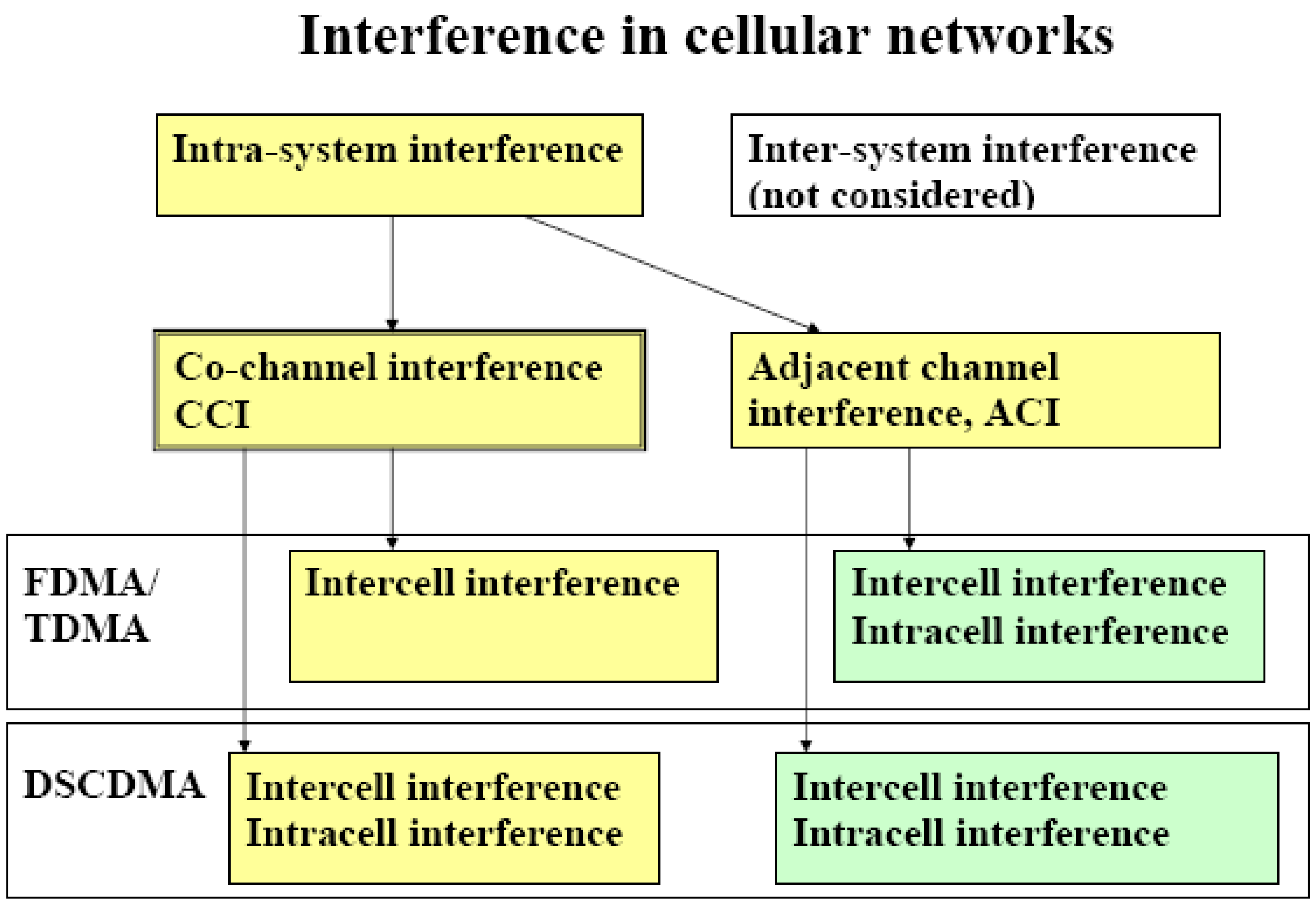
TEKNILLINEN KORKEAKOULU
TEKNISKA HÖGSKOLAN
HELSINKI UNIVERSITY OF TECHNOLOGY

Cellular Network Planning and Optimization Part III: Interference

Jyri Hämäläinen,
Communications and Networking Department,
TKK, 18.1.2007

Interference classification



Co-channel interference

- Co-channel interference arise when same radio resources are used in different cells (nearby each other) at the same time.
  - If there is no co-channel interference or amount of co-channel interference is small then system is said to be noise limited (here noise = AWGN)
  - If co-channel interference is limiting the system operability then system is said to be interference limited.
- In cellular networks there is always co-channel interference. By using various radio resource reuse techniques the impact of interference can be removed. Yet, the cost of such resource reuse is usually lower overall capacity in the system.

Adjacent channel interference

- Adjacent-channel interference is interference that is caused by power leakage from a signal in an adjacent channel.
- Adjacent channel interference can be attenuated by adequate filtering
  - For each cellular system there are certain RF specifications that put requirements to adjacent channel filtering
- Adjacent channel interference should be also taken into account in network planning.
  - Adjacent channel interference can be mitigated also through proper frequency planning
- Adjacent-channel interference is also sometimes called as crosstalk.
  - In analog systems (e.g. NMT) there can be crosstalk (literally) between adjacent channels

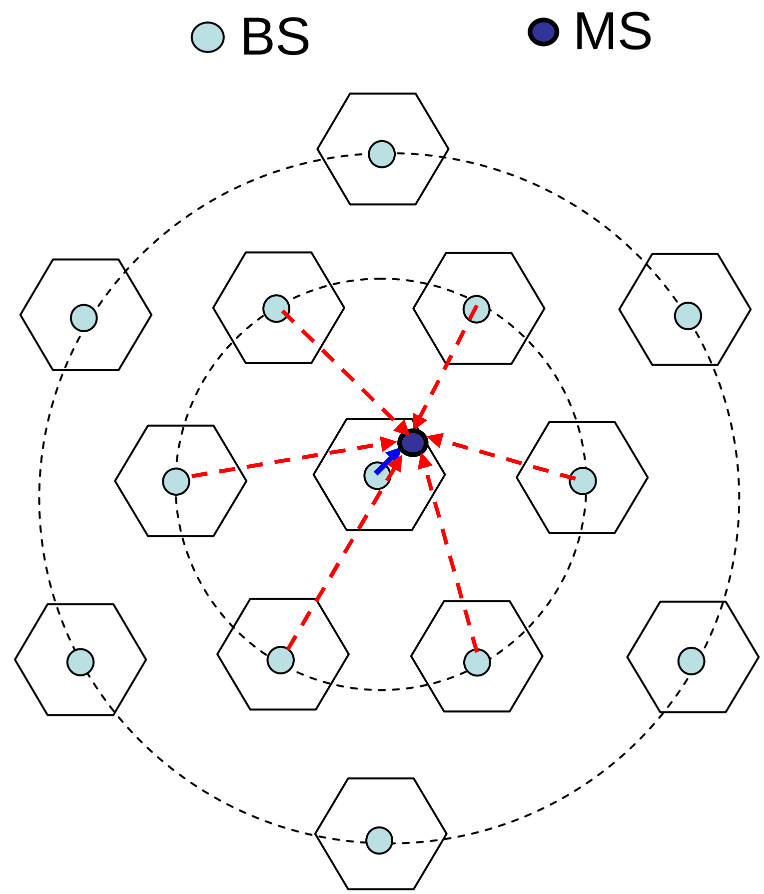
Co-channel/adjacent channel interference

- In the following we mainly concentrate on co-channel interference.
  - Co-channel interference is a system issue: By proper system design and network planning we can mitigate the co-channel interference partly.
  - There will be always trade-off between co-channel interference and system efficiency
- Adjacent channel interference is more related to hardware.
  - Adjacent channel interference is usually taken into account in specifications regarding to HW requirements
  - Adjacent channel interference needs to be kept in mind also in network planning.

