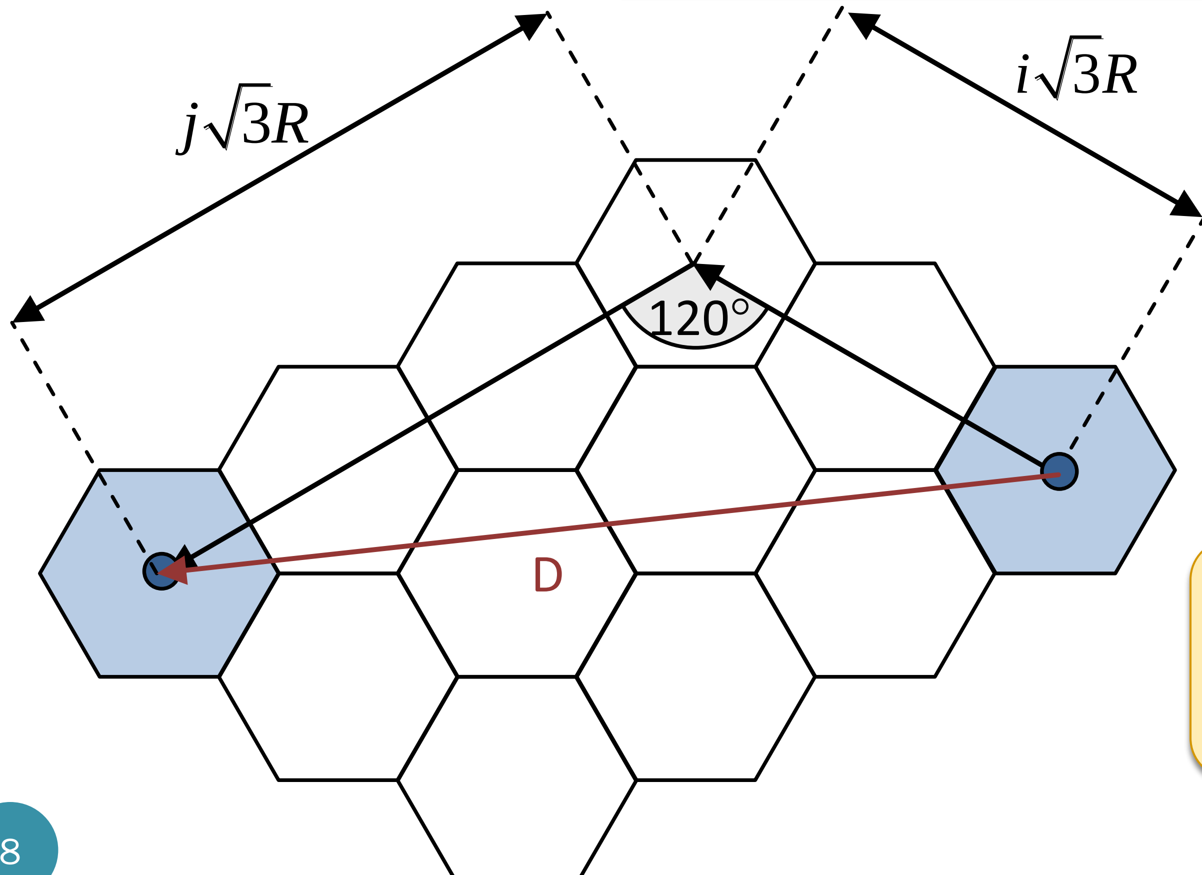




$$\text{Area} = 6 \times 2 \times \left(\frac{1}{2} \times \frac{\sqrt{3}}{2} R \times \frac{1}{2} R \right) = \frac{3\sqrt{3}}{2} R^2 \approx 2.598 R^2$$

Center-to-center distance (D)

$$D=\sqrt{\left(i\sqrt{3}R\right)^2+\left(j\sqrt{3}R\right)^2-2\left(i\sqrt{3}R\right)\left(j\sqrt{3}R\right)\cos\left(120^\circ\right)}$$
$$=R\sqrt{3\left(i^2+j^2+ij\right)}=R\sqrt{3N}$$



This distance, D, is called **reuse distance**.

