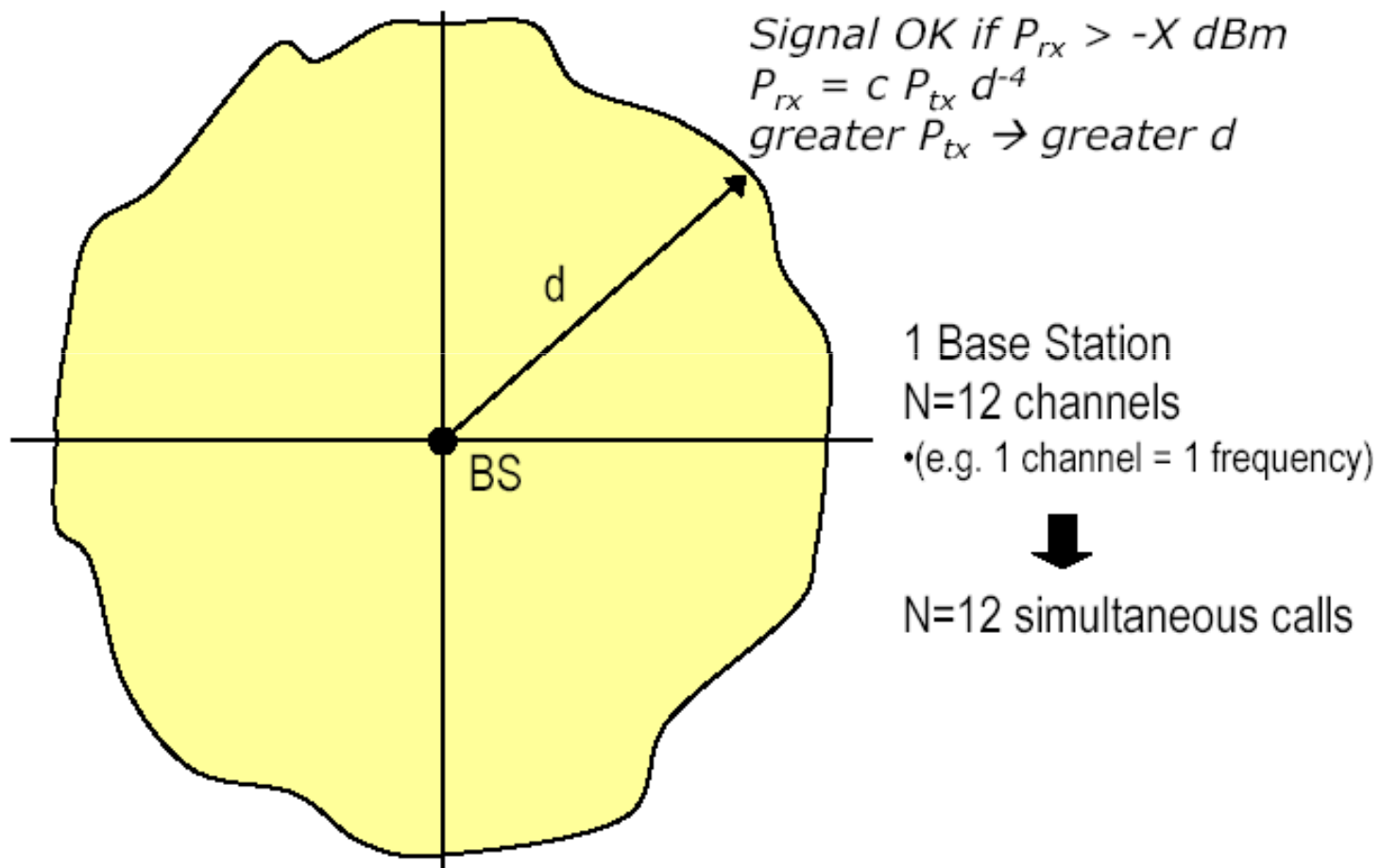




# Cellular Coverage Concepts



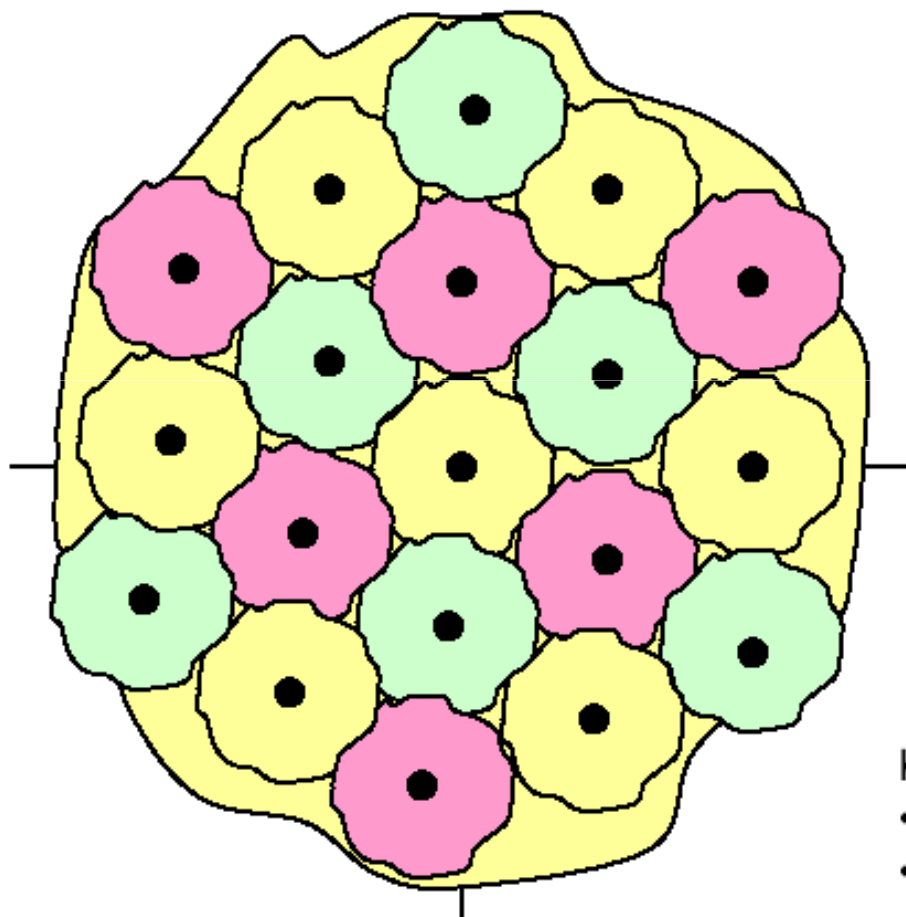
## Coverage for a terrestrial zone





## Cellular coverage

target: cover the same area with a larger number of BSs



19 Base Station  
12 frequencies  
4 frequencies/cell



Worst case:  