Co-channel interference

- Co-channel interference is one of the main limiting factors for cellular system capacity
- Co-channel interference can be mitigated by system level design (frequency planning) and/or by receiver processing (interference cancellation)

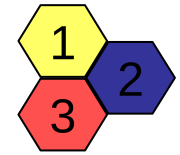
Down link co-channel interference



Wanted signal

Unwanted signal=co-channel interference

Co-channel interference/frequency planning



- Frequency planning is the conventional approach. In frequency planning each cell is assigned a subset of the available frequencies.
  - Frequency allocation can be fixed: Each cell has a fixed number of frequencies
  - Frequency allocation can be dynamic so that each cell may use all (or almost all) frequencies according to some rule that take into account the traffic variations in the network

Frequency planning

- In the following we consider in more details
  - **Reuse distance and clustering.** This is a basic concept that is very important from FDMA/TDMA perspective. Example technologies: GSM/EDGE, WiMAX
  - **Reuse partitioning and fractional reuse.** Due to increased capacity and coverage requirements these concepts are gaining importance. Example technologies: WiMAX, LTE

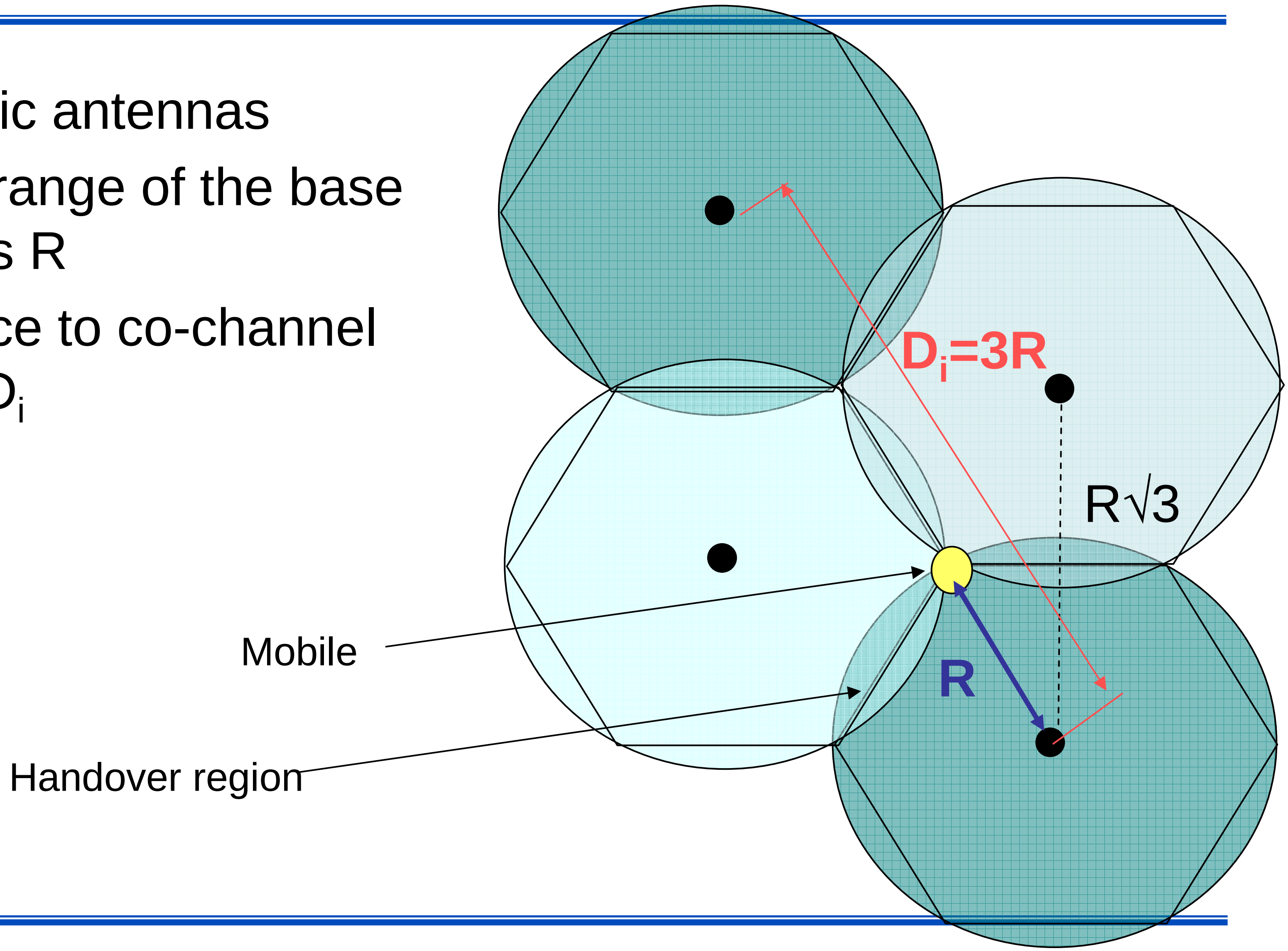
Reuse distance and clustering

Frequency planning based on SINR

- Service area is subdivided into cells.
- To simplify analysis cells are usually modeled as hexagons or squares.
- Each cell is assigned a subset of the available frequencies from the bundle assigned to the mobile network operator.
- Cells utilizing the same frequency cause co-channel interference to each other.
- In order to achieve tolerable signal-to-interference+noise ratio (SINR) cells using the same frequency must be separated by distance D (reuse distance)
- When a mobile is moving from cell to another an automatic channel/frequency change (handover) occurs.

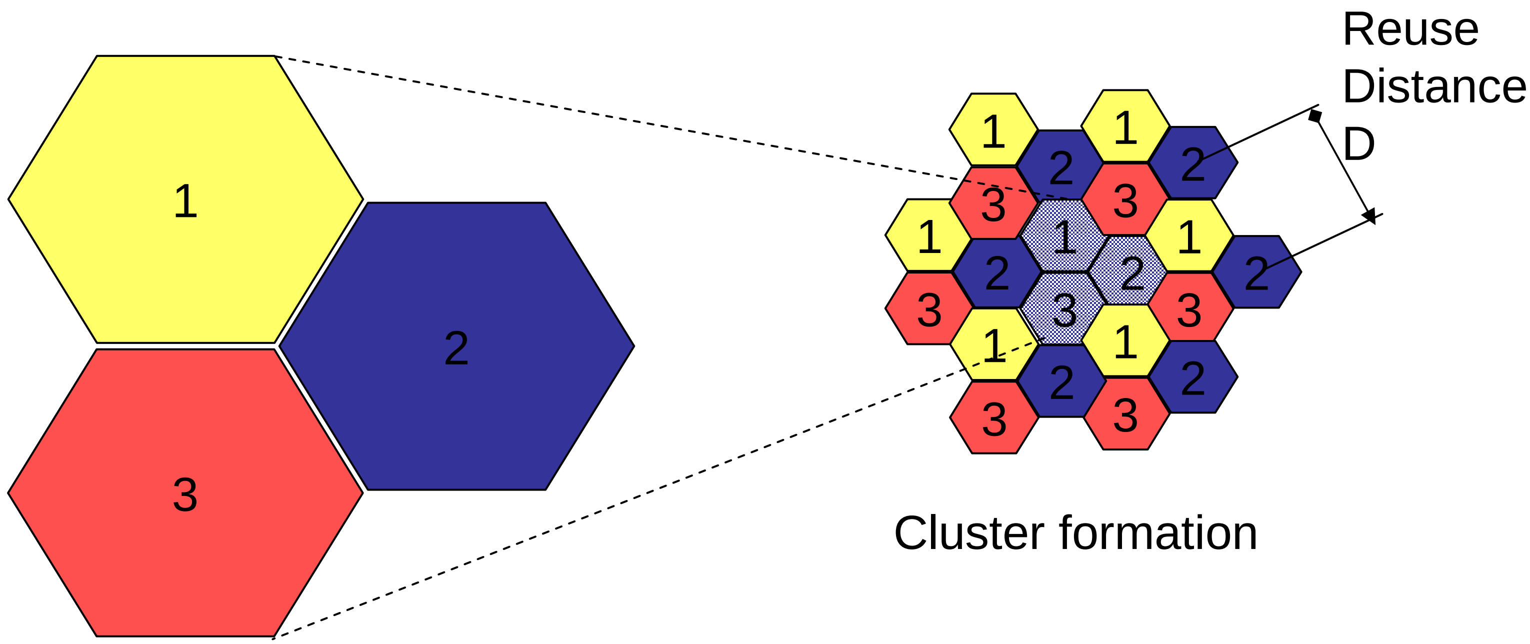
Cellular radio system

- Isotropic antennas
- Radio range of the base station is R
- Distance to co-channel cell i is D_i