Co-channel reuse ratio

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

Q and N

Co-channel reuse ratio

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

	Cluster Size (N)	Co-channel Reuse Ratio (Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 0, j = 3$	9	5.20
$i = 2, j = 2$	12	6

SIR

- Frequency reuse → co-channel interference
- K = the number of co-channel interfering cells
- The **signal-to-interference ratio** (S/I or SIR) for a mobile receiver which monitors a forward channel can be expressed as

$$SIR = \frac{S}{I} = \frac{S}{\sum_{i=1}^{K} I_i}$$

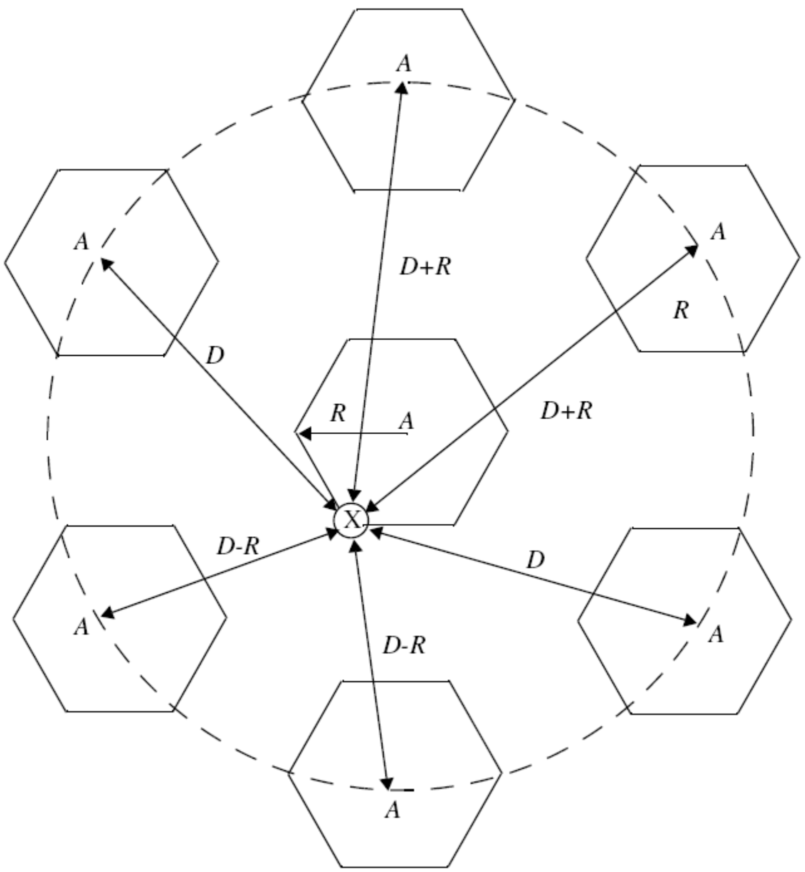
- S = the desired signal power from the desired base station
- I_i = the interference power caused by the *i*th interfering co-channel cell base station.

SIR

- The SIR should be greater than a specified threshold for proper signal operation.
  - In the first-generation AMPS system, designed for voice calls, the desired performance threshold is SIR equal to 18 dB.
  - For the second-generation digital AMPS system (D-AMPS or IS-54/136), a threshold of 14 dB is deemed suitable.
  - For the GSM system, a range of 7–12 dB, depending on the study done, is suggested as the appropriate threshold.
- Only a relatively small number of nearby interferers need be considered, because of the rapidly decreasing received power as the distance increases.
  - In a fully equipped hexagonal-shaped cellular system, there are always six cochannel interfering cells in the first tier.
- Approximation:

$$\frac{S}{I} \approx \frac{kR^{-\gamma}}{K \times \left(kD^{-\gamma}\right)} = \frac{1}{K}\left(\frac{D}{R}\right)^{\gamma} = \frac{1}{K}\left(\sqrt{3N}\right)^{\gamma}$$