4 calls (all users in same cell)

Best case:  
76 calls (4 users per cell)

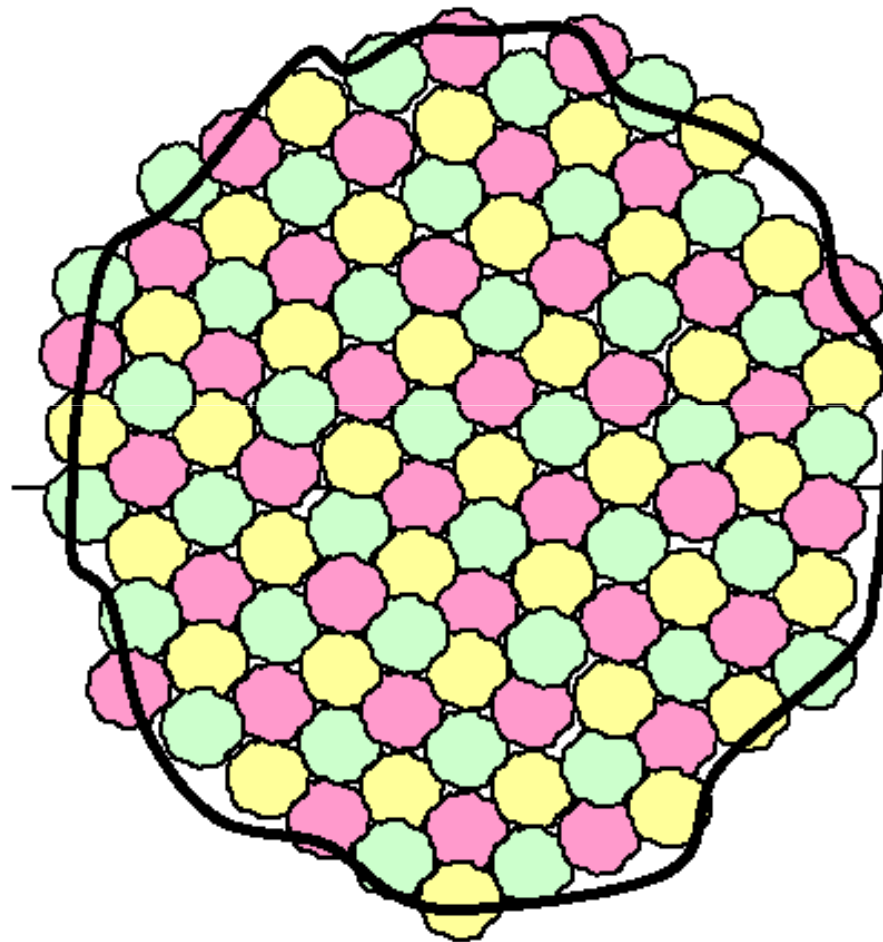
Average case  $\gg 12$   
Low transmit power

### Key advantages:

- Increased capacity (freq. reuse)
- Decreased tx power



## Cellular coverage (microcells)



many BS

Very low power!!

Unlimited capacity!!