Frequency reuse

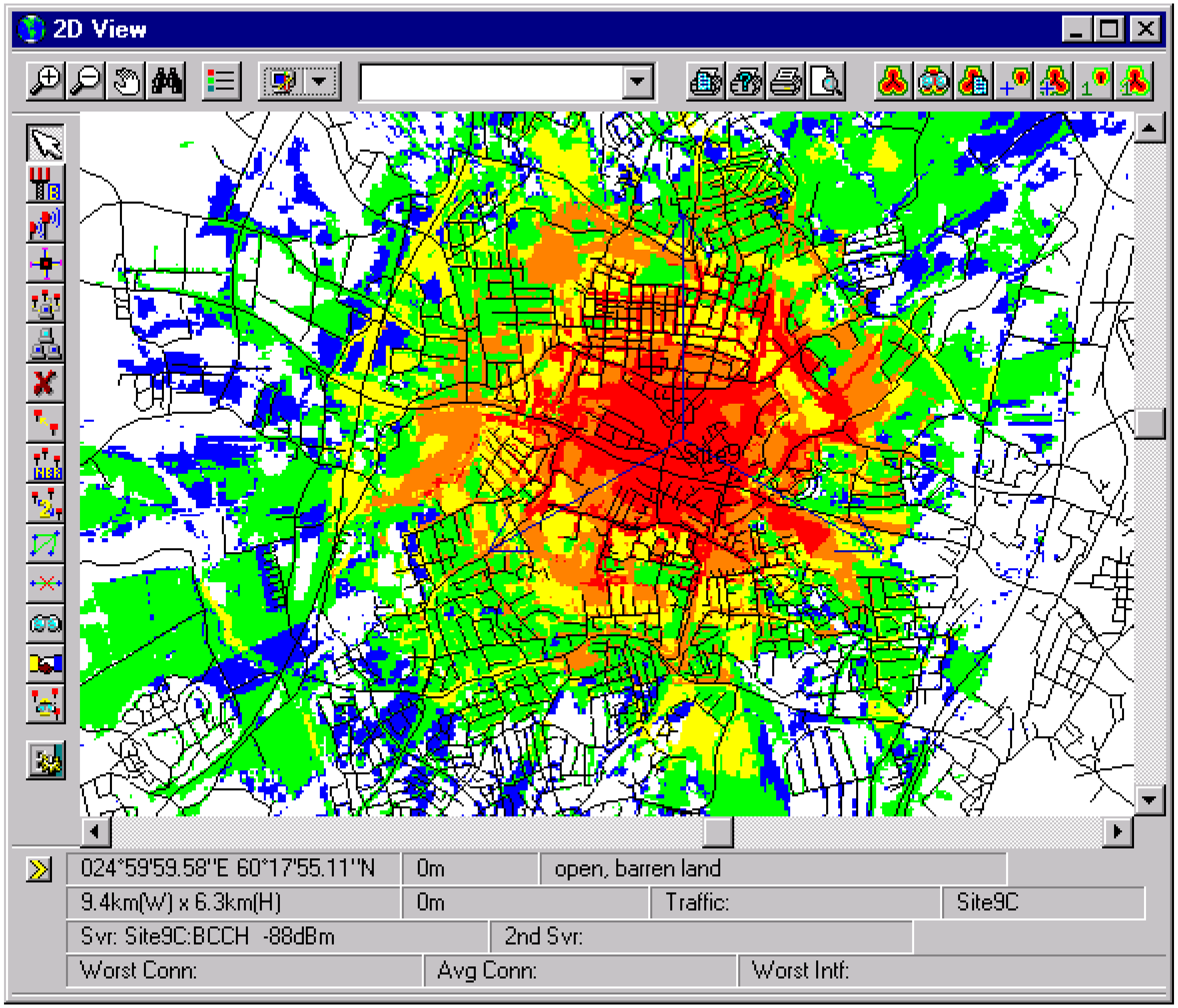
- Example: Number of available frequencies is 3