SIR: N = 7

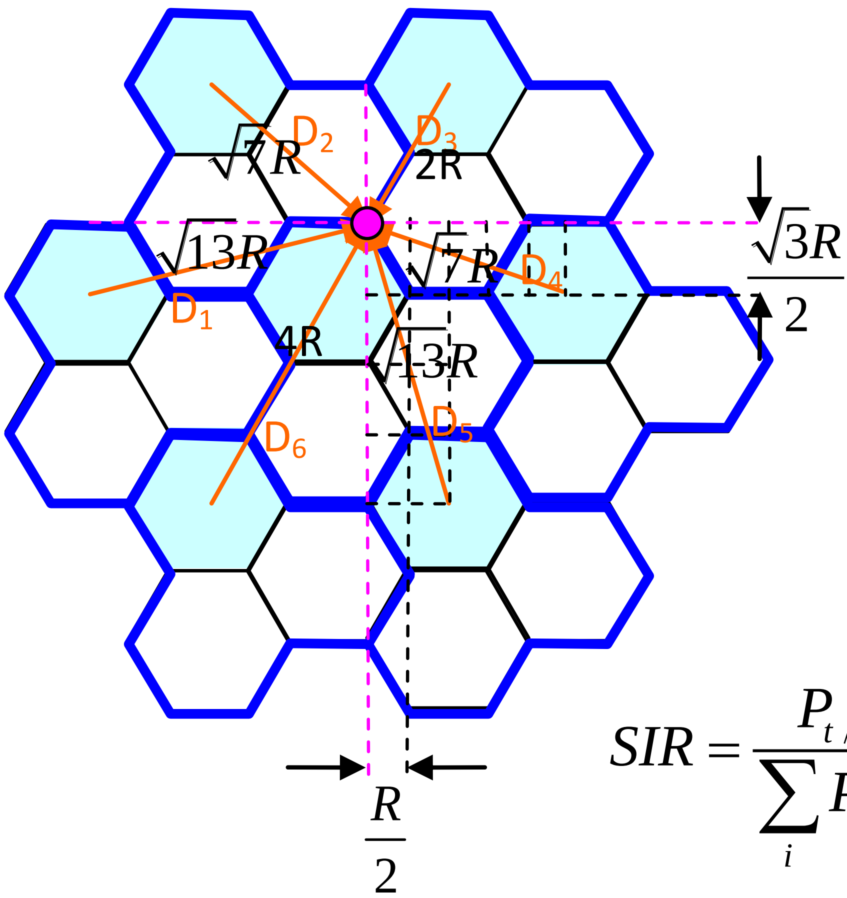


More accurate calculation…

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

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

SIR: N = 3



Even more accurate calculation…

$$D_1 = D_5 = R\sqrt{(1)^2 + \left(4\frac{\sqrt{3}}{2}\right)^2} = R\sqrt{13}$$

$$D_2 = D_4 = R\sqrt{\left(\frac{5}{2}\right)^2 + \left(\frac{\sqrt{3}}{2}\right)^2} = R\sqrt{4}$$

$$D_3 = 2R$$

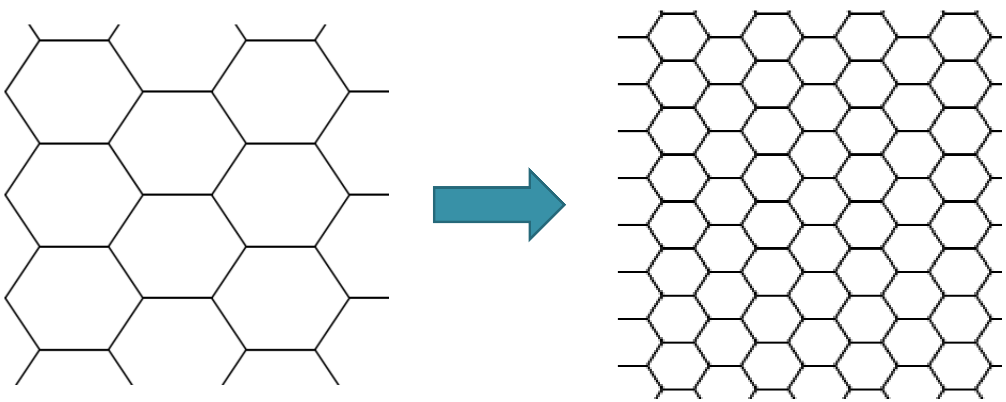
$$D_6 = 4R$$

$$SIR = \frac{P_t / R^{-\gamma}}{\sum_i P_t / D_i^{-\gamma}} = \frac{1}{2\left(\sqrt{7}\right)^{-\gamma} + 2\left(\sqrt{13}\right)^{-\gamma} + 2^{-\gamma} + 4^{-\gamma}}$$

Improving Coverage and Capacity

- As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users.
- At this point, cellular design techniques are needed to provide more channels per unit coverage area.
- Easy!?