Usage of same spectrum  
(12 frequencies)  
(4 freq/cell)

Disadvantage:  
mobility management



# Cellular system architecture

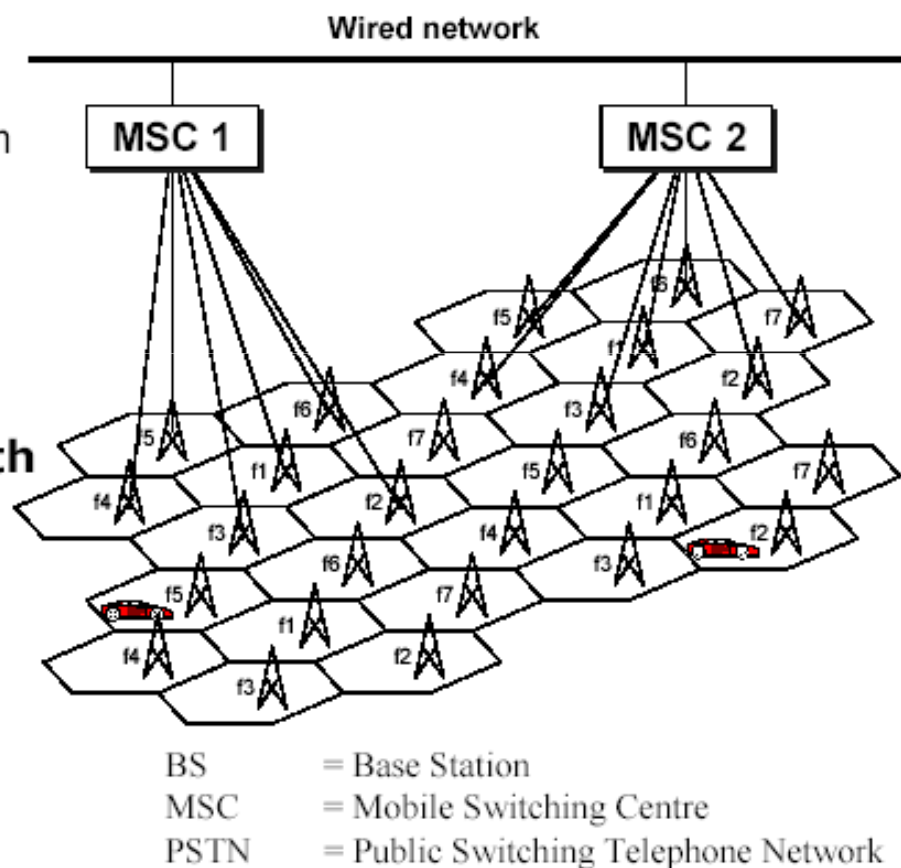
## → 1 BS per cell

- ⇒ Cell: Portion of territory covered by one radio station
- ⇒ One or more carriers (frequencies; channels) per cell

## → Mobile users full-duplex connected with BS

## → 1 MSC controls many BSs

## → MSC connected to PSTN





# Cellular capacity

## → Increased via frequency reuse

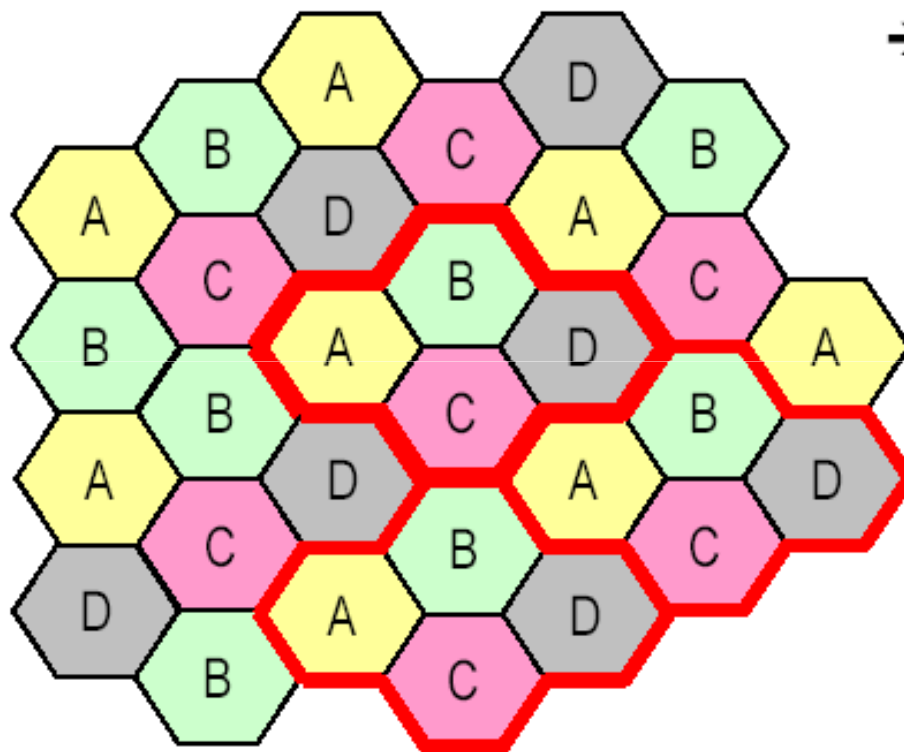
- ⇒ Frequency reuse depends on interference
- ⇒ need to sufficiently separate cells
  - reuse pattern = cluster size ( $7 \rightarrow 4 \rightarrow 3$ ):  
discussed later