Cluster formation

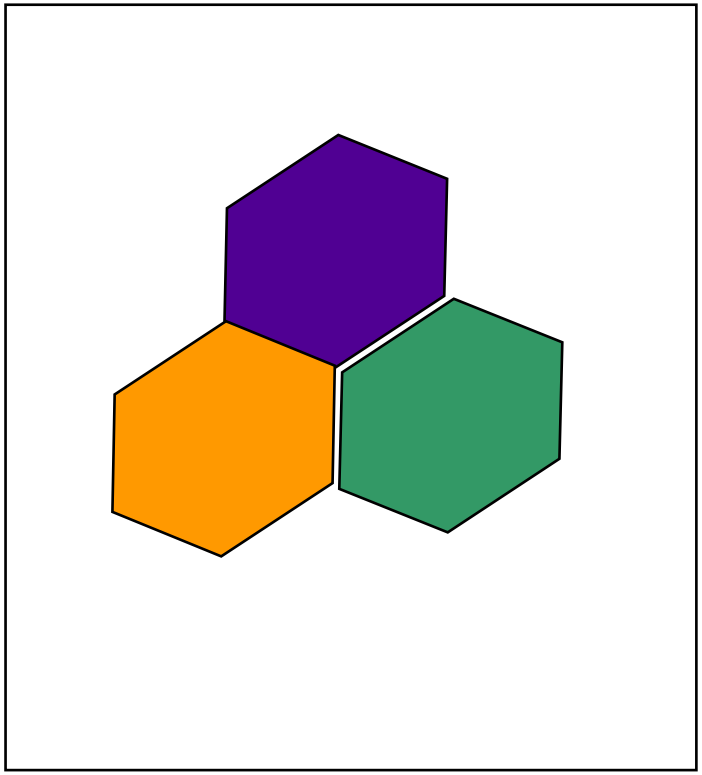
Cluster size K =3

Hexagonal cell vs true cell

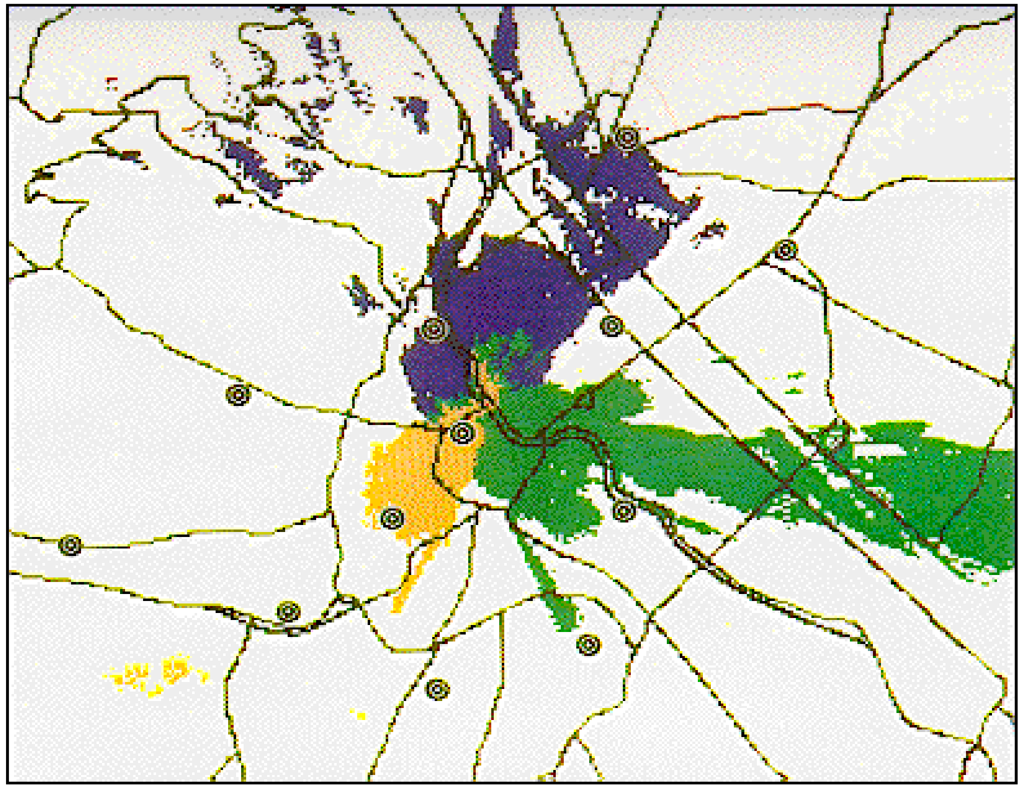


Hexagonal cells vs true cells

Three hexagons

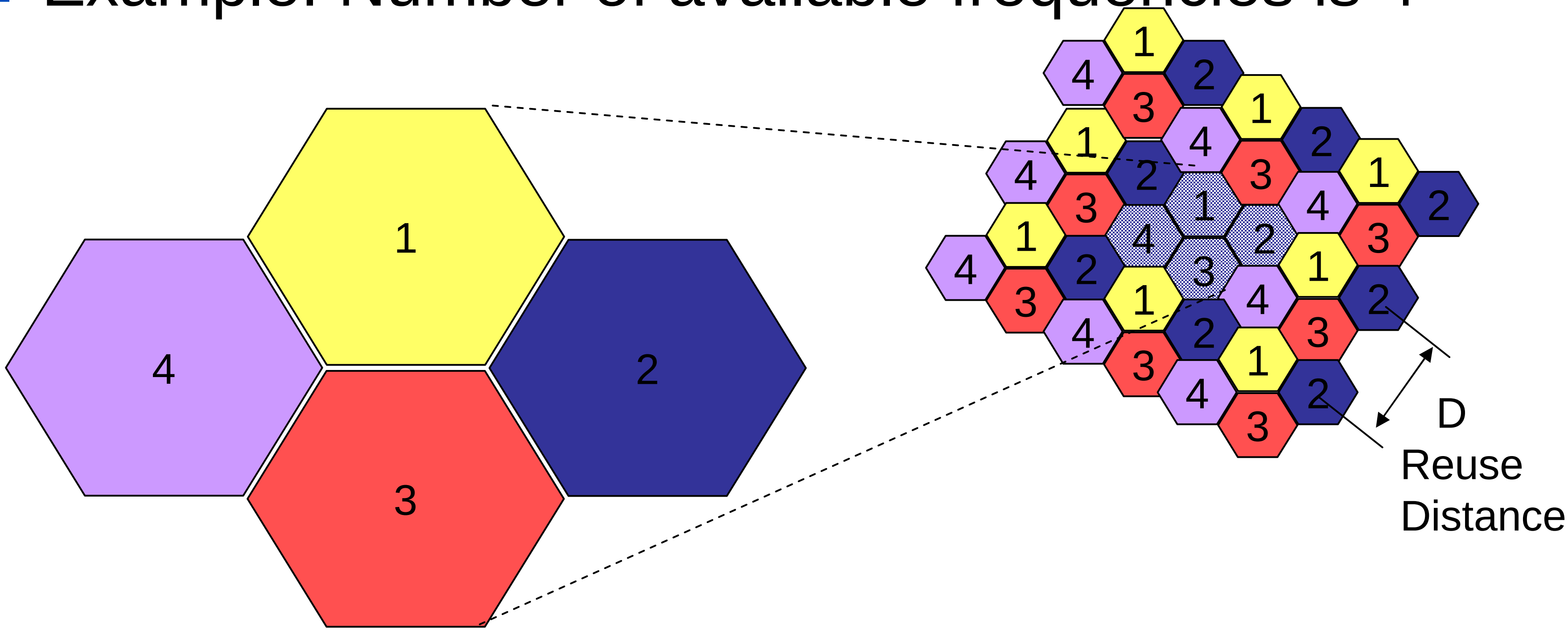


Three cells



Frequency reuse

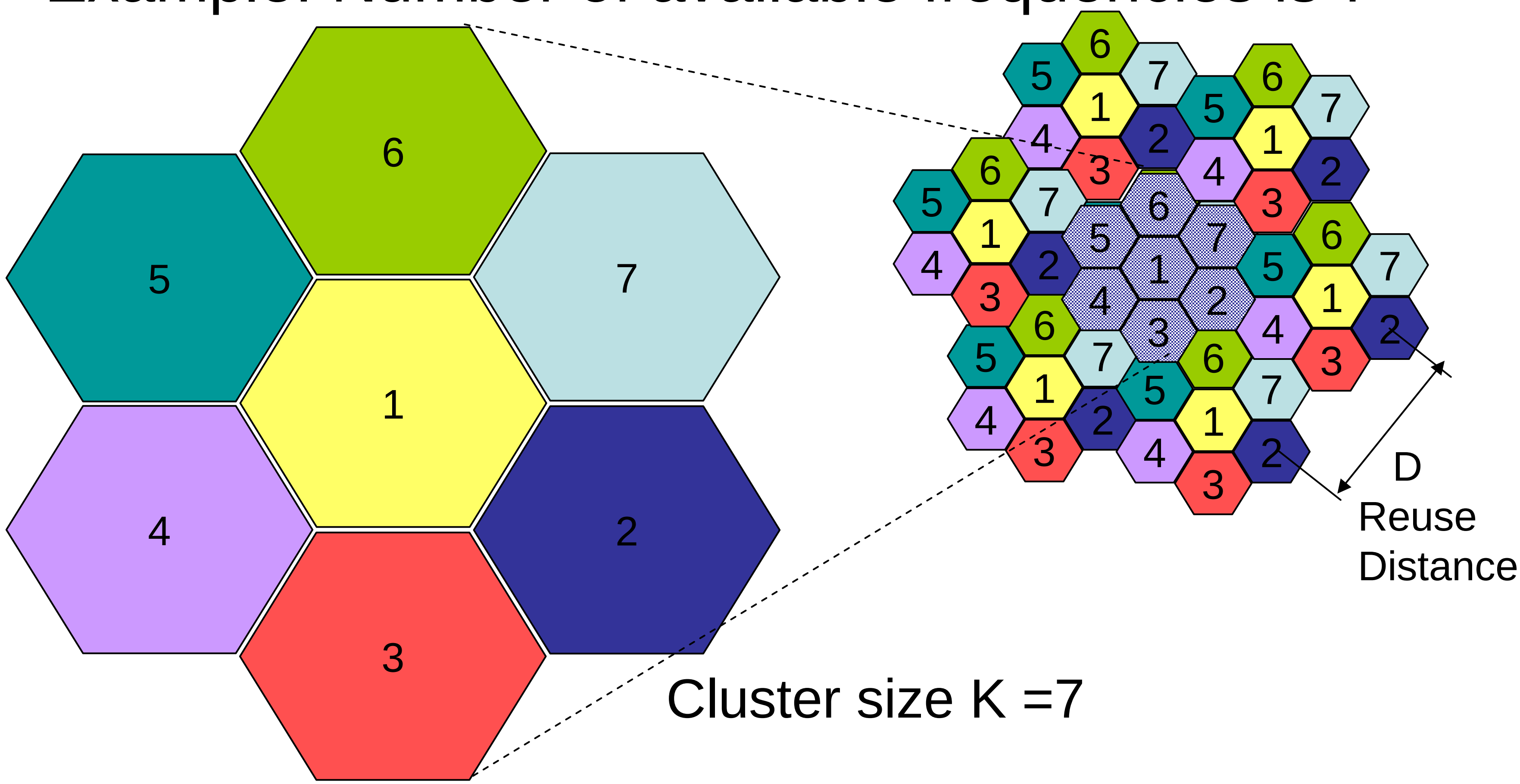
- Example: Number of available frequencies is 4



