ECS455 Chapter 2

Cellular Systems

2.2 Co-Channel Interference

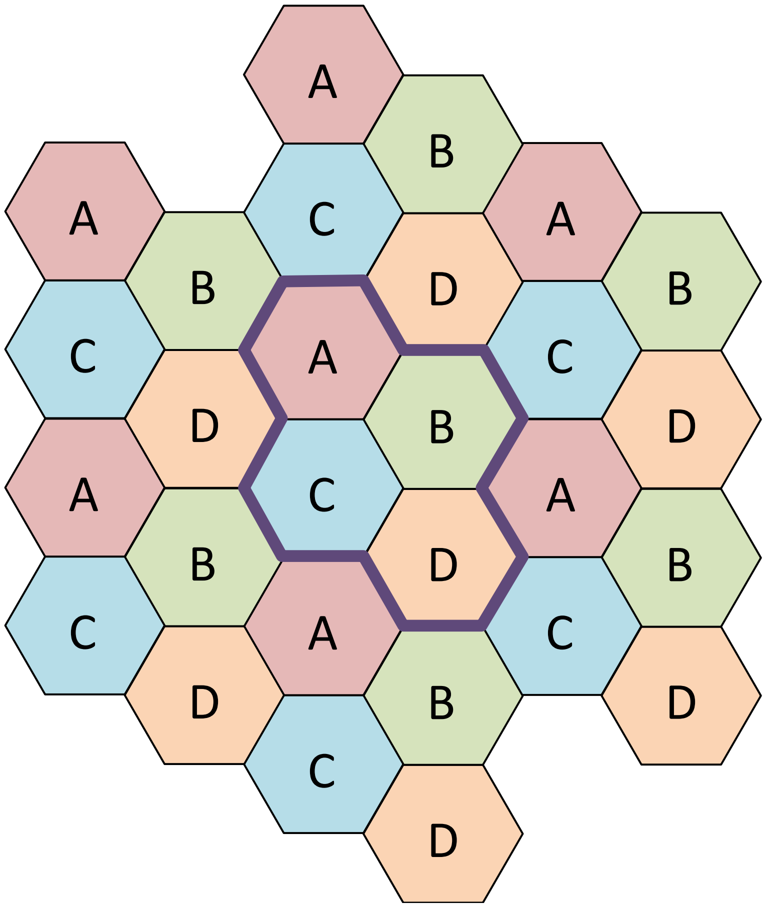
Dr.Prapun Suksompong
prapun.com/ecs455

Office Hours:
BKD 3601-7
Monday 9:20-10:20
Wednesday 9:20-10:20

(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) $\text{SNR} = \dfrac{P_r}{P_{\text{noise}}}$
- Consider both noise & interference $\text{SINR} = \dfrac{P_r}{P_{\text{interference}} + P_{\text{noise}}}$
- 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.

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

“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

Signal

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

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

[Rappaport, 2002]