## → Cellular system capacity: depends on

- ⇒ overall number of frequencies
  - Larger spectrum occupation
- ⇒ frequency reuse pattern
- ⇒ Cell size
  - Smaller cell (cell  $\rightarrow$  microcell  $\rightarrow$  picocell) = greater capacity
  - Smaller cell = lower transmission power
  - Smaller cell = increased handover management burden



## hexagonal cells

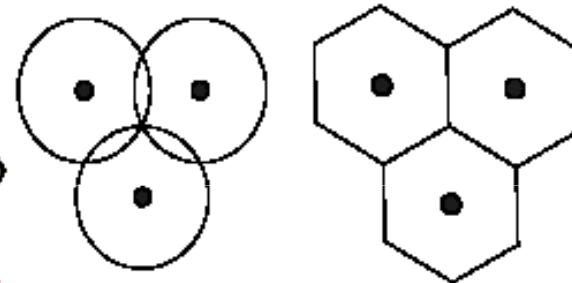


→ **Example case:**

⇒ Reuse pattern = 4

→ **Hexagon:**

⇒ Good approximation for circle



⇒ Ideal coverage pattern

→ no “holes”

→ no cell superposition

*Cell border: local threshold, beyond which neighboring BS signal is received stronger than current one*



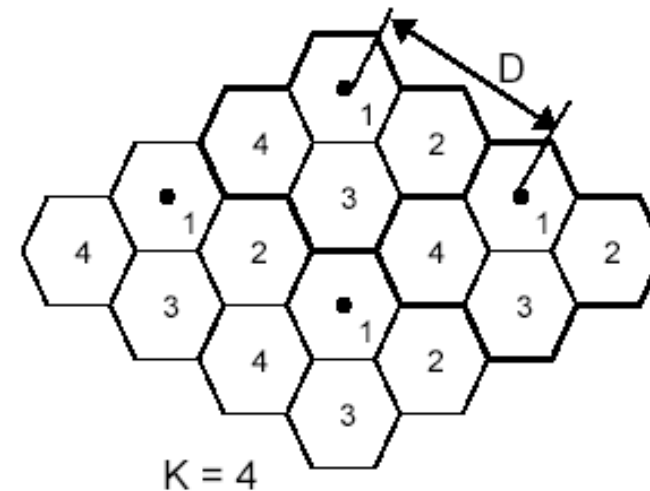
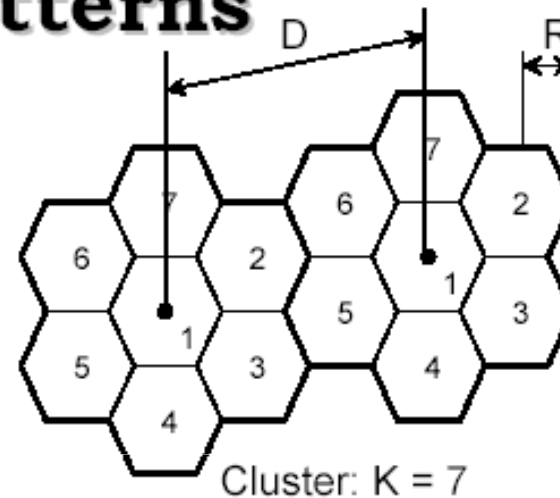
## Reuse patterns

### → Reuse distance:

- ⇒ Key concept
- ⇒ In the real world depends on
  - Territorial patterns (hills, etc)
  - Transmitted power
    - » and other propagation issues such as antenna directivity, height of transmission antenna, etc

### → Simplified hexagonal cells model:

- ⇒ reuse distance depends on reuse pattern (cluster size)
- ⇒ Possible clusters:
  - 3, 4, 7, 9, 12, 13, 16, 19, ...





## Reuse distance

→ General formula

$$D = R\sqrt{3K}$$

→ Valid for hexagonal geometry

→  $D$  = reuse distance

→  $R$  = cell radius

→  $q = D/R$  = frequency reuse factor

K	$q=D/R$
3	3,00
4	3,46
7	4,58
9	5,20
12	6,00
13	6,24



## Proof

→ **Distance between two cell centers:**

$$\Leftrightarrow (u_1, v_1) \leftrightarrow (u_2, v_2)$$

$$D = \sqrt{\left[(u_2 - u_1) \cos 30^\circ\right]^2 + \left[(v_2 - v_1) + (u_2 - u_1) \sin 30^\circ\right]^2}$$

⇒ Simplifies to:

$$D = \sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2 + (u_2 - u_1)(v_2 - v_1)}$$

⇒ Distance of cell (i,j) from (0,0):