Cluster size K =4

Frequency reuse

- Example: Number of available frequencies is 7



Frequency reuse

- Not all cluster sizes are possible
- Feasible cluster sites

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

i=0,1,2,…

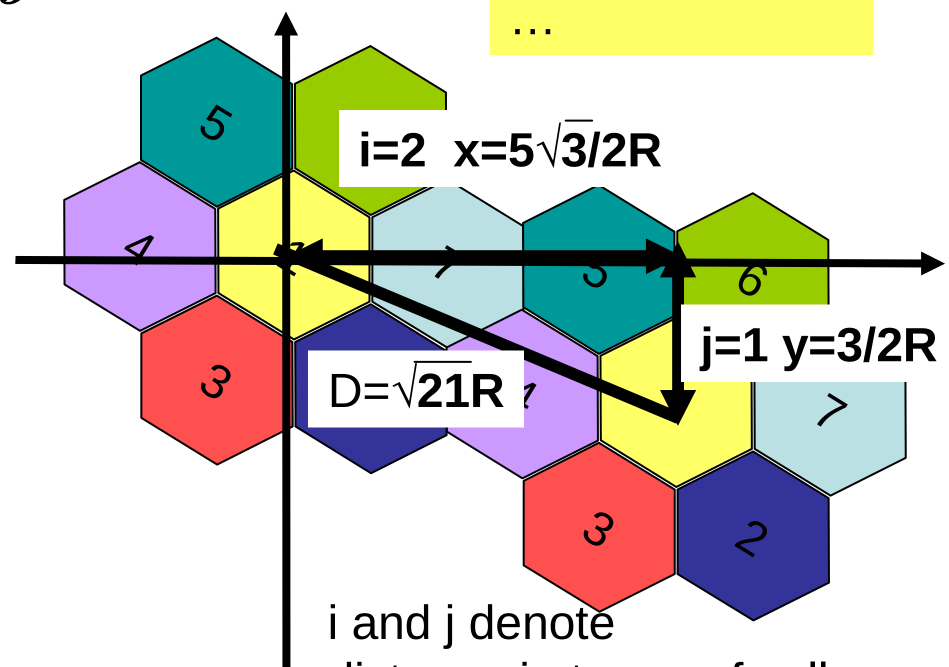
j=0,1,2,…

i=0, j=0 excluded

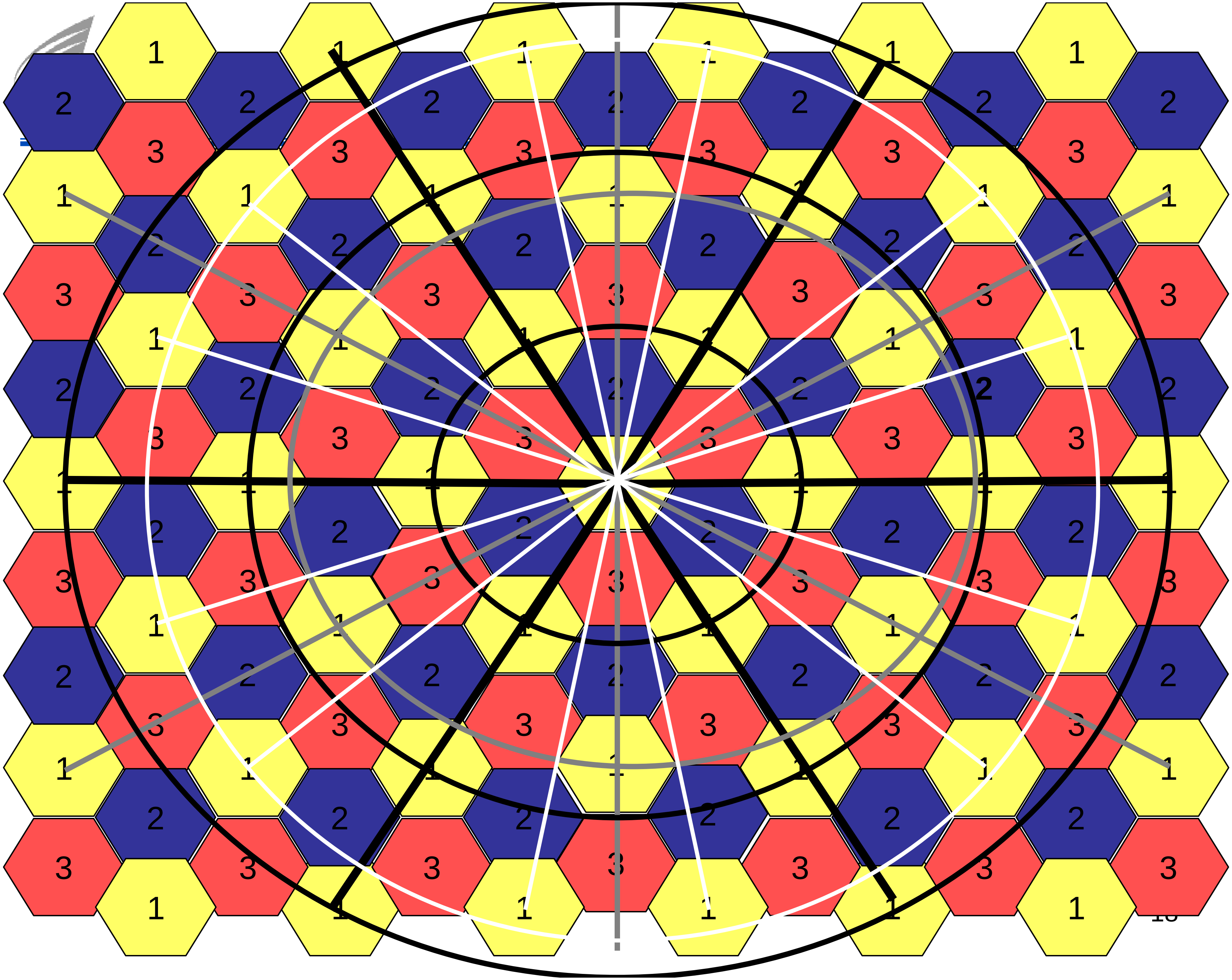
- Reuse distance

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

i=1, j=0 => k=1
i=1, j= 1=> k=3
i=2, j=0 => k=4
i=2, j=1 => k=7
i=3, j=0 => k=9
i=2, j=2 => k=12
…



i and j denote distance in terms of cells

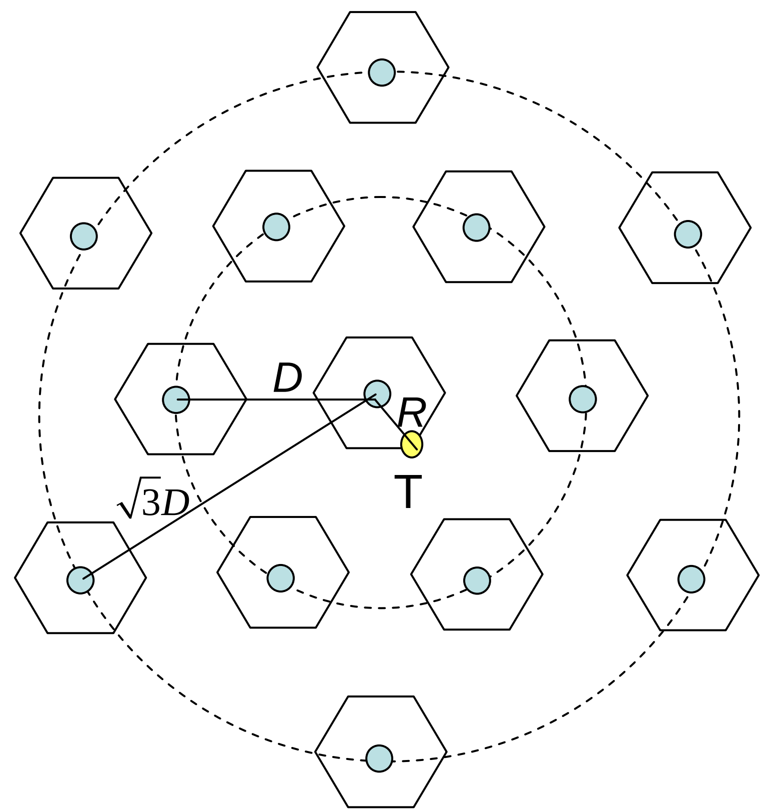


SINR/uplink

- Mobile positions are uniformly distributed in the cell. The average interference is obtained by considering interference sources at the middle of the cell.

$$\Gamma = \frac{PR^{-\alpha}}{\sum_j D_i^{-\alpha} P + N}$$

α	attenuation exponent α=2 in free space α up to 4 in macro cell environment
P	Transmit power
N	Noise power
R	cell radius
D	reuse distance
D_i	distance from base station i



Two first tires of co-channel interferers

SINR

- Distance to base station i

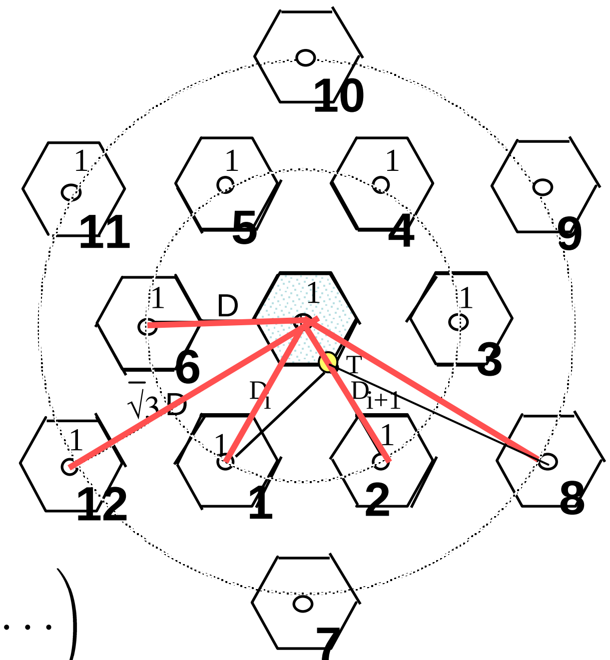
  $D_i \approx D$ for $i \in [1,6]$ First tire

  $D_i \approx D\sqrt{3}$ $i \in [7,12]$ Second tire

  $D_i \approx D\sqrt{4}$ $i \in [13,18]$ Third tire

  $D_i \approx D\sqrt{7}$ $i \in [19,24]$ Fourth tire

  etc.



