ECS455 Chapter 2

Cellular Systems

2.2 Co-Channel Interference

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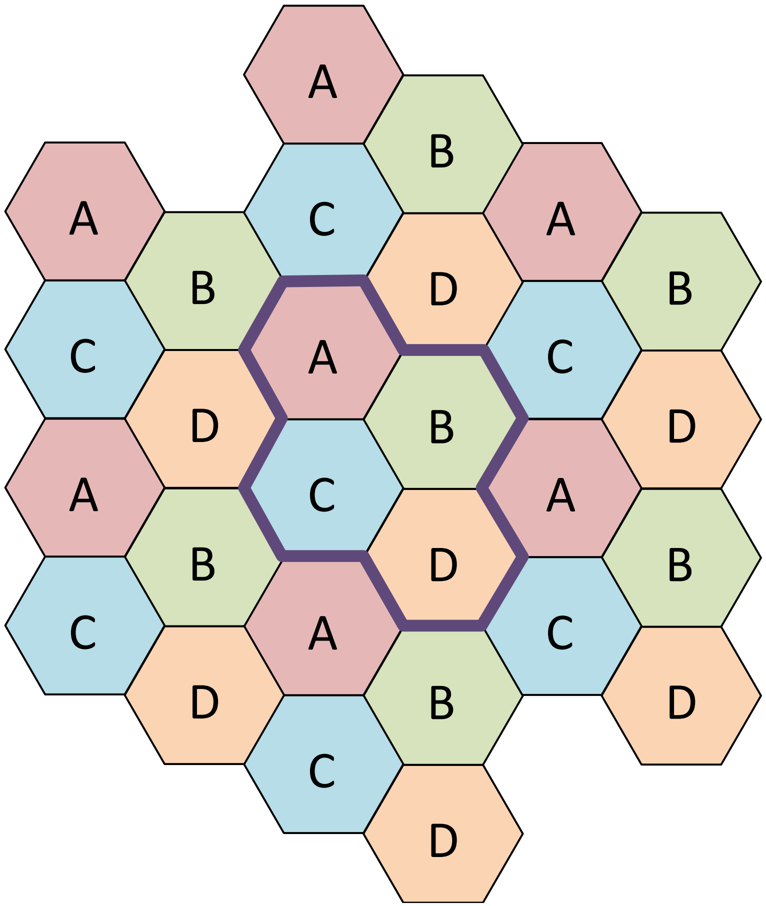
(Intercell)

Co-Channel Interference

- Frequency reuse → co-channel interference
- Consider only nearby interferers.
  - Power decreases rapidly as the distance increases.
- In a **fully equipped hexagonal-shaped** cellular system, there are always K = 6 cochannel interfering cells in the **first tier**.



Three Measures of Signal Quality

- Old (**noise-limited** systems) $\text{SNR} = \frac{P_r}{P_{\text{noise}}}$ Signal-to-noise ratio
- Consider both noise & interference $\text{SINR} = \frac{P_r}{P_{\text{interference}} + P_{\text{noise}}}$ signal-to-interference-plus-noise ratio
- The best cellular system design places users that share the same channel at a separation distance (as close as possible) where the intercell interference is just below the maximum tolerable level for the required data rate and BER. Why?
- Good cellular system designs are interference-limited, meaning that the interference power is much larger than the noise power. Signal-to-interference ratio

$$\text{SIR} = \frac{P_r}{P_{\text{interference}}}$$

"Reliable"/"tolerable"?

(Why not as far as possible?)

Co-channel cells, must be spaced **far enough** apart so that interference between users in co-channel cells does not degrade **signal quality** below tolerable levels.

Subjective tests found that people regard an FM signal using a 30 kHz channel bandwidth to be clear if the signal power is at least **sixty times** higher than the noise/interference power.

[Klemens, 2010, p 54]

$$10\log_{10} 60 = 17.78 \approx 18 \text{ dB}$$

We will soon revisit and use these numbers for some more specific calculations

Review: Simplified Path Loss Model

$$\frac{P_r}{P_t} = K\left(\frac{d_0}{d}\right)^{\gamma} \Rightarrow P_r = \frac{P_t K d_0^{\gamma}}{d^{\gamma}} \propto \frac{1}{d^{\gamma}}$$

Captures the essence of signal propagation without resorting to complicated path loss models, which are only approximations to the real channel anyway!