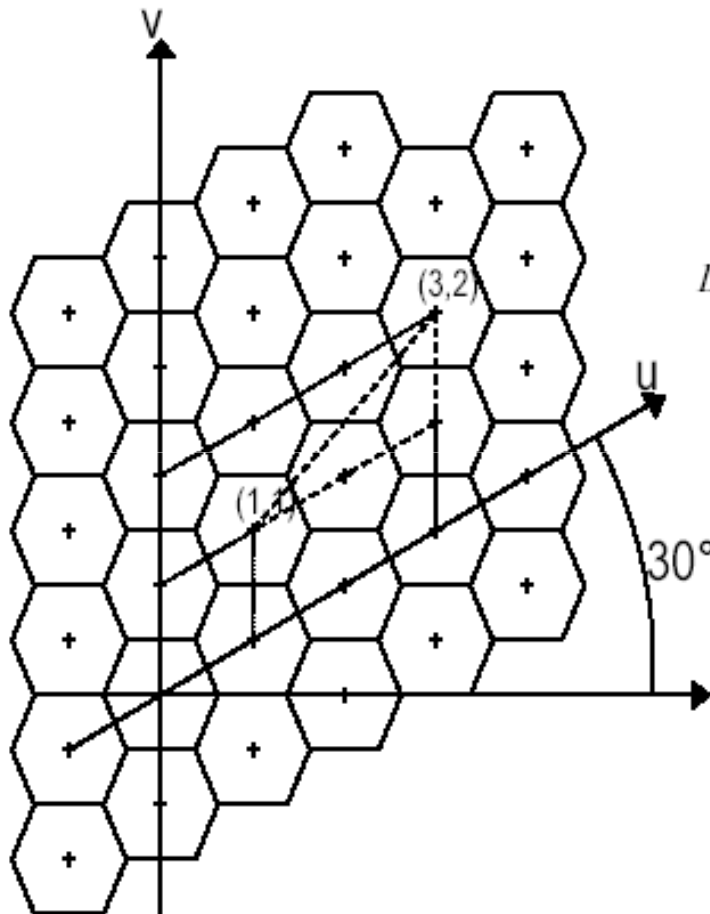
$$D = \sqrt{i^2 + j^2 + ij} \sqrt{3} R$$

$$D_R = \sqrt{i^2 + j^2 + ij}$$

⇒ Cluster: easy to see that

$$K = D_R^2 = i^2 + j^2 + ij$$

$$\Leftrightarrow \text{hence: } D = R \sqrt{3K}$$

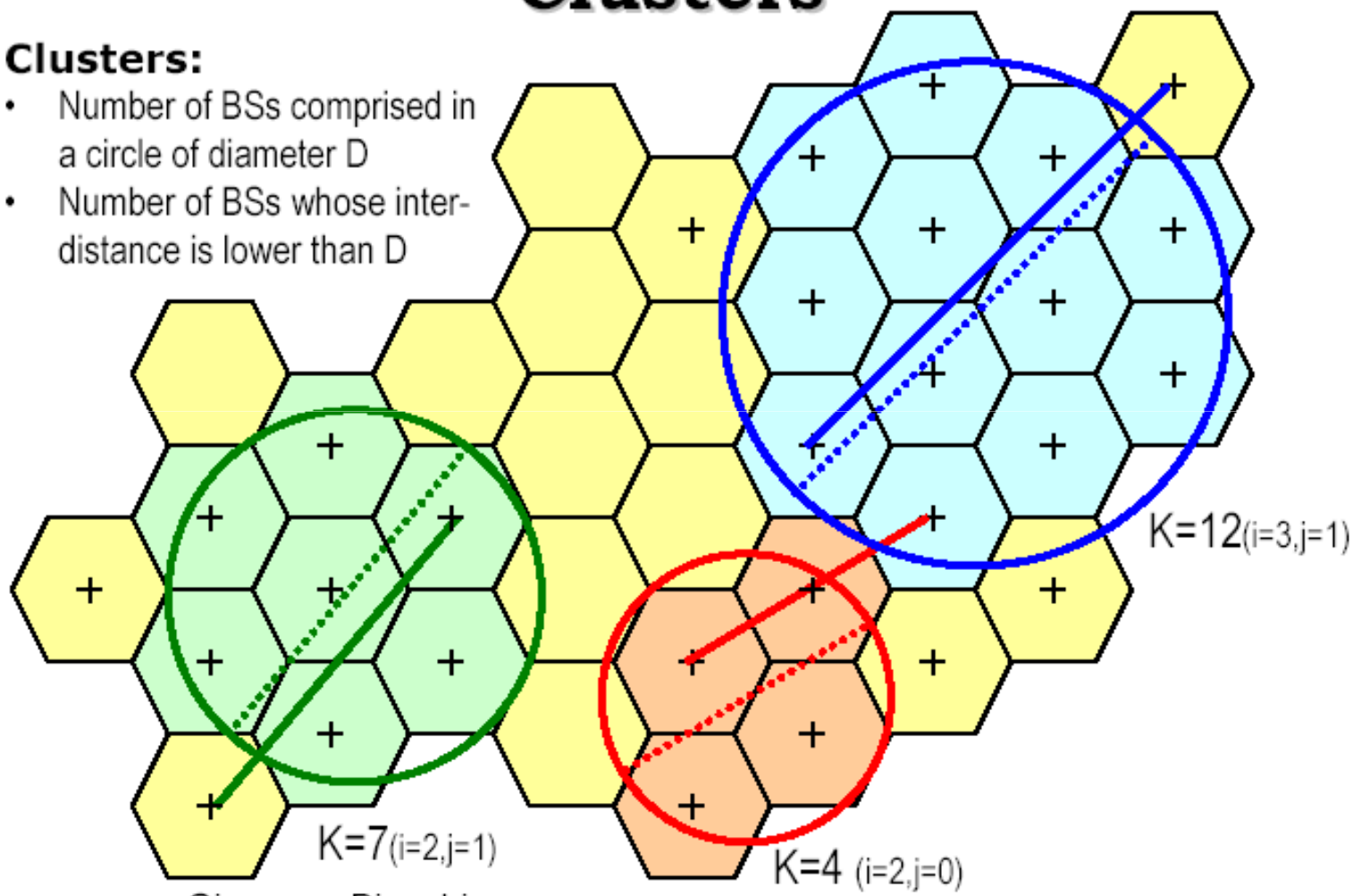




## Clusters

### Clusters:

- Number of BSs comprised in a circle of diameter  $D$
- Number of BSs whose inter-distance is lower than  $D$