- Interference power

$$I = \frac{P}{D^\alpha} 6 \left(1 + \left(\frac{1}{\sqrt{3}}\right)^\alpha + \left(\frac{1}{\sqrt{4}}\right)^\alpha + \left(\frac{1}{\sqrt{7}}\right)^\alpha + \cdots\right)$$

$$= \frac{P}{D^\alpha} 6 \sum_{k \in \mathcal{K}} k^{-\frac{\alpha}{2}}$$

$$\mathcal{K} = \{1, 3, 4, 7, 9, 12, 13, \cdots\}$$

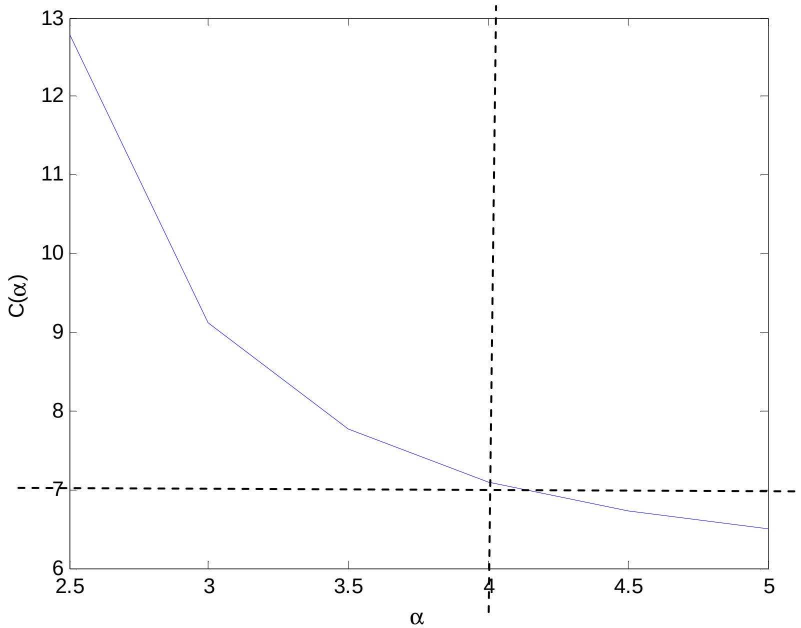
SINR

- Define

$$C(\alpha) = 6\sum_{k\in\mathcal{K}} k^{-\frac{\alpha}{2}}$$

If $\alpha>2$, $C(\alpha)<1$

- The larger α, the smaller co-channel interference. That is, the better the isolation between cells.



- In macro cellular environment

$\alpha < 4$ and $C(\alpha) > 7$

SINR

- The SINR can now be written as

$$\Gamma = \left(\frac{D}{R}\right)^{\alpha} \frac{1}{C(\alpha) + \frac{N}{P} D^{\alpha}}$$

- If N/P $\rightarrow$ 0, the system capacity is *interference limited*

$$\Gamma \approx \left(\frac{D}{R}\right)^{\alpha} \frac{1}{C(\alpha)}$$

- Recall that $D = \sqrt{3K}R$

$$\Gamma \approx (\sqrt{3K})^{\alpha} \frac{1}{C(\alpha)}$$

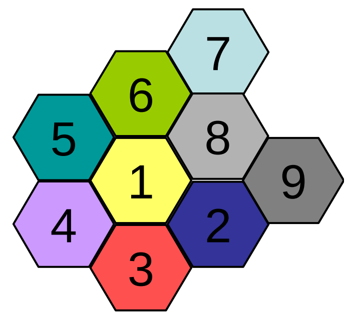
Frequency planning example

- Number of channels C=100
- Required SINR = 20 dB => $\Gamma = 10^{\frac{20}{10}} = 100$
- Propagation exponent α = 4 => C(α) ~ 7

$$\Gamma \approx (\sqrt{3K})^{\alpha}\frac{1}{C(\alpha)} \approx \frac{9}{7}K^2 = 100$$

- Solving for K yields $K = \sqrt{100\frac{7}{9}} \approx 8.8$
- The closest $\mathcal{K} = \{1, 3, 4, 7, 9, 12, \cdots\}$ is K=9
- Hence the cluster size K=9
- Number of channels per cell is then $c = \lfloor \frac{C}{K} \rfloor = 11$

$\lfloor . \rfloor$ denots the floor-operator (round down)



SINR

- If N/P>> C(α) the system is called *range limited* or *noise limited*

$$\Gamma \approx \left(\frac{1}{R}\right)^{\alpha} \frac{P}{N}$$

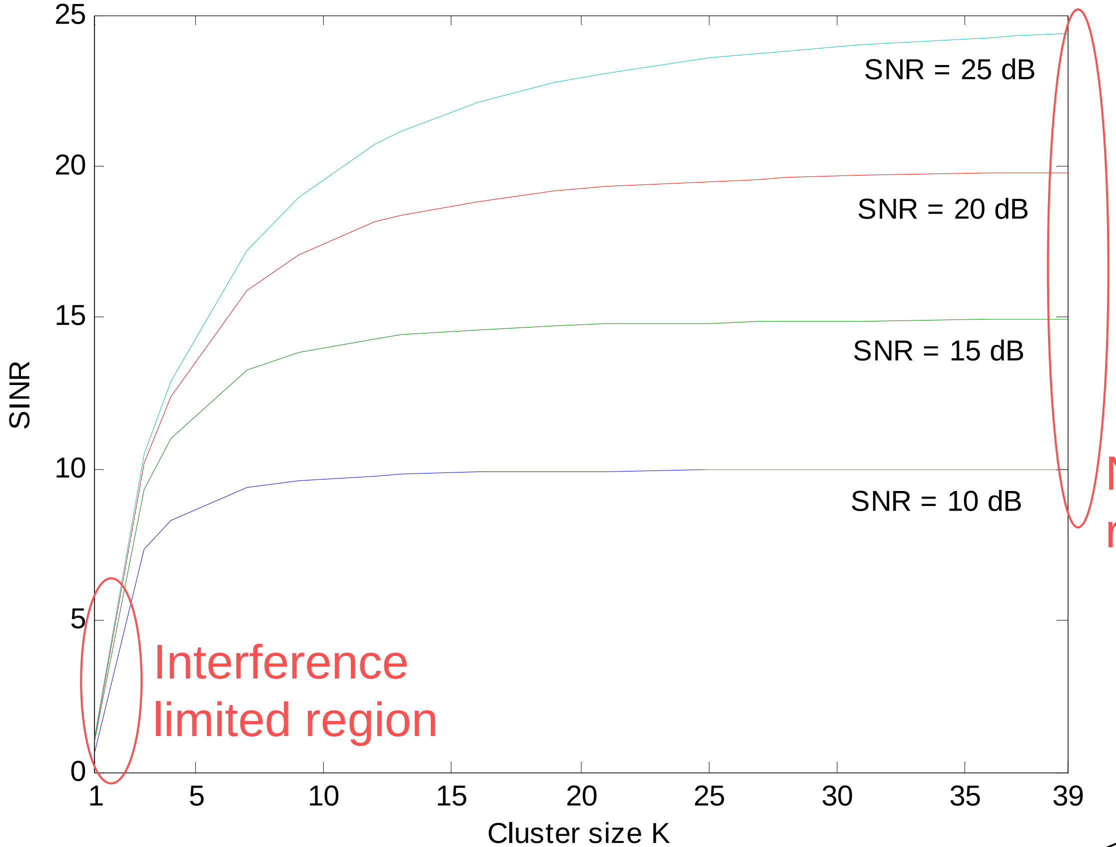
- Cell radius R is bounded by

$$R \approx \left(\frac{1}{\Gamma}\frac{P}{N}\right)^{\frac{1}{\alpha}}$$

  - The larger the required SINR, the smaller the cell radius.

Frequency planning

- SINR as a function of cluster size K



$SNR = R^{-\alpha}P/N$

Signal-to-noise ratio

on the cell edge

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

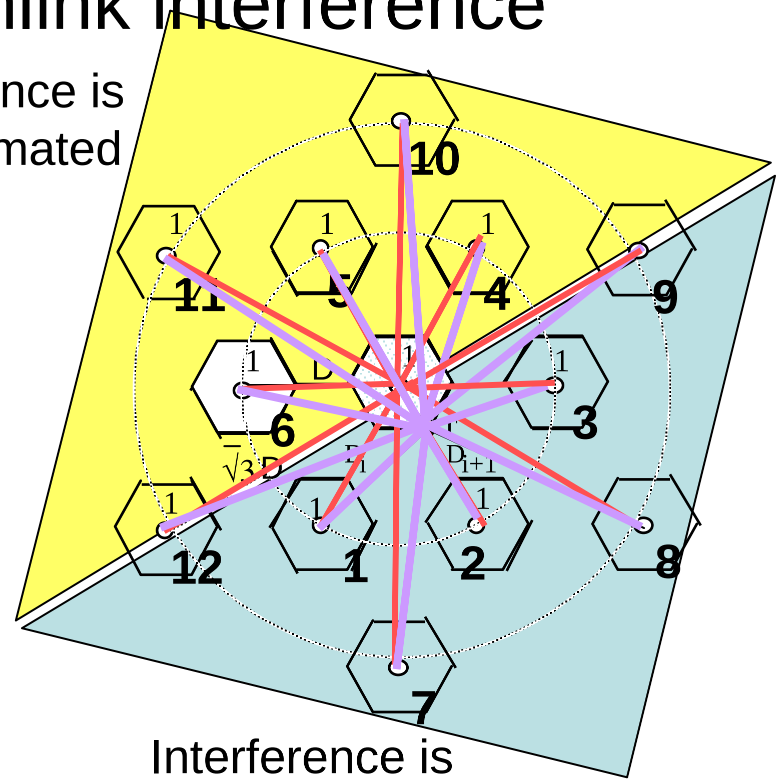
$$\Gamma = \left(\frac{D}{R}\right)^{\alpha} \frac{1}{C(\alpha) + \frac{N}{P}D^{\alpha}} = \left(\frac{D}{R}\right)^{\alpha} \frac{1}{C(\alpha) + \left(\frac{D}{R}\right)^{\alpha} \frac{1}{SNR}}$$