- K is a unitless constant which depends on the antenna characteristics and the average channel attenuation
- d_0 is a reference distance for the antenna far-field
  - Typically 1-10 m indoors and 10-100 m outdoors.
- γ is the **path loss exponent**.
  - 2 in free-space model
  - 4 in two-ray model [Goldsmith, 2005, eq. 2.17]

Environment	γ range
Urban macrocells	3.7-6.5
Urban microcells	2.7-3.5
Office Building (same floor)	1.6-3.5
Office Building (multiple floors)	2-6
Store	1.8-2.2
Factory	1.6-3.3
Home	3

[Goldsmith, 2005, Table 2.2]

SIR (S/I): Definition/Calculation

Not the same as the K shown on the previous slide

- K = # 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

$$\frac{S}{I} = \text{SIR} = \frac{P_r}{P_{\text{interference}}} = \frac{P_r}{\sum_{i=1}^{K} P_{\text{of the } i^{th} \text{ interferer}}}$$

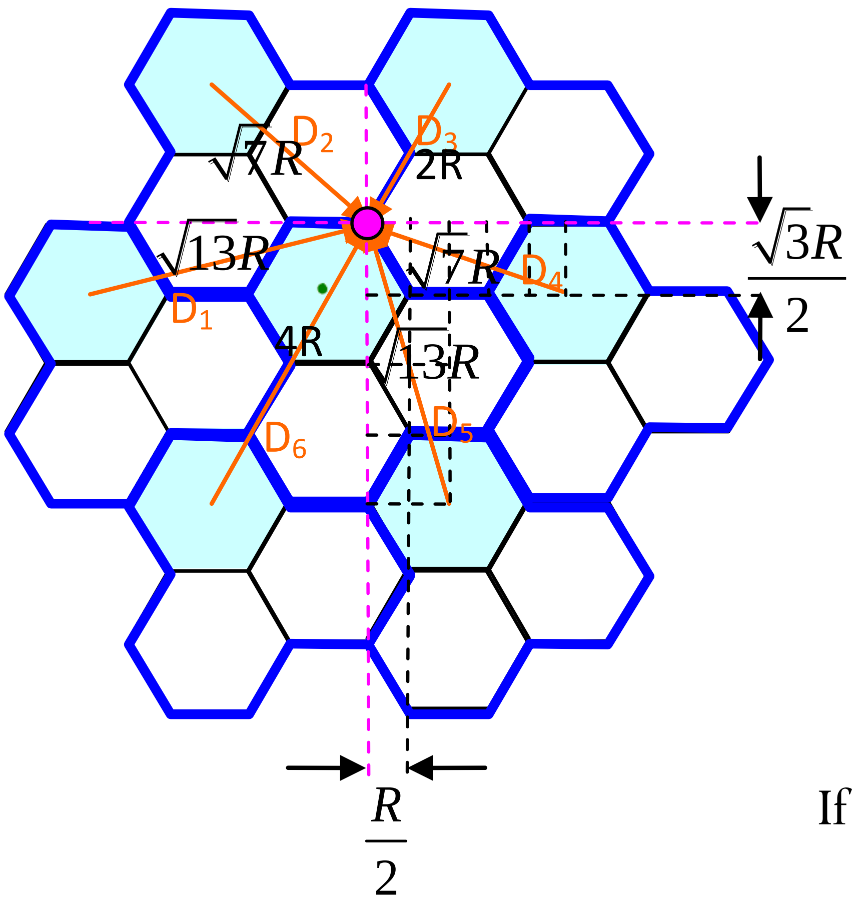
- S = the desired signal **power** from the desired base station (P_r)
- I_i = the interference **power** caused by the ith interfering co-channel cell base station. (P_i)
- Often called the **carrier-to-interference ratio**: CIR.

SIR Threshold

[Schwartz, 2005, p 64]

- The SIR should be greater than a specified threshold for proper signal operation.
- In the 1G **AMPS** system, designed for **voice** calls, the threshold for acceptable voice quality is SIR equal to **18 dB**.
- For the 2G 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.
- The probability of error in a digital system depends on the choice of this threshold as well.