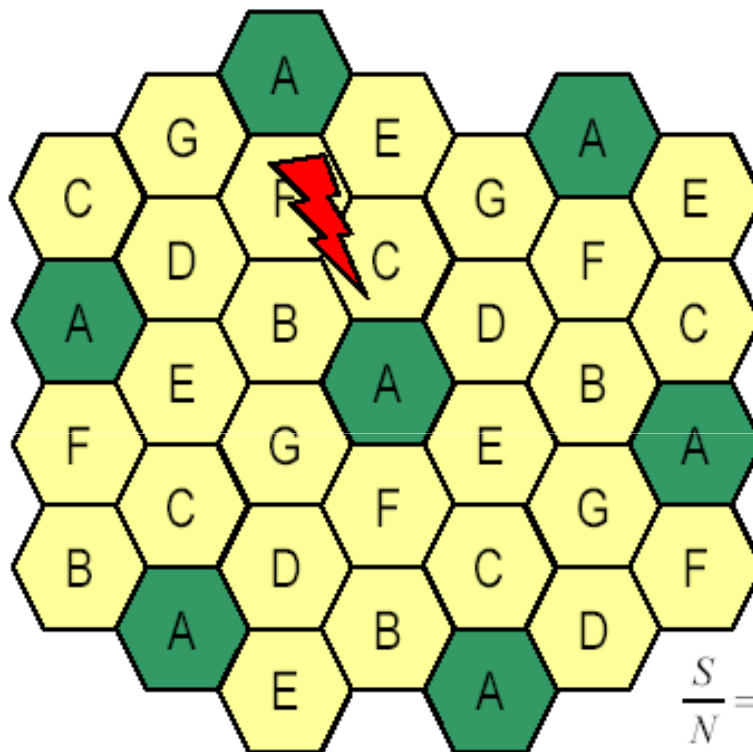


## Possible clusters all integer $i, j$ values

$i$	$j$	$K=ii+jj+ij$	$q=D/R$
1	0	1	1,73
1	1	3	3,00
2	0	4	3,46
2	1	7	4,58
2	2	12	6,00
3	0	9	5,20
3	1	13	6,24
3	2	19	7,55
3	3	27	9,00
4	0	16	6,93
4	1	21	7,94
4	2	28	9,17
4	3	37	10,54
4	4	48	12,00
5	0	25	8,66
5	1	31	9,64



## Co-Channel Interference



→ Frequency reuse implies that remote cells interfere with tagged one

→ Co-Channel Interference (CCI)

⇒ sum of interference from remote cells

$$\frac{S}{N} = \frac{\text{signal power (S)}}{\text{noise power (N}_s\text{)} + \text{interfering signal power (I)}}$$

$$\frac{S}{I} = \frac{\text{signal power (S)}}{\text{interfering signal power (I)}}$$

$$\frac{S}{N} \approx \frac{S}{I} \quad \text{as } N_s \text{ small}$$



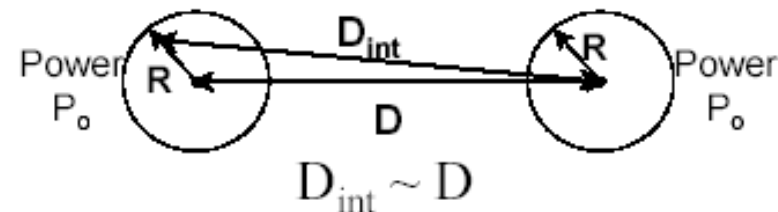
# CCI Computation - assumptions

## → Assumptions

- ⇒  $N_I=6$  interfering cells
  - $N_I=6$ : first ring interferers only
  - we neglect second-ring interferers
- ⇒ Negligible Noise  $N_S$ 
  - $S/N \sim S/I$
- ⇒  $d^{-\eta}$  propagation law
  - $\eta=4$  (in general)
- ⇒ Same parameters for all BSs
  - Same  $P_{tx}$ , antenna gains, etc

## → Key simplification

- ⇒ Signal for MS at distance  $R$
- ⇒ Signal from BS interferers at distance  $D$





## CCI computation

$$\frac{S}{N} \approx \frac{S}{I} = \frac{\text{cost} \cdot R^{-\eta}}{\sum_{k=1}^{N_I} \text{cost} \cdot D^{-\eta}} = \text{By using the assumptions of same cost and same } D:$$
$$= \frac{1}{N_I} \left( \frac{R}{D} \right)^{-\eta} = \frac{1}{N_I} \left( \frac{D}{R} \right)^{\eta} = \frac{1}{N_I} q^{\eta}$$