$$C = \frac{A_{\text{total}}}{A_{\text{cell}}} \times \frac{S}{N}$$



Sectoring (N = 7)

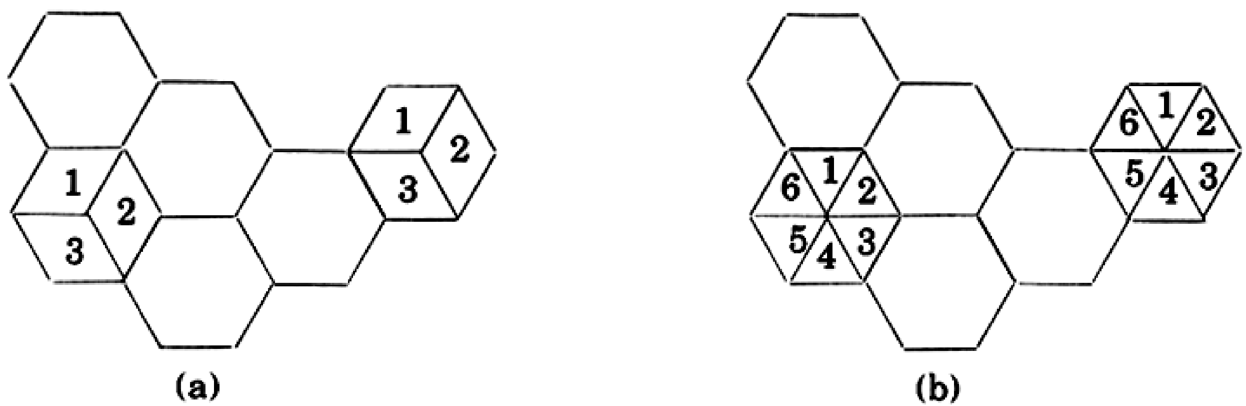


Figure 3.10 (a) 120° sectoring; (b) 60° sectoring.

Sectoring (N = 7)