SINR

- The derived interference model can serve as an approximation for downlink interference

Interference is overestimated

Aggregate interference is close to the real value



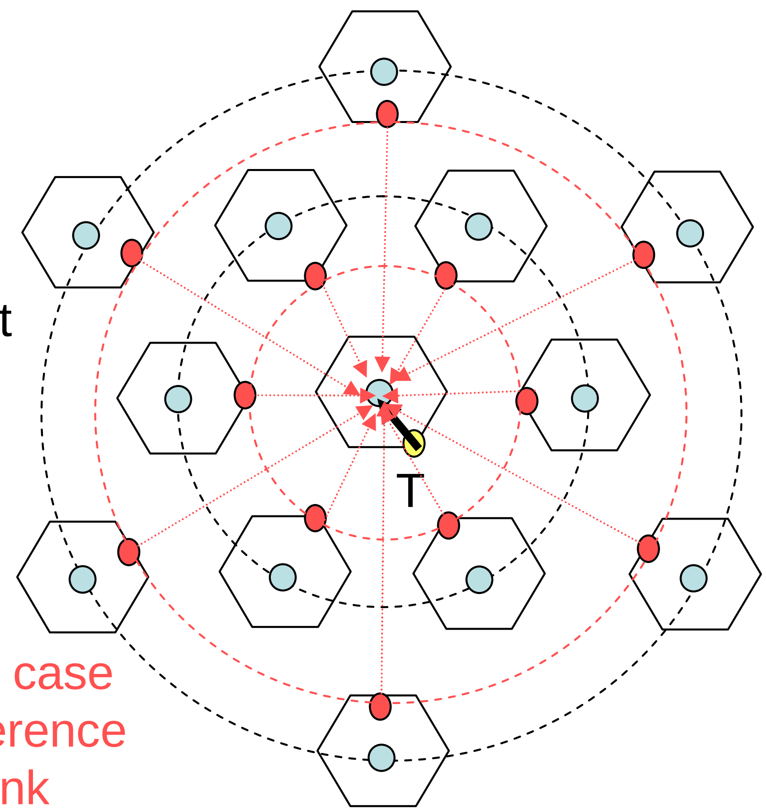
Interference is underestimated

SINR/uplink, worst case

- In worst case interference comes from users on the cell edge

$$\Gamma \geq \frac{PR^{-\alpha}}{\sum_j (D_j - R)^{-\alpha} P + N}$$

α	attenuation exponent α=2 in free space α up to 4 in macro cell environment
P	Transmit power
N	Noise power
R	cell radius
D	reuse distance
D_i	distance to base station i

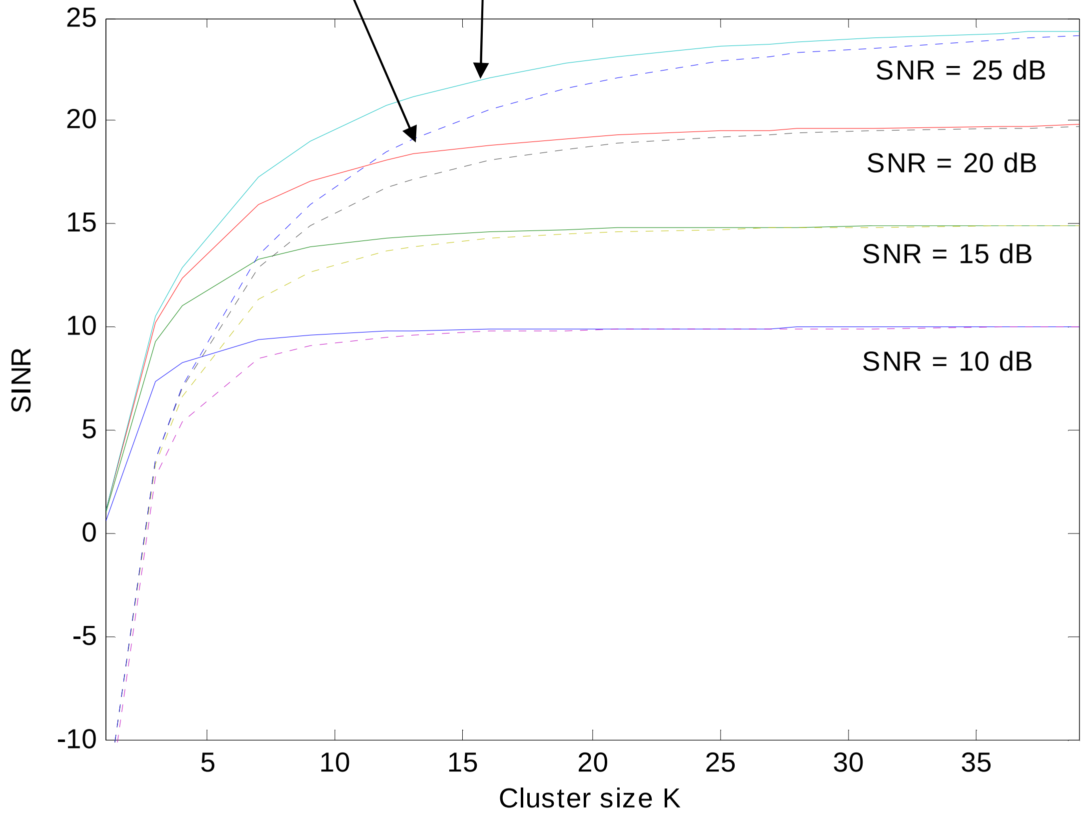


Worst case interference in uplink

Worst case analysis

Worst case uplink interference (dotted line)

Average uplink interference < downlink case



SNR = $R^{-\alpha}P/N$

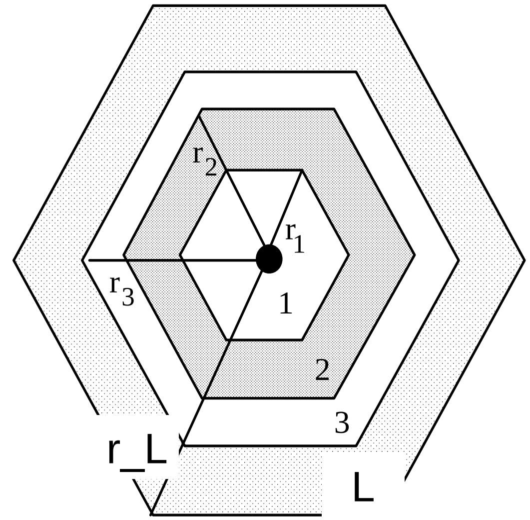
Signal-to-noise ratio

on the cell edge

Reuse partitioning and fractional reuse

Reuse Partitioning

- Overlaid cell plans with different reuse distances chose channel based on received signal strength RSS.
- Mobiles with high RSS may use channels with higher interference while mobiles with low RSS use low interference channels.



$$\Gamma_l = \left(\frac{D_l}{r_l}\right)^{\alpha} \frac{1}{C(\alpha) + \frac{N}{P} D_l^{\alpha}}$$

$$D_l = \sqrt{3K_l} R$$

Reuse Partitioning

- Number of channels in zone l: c_l
- Cluster size utilized in zone l: K_l
- Total number of channels allocated to cell

$$c = \sum_{l=1}^{L} c_l$$

- Total number of channels

$$C = \sum_{l=1}^{L} K_l c_l$$

- Gains of 50 -100% in capacity
- Most gain achieved by going from one to two "zones"