SIR: N = 3



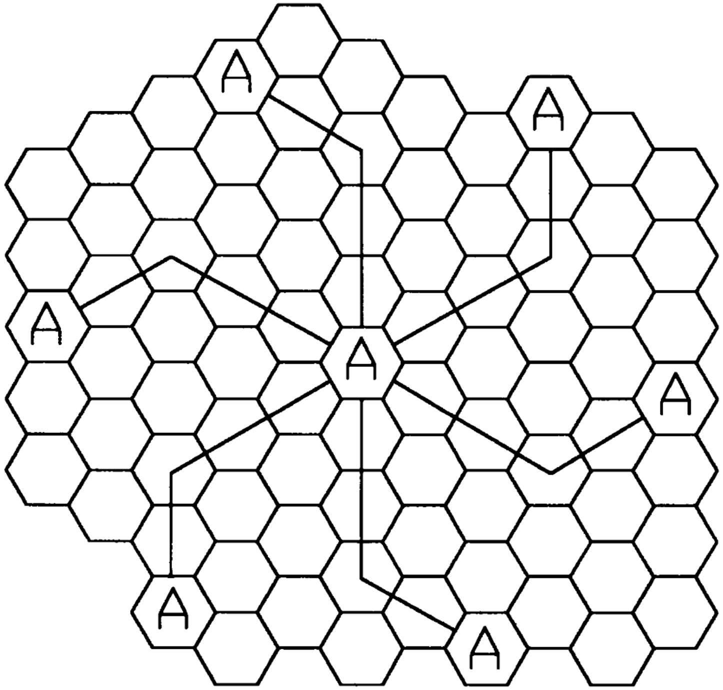
- Consider only first tier.
- Worse-case distance

$$\mathrm{SIR} \approx \frac{k/R^{\gamma}}{\sum_i k/D_i^{\gamma}} = \frac{1}{\sum_i 1\Big/\left(\frac{D_i}{R}\right)^{\gamma}} = \frac{1}{\sum_i \left(\frac{D_i}{R}\right)^{-\gamma}}$$

$$= \frac{1}{2\left(\sqrt{7}\right)^{-\gamma} + 2\left(\sqrt{13}\right)^{-\gamma} + 2^{-\gamma} + 4^{-\gamma}}$$

If N = 19, will the SIR be better or worse?

Approximation

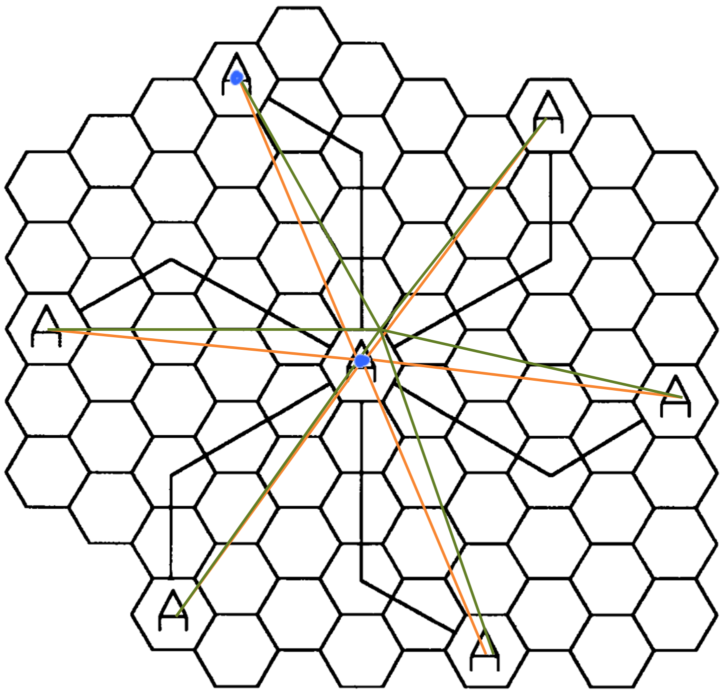


- Consider only first tier.
- Worse-case distance

$$\mathrm{SIR} \approx \frac{1}{\sum_i \left(\frac{D_i}{R}\right)^{-\gamma}}$$

- Use the same D for D_i

Approximation



- Consider only first tier.
- Worse-case distance

$$\mathrm{SIR} \approx \frac{1}{\sum_i \left(\frac{D_i}{R}\right)^{-\gamma}}$$

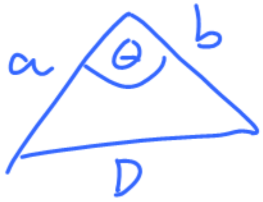
- Use the same D for D_i

$$\mathrm{SIR} \approx \frac{1}{\sum_i \left(\frac{D}{R}\right)^{-\gamma}} \approx \frac{1}{K\left(\frac{D}{R}\right)^{-\gamma}} = \frac{1}{K}\left(\frac{D}{R}\right)^{\gamma}$$

important quantity.