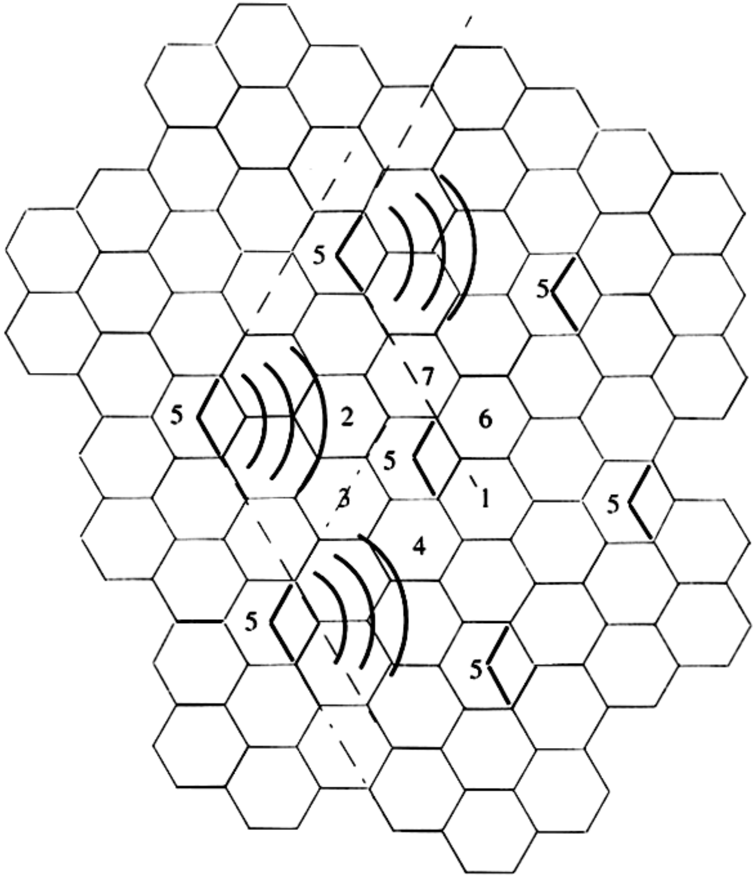
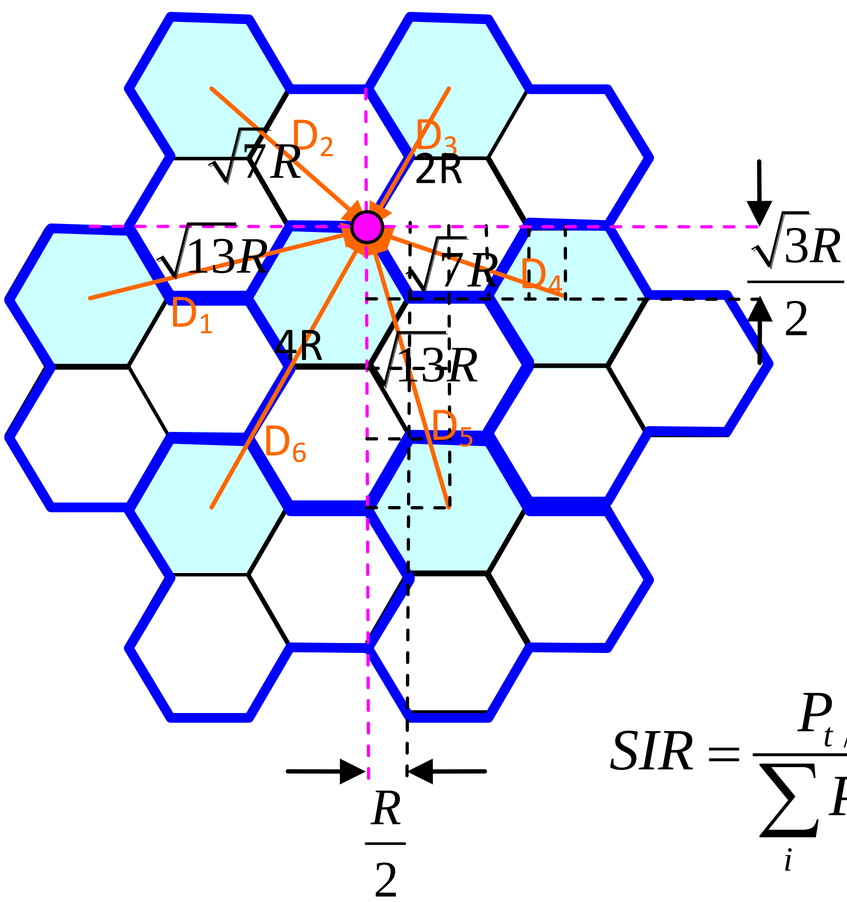


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.

SIR: N = 3



$$D_1 = D_5 = R\sqrt{(1)^2 + \left(4\frac{\sqrt{3}}{2}\right)^2} = R\sqrt{13}$$

$$D_2 = D_4 = R\sqrt{\left(\frac{5}{2}\right)^2 + \left(\frac{\sqrt{3}}{2}\right)^2} = R\sqrt{4}$$