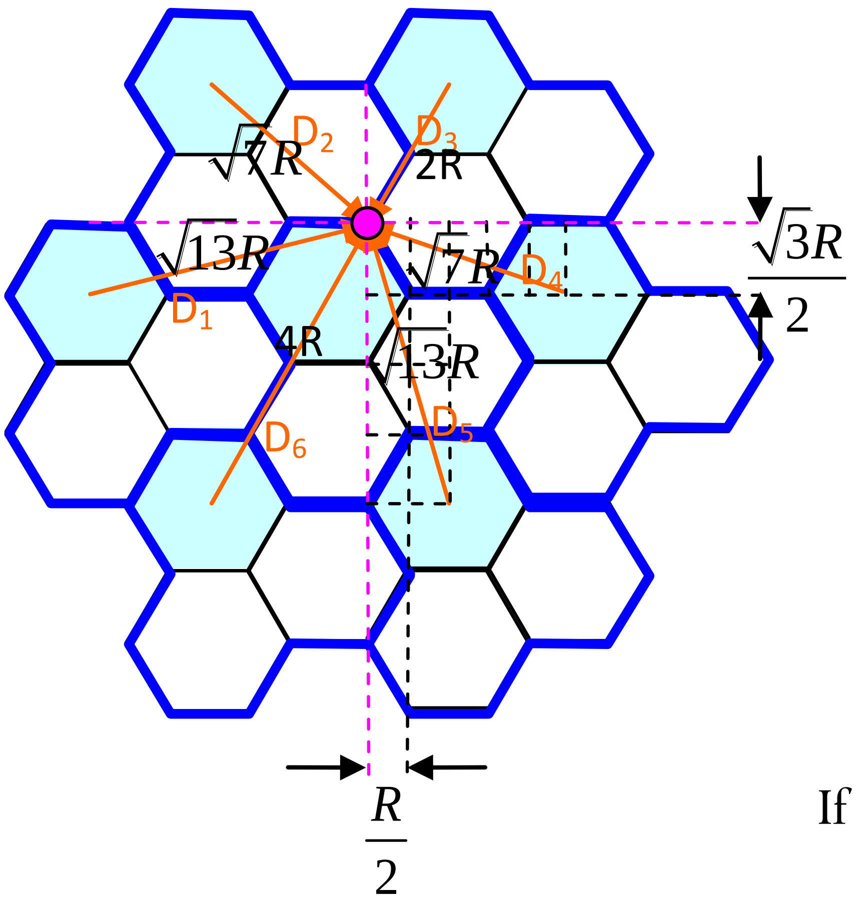
SIR Threshold

[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

(Ignore co-channel cells that are too far away)



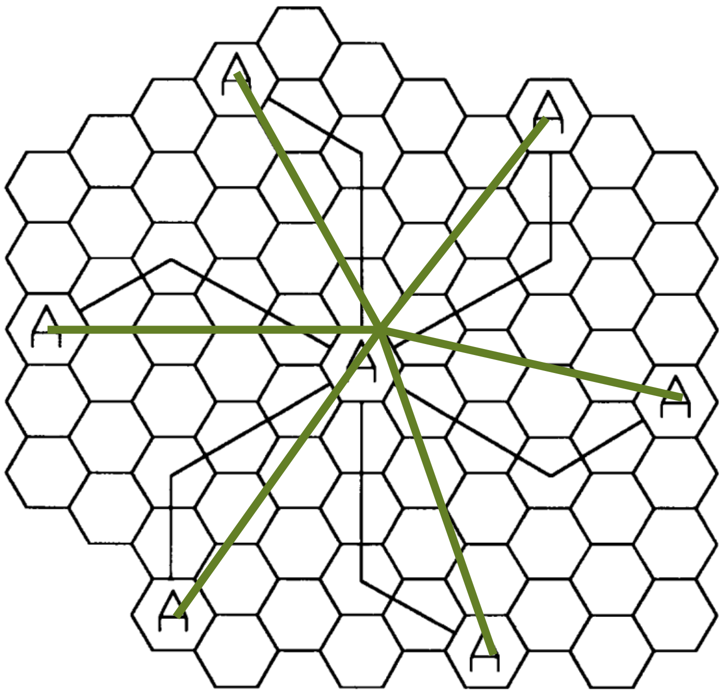
- Consider only first tier.
- Worse-case distance