**Results depend on ratio  $q=D/R$  ( $q$ =frequency reuse factor)**

Alternative expression: recalling that  $D = R\sqrt{3K}$

$$\frac{S}{N} \approx \frac{S}{I} = \frac{1}{N_I} \left( \frac{R}{R\sqrt{3K}} \right)^{-\eta} = \frac{1}{N_I} (3K)^{\eta/2} = \frac{(3K)^{\eta/2}}{6}$$
$$N_I=6, \mu=4 \rightarrow \frac{S}{I} = \frac{(3K)^2}{6} = \frac{3}{2} K^2$$

**USAGE:** Given an S/I target, cluster size  $K$  is obtained



## Examples

→ target conditions:

$$\Rightarrow S/I = 9 \text{ dB}$$

→ Solution:

$$\frac{S}{I} = 10^{0.9} = 7.94 \approx 8$$

$$\frac{S}{I} = \frac{(3K)^{\eta/2}}{6} \bigg|_{\eta=4} \Rightarrow K = \sqrt{\frac{2}{3} \cdot \frac{S}{I}}$$

$$K \geq 2.3 \Rightarrow K = 3$$

→ target conditions:

$$\Rightarrow S = 18 \text{ dB}$$

$$\Rightarrow \eta = 4.2$$

→ Solution:

$$\frac{S}{I} [\text{dB}] = 5\eta \log(3K) - 10 \log 6$$

$$\log(3K) = \frac{18 + 7.78}{21} = 1.23$$

$$K \geq \frac{10^{1.23}}{3} = 5.63 \Rightarrow K = 7$$



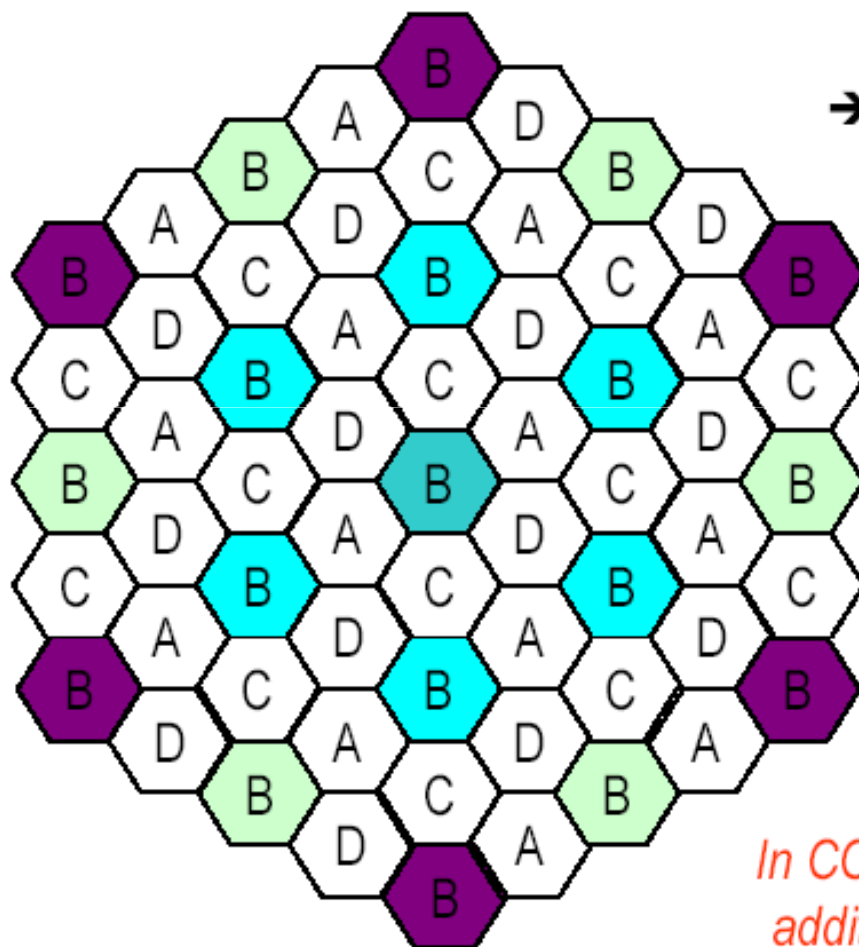
## **S/I computation**

**assuming 6 interferers only (first ring)**

K	$q=D/R$	S/I	S/I dB
3	3,00	13,5	11,3
4	3,46	24,0	13,8
7	4,58	73,5	18,7
9	5,20	121,5	20,8
12	6,00	216,0	23,3
13	6,24	253,5	24,0
16	6,93	384,0	25,8
19	7,55	541,5	27,3
21	7,94	661,5	28,2
25	8,66	937,5	29,7