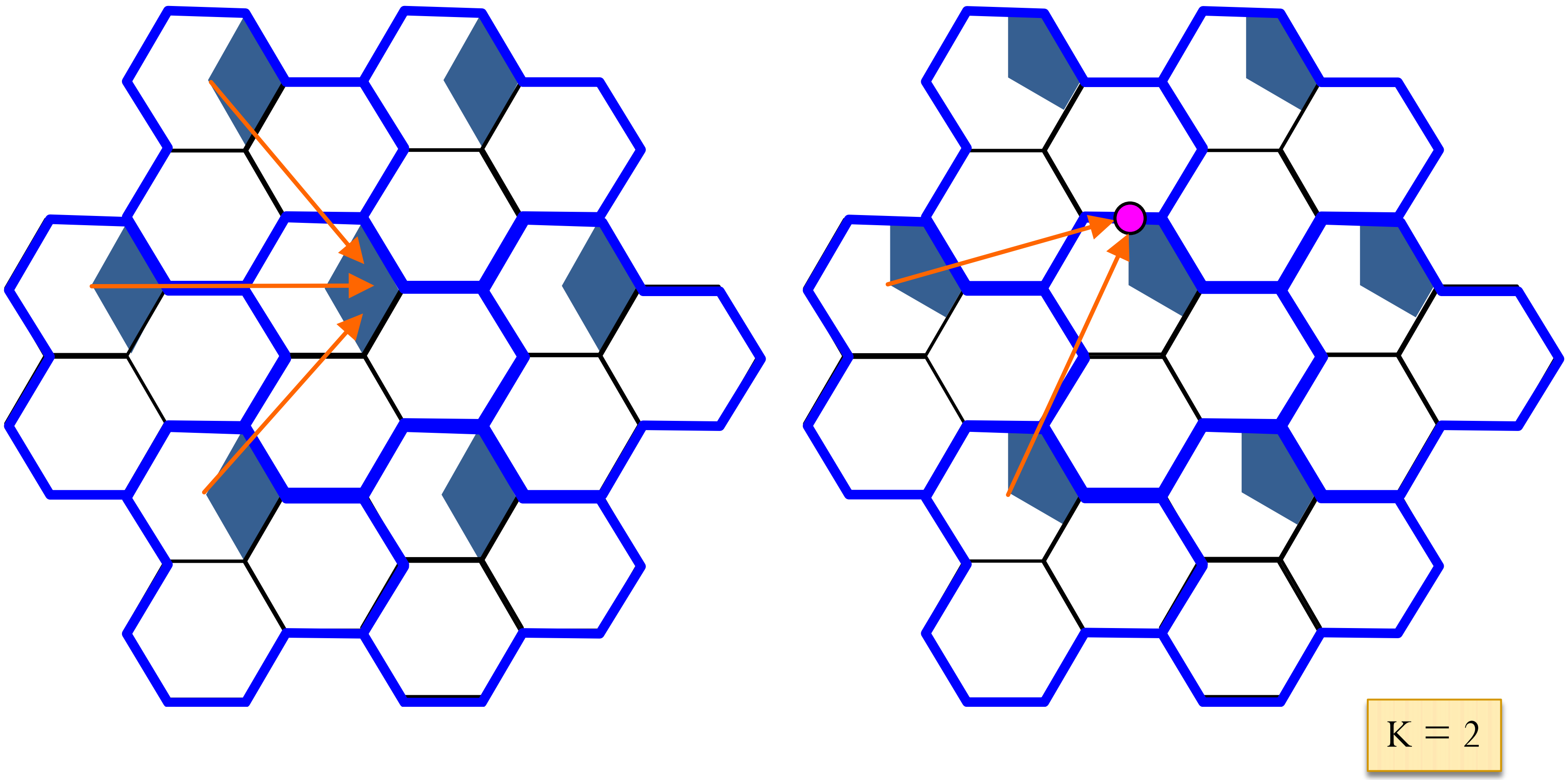
$$D_3 = 2R$$

$$D_6 = 4R$$

$$SIR = \frac{P_t / R^{-\gamma}}{\sum_i P_t / D_i^{-\gamma}} = \frac{1}{2\left(\sqrt{7}\right)^{-\gamma} + 2\left(\sqrt{13}\right)^{-\gamma} + 2^{-\gamma} + 4^{-\gamma}}$$