reuse distance D

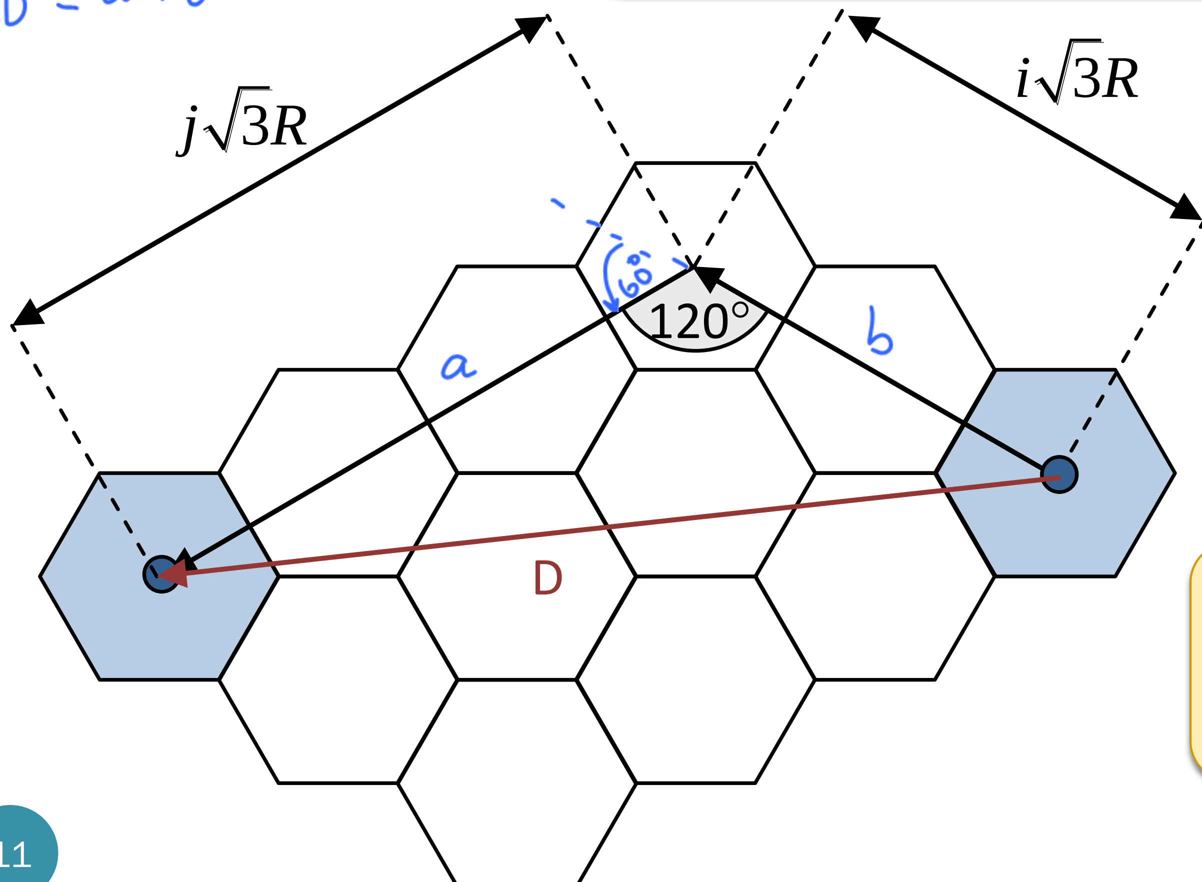
Center-to-center distance (D)