## Additional interferers



→ case  $K=4$

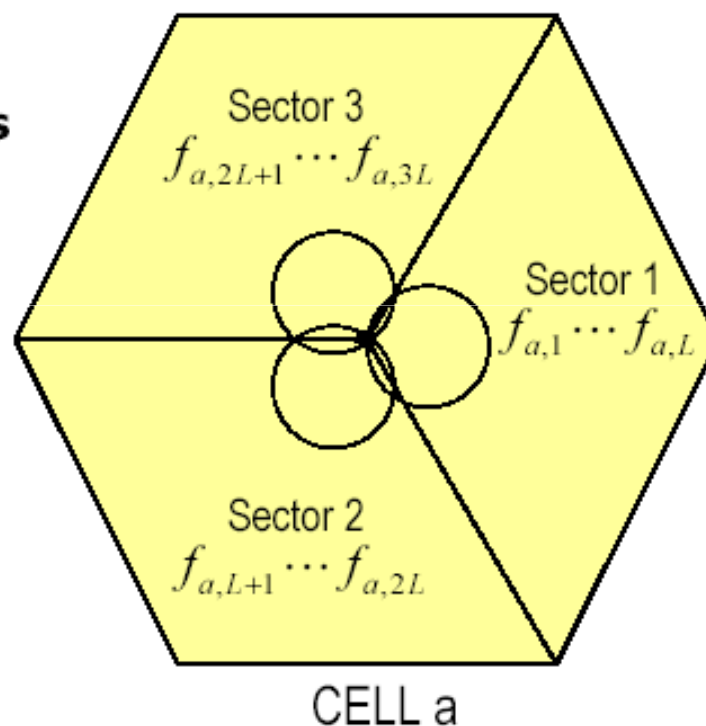
⇒ note that for each cluster there are always  $N_1=6$  first-ring interferers

*In CCI computation, contribute of additional interferers is marginal*



## sectorization

- **Directional antennas**
- **Cell divided into sectors**
- **Each sector uses different frequencies**
  - ⇒ To avoid interference at sector borders
- **PROS:**
  - ⇒ CCI reduction
- **CONS:**
  - ⇒ Increased handover rate
  - ⇒ Less effective “trunking” leads to performance impairments





## CCI reduction via sectorization

### three sectors case

#### → Inference from 2 cells, only

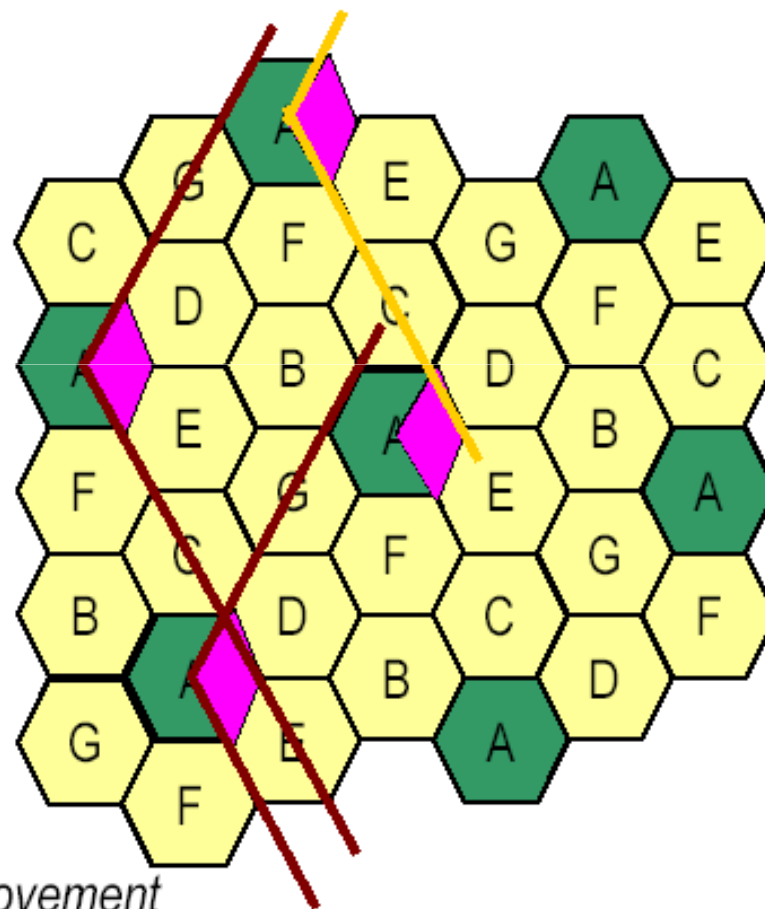
⇒ Instead of 6 cells

With usual approx  
(specifically,  $D_{\text{int}} \sim D$ )

$$\left[ \frac{S}{I} \right]_{120^\circ} = \frac{R^{-\eta}}{2D^{-\eta}} = 3 \cdot \left[ \frac{S}{I} \right]_{\text{omni}}$$

$$\left[ \frac{S}{I} \right]_{120^\circ} \text{ dB} = \left[ \frac{S}{I} \right]_{\text{omni}} \text{ dB} + 4.77$$

Conclusion: 3 sectors = 4.77 dB improvement





## 6 sectors

→ **60° Directional antennas**

→ **CCI reduction:**

- ⇒ 1 interfereer only
- ⇒ 6 x S/I in the omni case
- ⇒ Improvement: 7.78 dB