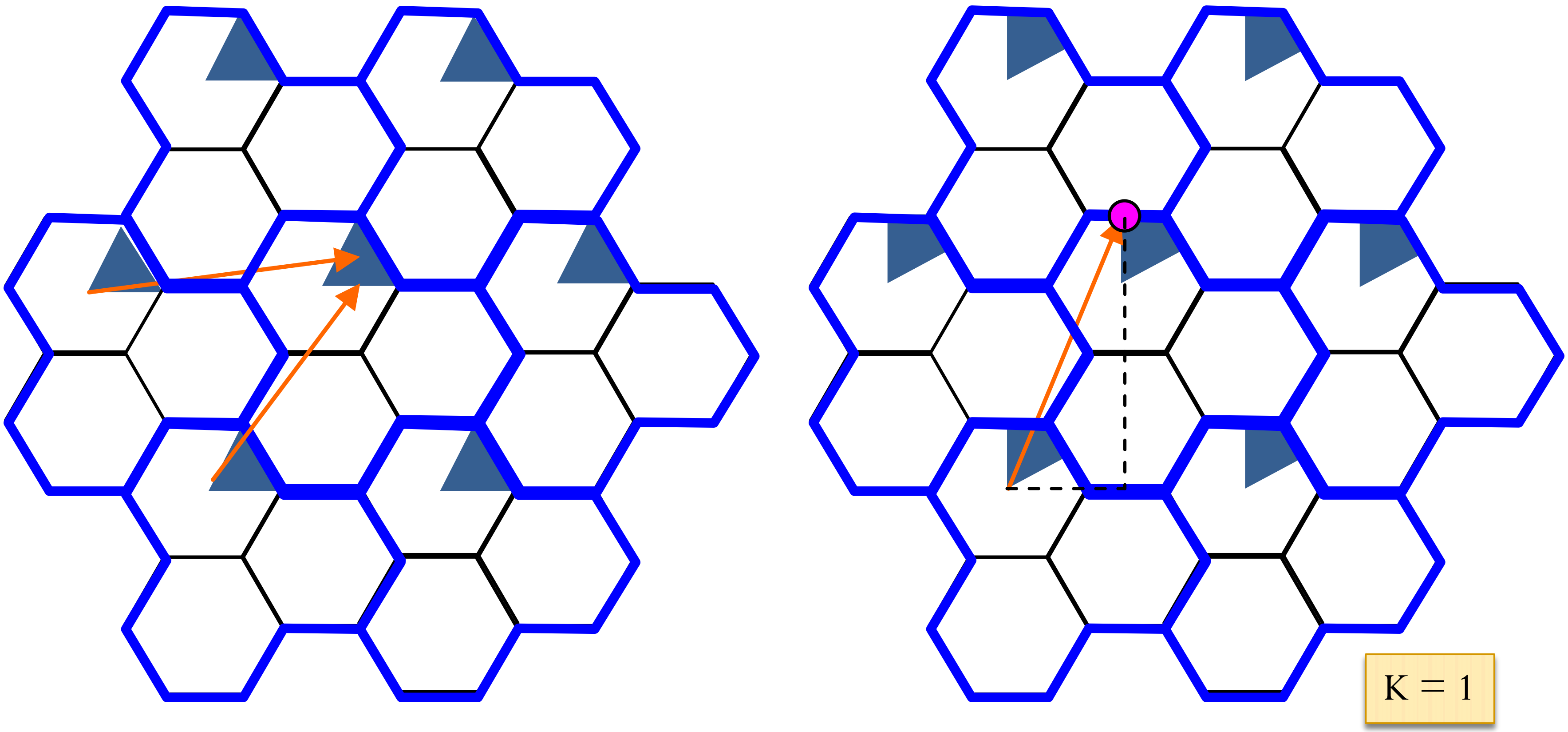
Sectoring (N = 3, 120°)

$$\frac{S}{I} \approx \frac{1}{K}\left(\sqrt{3N}\right)^{\gamma}$$



Sectoring (N = 3 , 60°)

$$\frac{S}{I} \approx \frac{1}{K}\left(\sqrt{3N}\right)^{\gamma}$$



$$\frac{S}{I} \approx \frac{1}{K}\left(\sqrt{3N}\right)^{\gamma} \qquad C = \frac{A_{\text{total}}}{A_{\text{cell}}} \times \frac{S}{N}$$

Sectoring

- Advantages
  - Assuming seven-cell reuse, for the case of 120° sectors, the number of interferers in the first tier is reduced from six to two.

- Disadvantages
  - Increase number of antennas at each base station.
  - Decrease **trunking efficiency** due to channel sectoring at the base station.
    - The available channels in the cell must be subdivided and dedicated to a specific antenna.

Estimating the number of users

- Trunking
- Allow a large number of users to share the relatively small number of channels in a cell by providing access to each user, on demand, from a pool of available channels.
- Exploit the statistical behavior of users
- Each user is allocated a channel on a per call basis, and upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels.

Common Terms

- **Traffic Intensity**: Measure of channel time utilization, which is the average channel occupancy measured in Erlangs.
  - This is a dimensionless quantity and may be used to measure the time utilization of single or multiple channels.
  - Denoted by ***A***.
- **Holding Time**: Average duration of a typical call. Denoted by $H = 1/\mu$.
- **Blocked Call**: Call which cannot be completed at time of request, due to congestion. Also referred to as a **lost call**.
- **Grade of Service (GOS)**: A measure of congestion which is specified as the probability of a call being blocked (for Erlang B).
  - The AMPS cellular system is designed for a GOS of 2% blocking. This implies that the channel allocations for cell sites are designed so that 2 out of 100 calls will be blocked due to channel occupancy during the busiest hour.
- **Request Rate**: The average number of call requests per unit time. Denoted by λ.