$$D^2 = a^2 + b^2 - 2ab\cos(\theta)$$

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

$$= R\sqrt{3\left(i^2 + j^2 + ij\right)} = R\sqrt{3N}$$



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

Co-channel reuse ratio

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

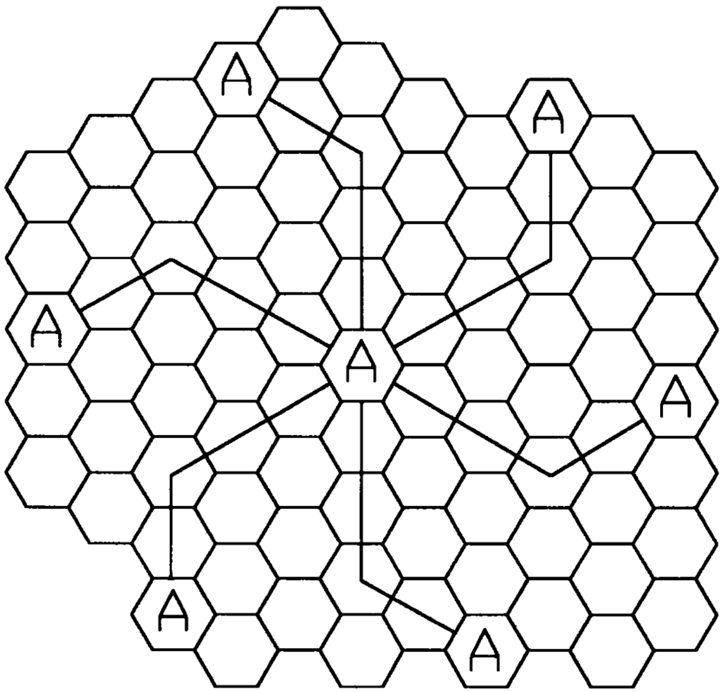
Q and N

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

Approximation: Crude formula



$$\mathrm{SIR} = \frac{P_r}{P_{\text{interference}}} = \frac{P_r}{\sum_{i=1}^{K} P_{\text{of the } i^{th} \text{ interferer}}}$$

$$\approx \frac{1}{\sum_i \left(\frac{D_i}{R}\right)^{-\gamma}} \approx \frac{1}{K\left(\frac{D}{R}\right)^{-\gamma}} = \frac{1}{K}\left(\frac{D}{R}\right)^{\gamma}$$

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

As the cell cluster size (N) increases, the spacing (D) between interfering cells increases, reducing the interference.

Summary: Quantity vs Quality

S = total # available duplex radio channels for the system

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

Tradeoff

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

Path loss exponent

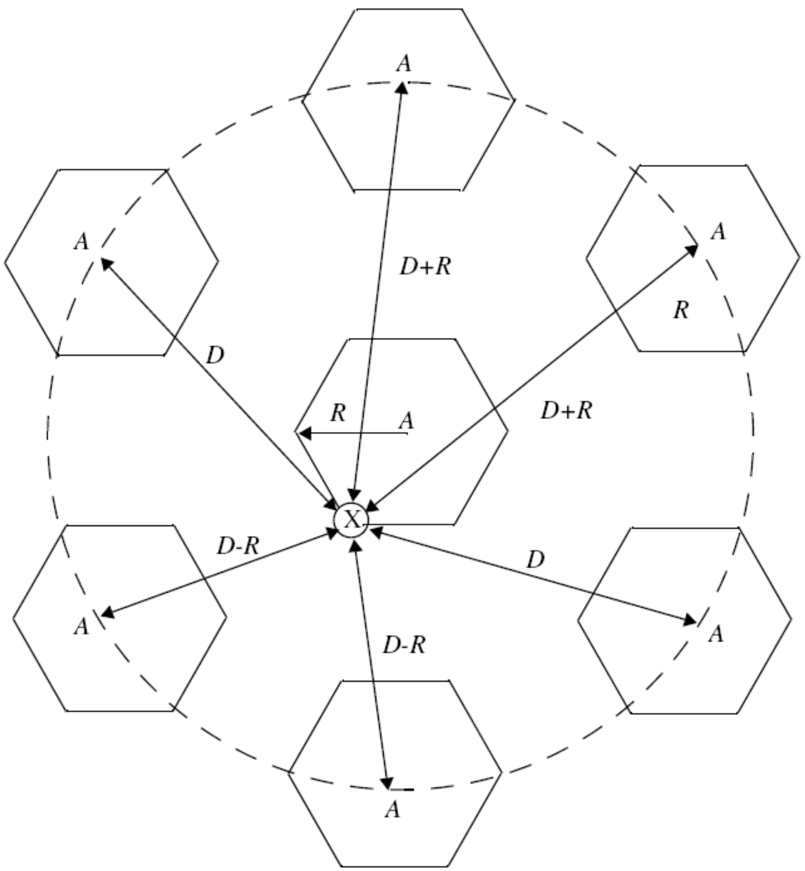
m = # channels allocated to each cell.

Frequency reuse with **cluster size *N***

This is only half of the big picture.

SIR: N = 7

More accurate calculation…



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

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