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

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

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

Approximation

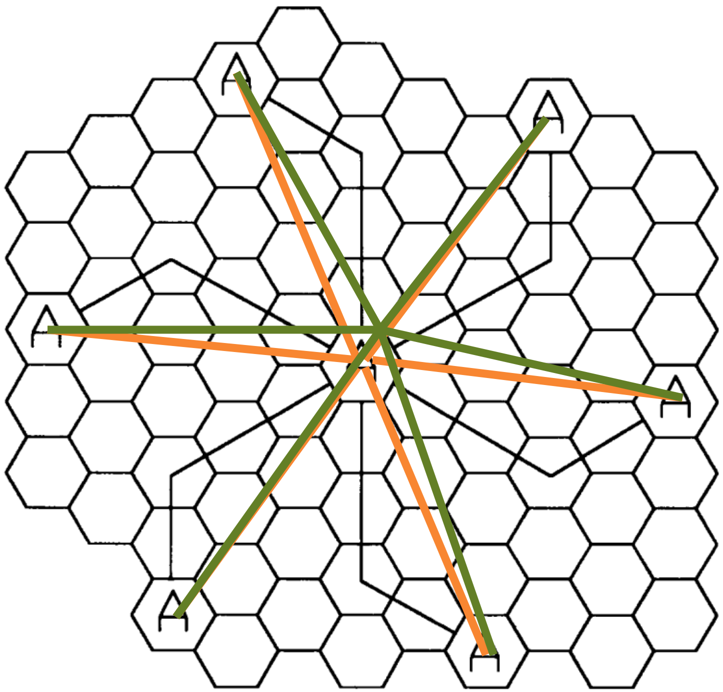


- Consider only first tier.
- Worse-case distance

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

- Use the same D for D_i

Approximation



- Consider only first tier.
- Worse-case distance

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

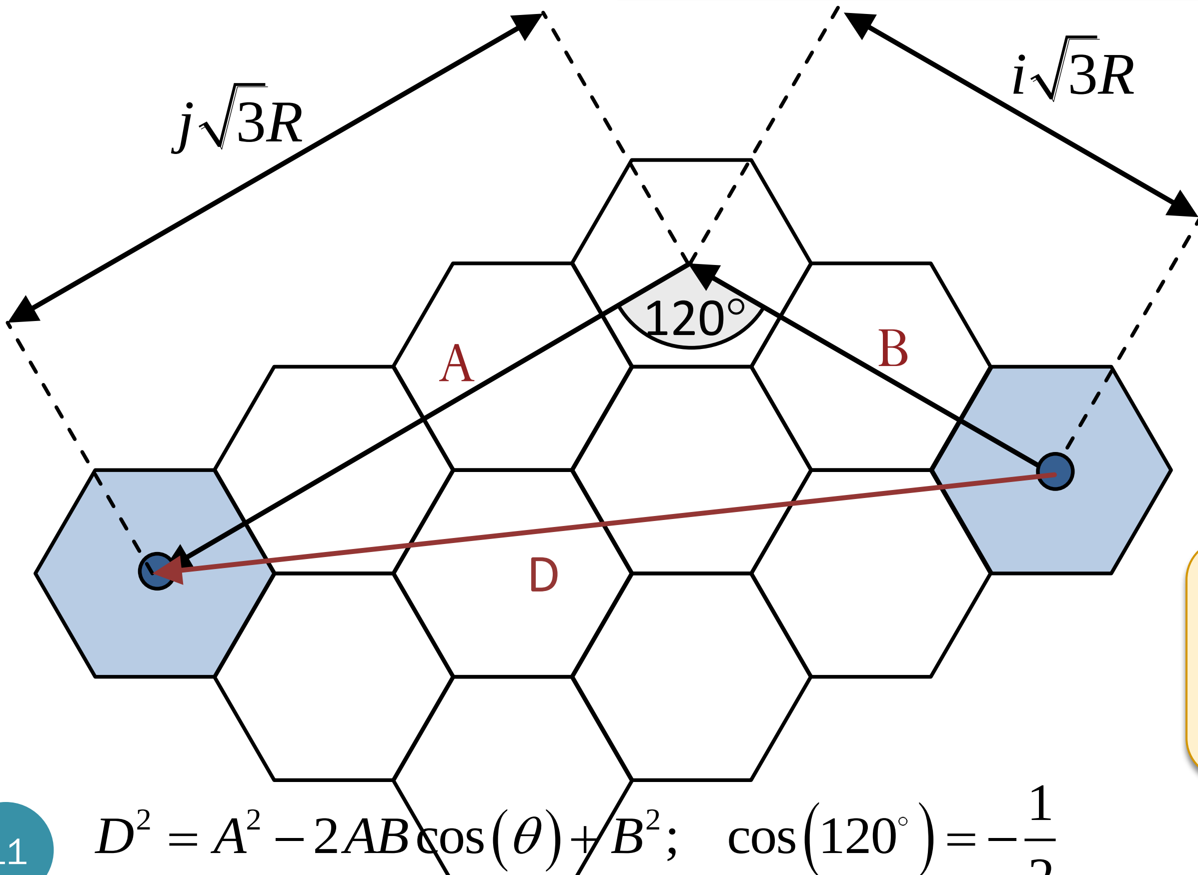
- Use the same D for D_i

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

Notice that D/R is an important quantity!

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

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

$$D^2=A^2-2AB\cos(\theta)+B^2;\quad \cos\left(120^\circ\right)=-\frac{1}{2}$$

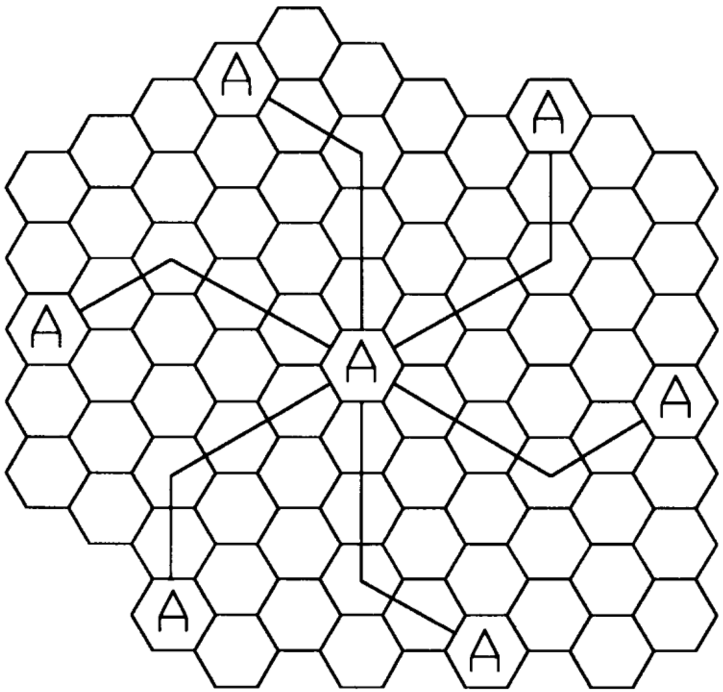
Q and N

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

Path loss exponent

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

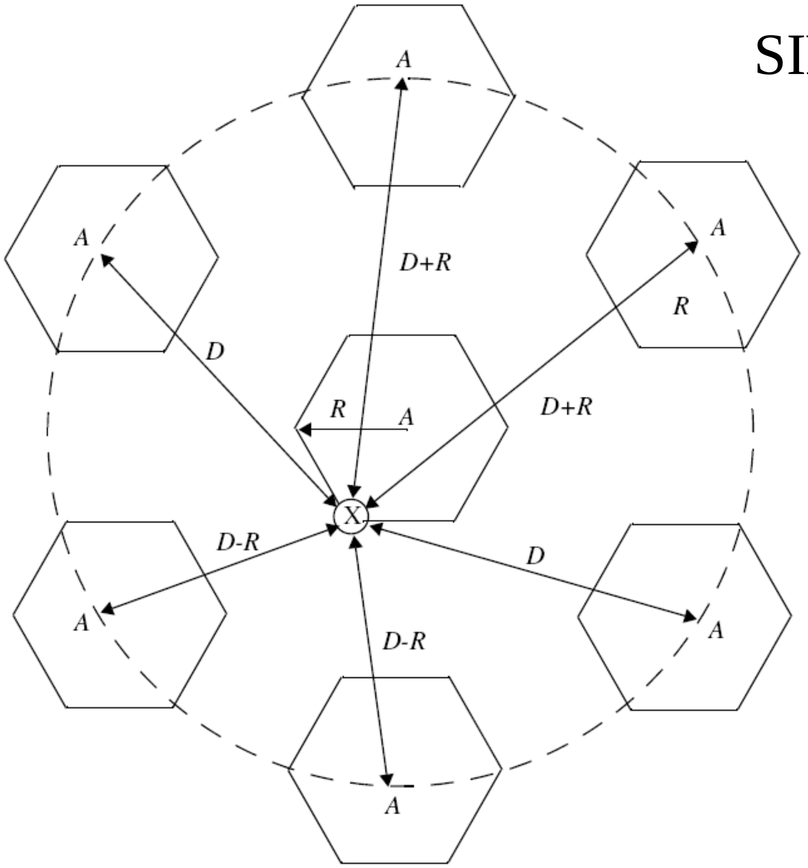
Tradeoff

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

m = # channels allocated to each cell.

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

SIR: N = 7



Better approximation…

$$\text{SIR} \approx \frac{R^{-\gamma}}{2(D-R)^{-\gamma} + 2(D+R)^{-\gamma} + 2D^{-\gamma}}$$

$$= \frac{1}{2(Q-1)^{-\gamma} + 2(Q+1)^{-\gamma} + 2Q^{-\gamma}}$$

Again, $Q = \dfrac{D}{R} = \sqrt{3N}$.