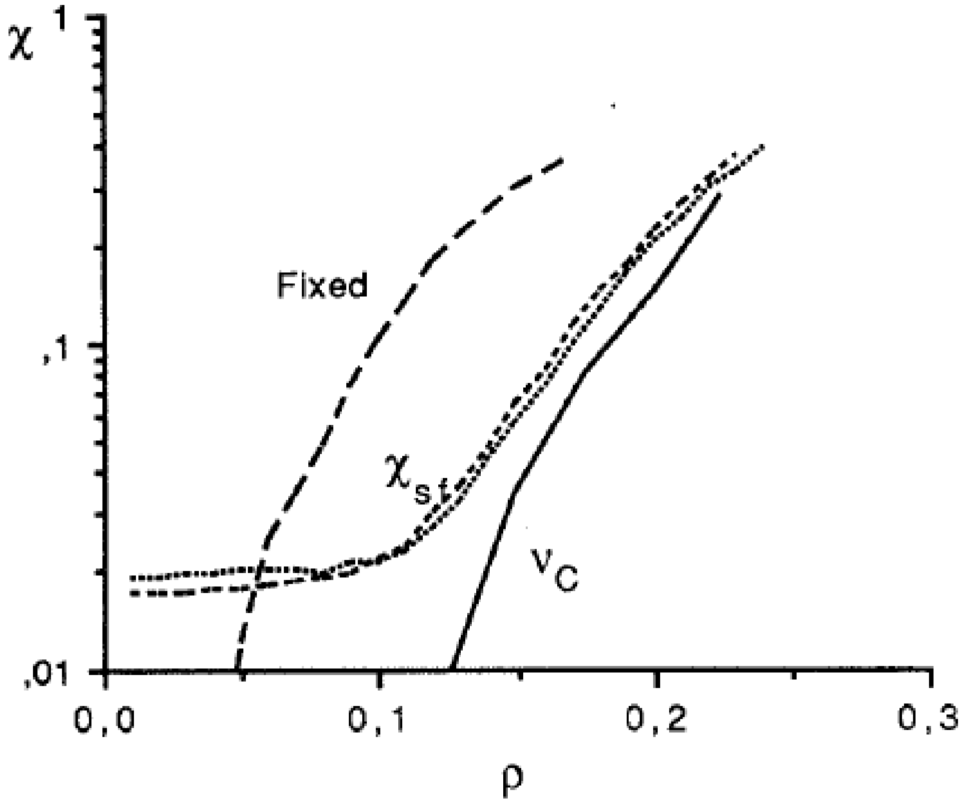
Reuse Partitioning

- Reuse partitioning will increase the average number of channels available to the mobiles.
- The number of mobiles in a zone is smaller than in single zone case. This will cause traffic variations to increase.
- In low traffic load, the effect of increased traffic variations will dominate leading to worse performance in terms of blocking than conventional scheme. (Trunking loss)
- In high traffic load, the effect of increased average number of channels will dominate leading to increased performance.

Reuse Partitioning

Channel Assignment Failure

Blocking Probability



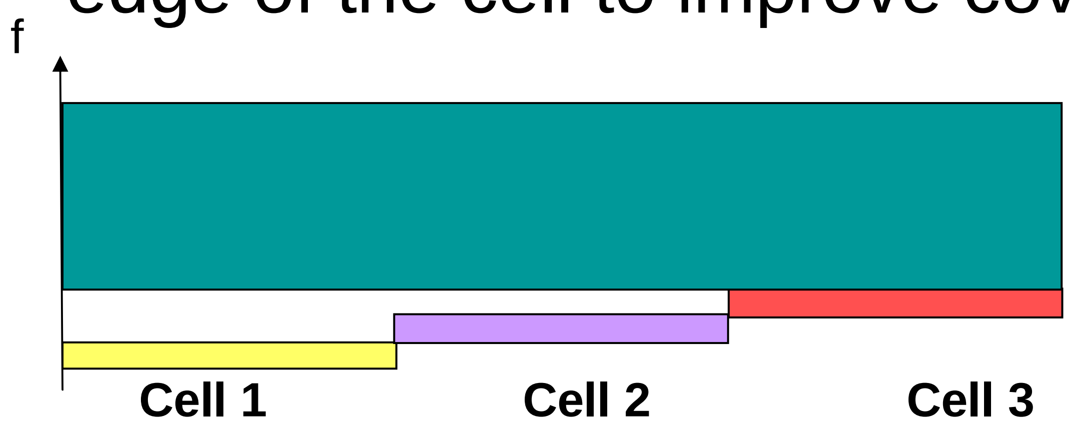
Offered traffic

Fig 1. Bonds for the link failure rate χ as function of relative load ρ compared with link failure rate for fixed assignment. Case I corresponds to lower of the two dotted curves.M=100 channels. γ_0 = 10 dB, **n** = (1,3,4,7,9), **c** = (2, 4, 2, 6, 4). σ = 6 dB, a=4.

Zander, J., "Generalized reuse partitioning in cellular mobile radio," *Vehicular Technology Conference, 1993 IEEE 43rd* , vol., no.pp.181-184, 18-20 May 1993

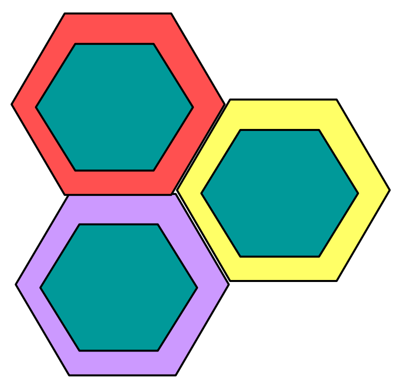
Fractional reuse

- In OFDMA systems the available sub-carriers constitute the channel pool that can be divided among the different zones.
- Typically close to the base station we want to have reuse K_1=1 and use larger reuse on the edge of the cell to improve coverage.



K_1=1

K_2=3



Frequency planning example

- Number of channels C=256
- Required SINR = 3 dB
- Propagation exponent $\alpha = 4 \Rightarrow C(\alpha) \sim 7$
- Cell radius R=700 m
- Transmit power per channel P= 16 dBm
- Noise power per channel -104 dBm
- Two zones
  - Zone 1: Universal reuse $K_1=1$, determine r_1
  - Zone 2: Determine K_2, $r_2=R=700$ m

Frequency planning example

- Required SINR

$$\Gamma_l = \left(\frac{D_l}{r_l}\right)^{\alpha} \frac{1}{C(\alpha) + \frac{N}{P} D_l^{\alpha}} \geq \Gamma \Leftrightarrow r_l \leq \left(\frac{1}{\Gamma_l} \frac{D_l^{\alpha}}{C(\alpha) + \frac{N}{P} D_l^{\alpha}}\right)^{\frac{1}{\alpha}}$$

$$D_1 = \sqrt{3}R$$

- Zone 1:

$$r_l \leq \left(\frac{1}{\Gamma_l} \frac{D_l^{\alpha}}{C(\alpha) + \frac{N}{P} D_l^{\alpha}}\right)^{\frac{1}{\alpha}} \approx 586 \text{ m}$$

Frequency reuse example

- Zone 2
  - SINR $D_2 = \sqrt{3K} r_2$

$$\Gamma_2 = \left(\frac{D_2}{r_2}\right)^{\alpha} \frac{1}{C(\alpha) + \frac{N}{P} D_2^{\alpha}} \geq \Gamma$$

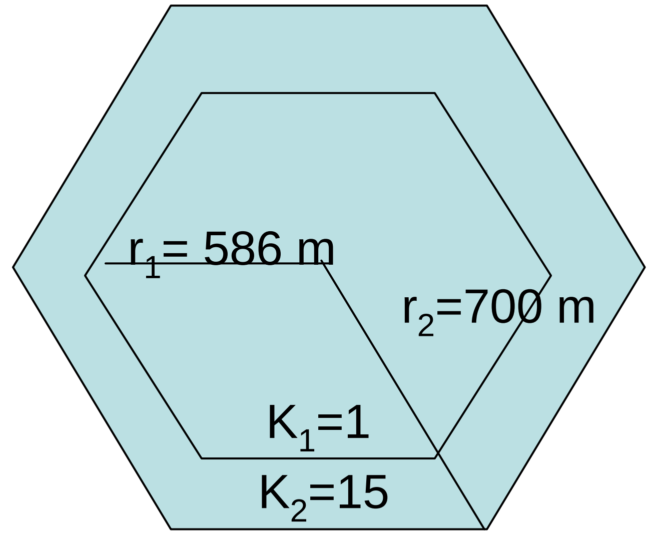
$$\gamma = \frac{P}{N} r^{\alpha}$$

SNR on the cell edge

$$\Gamma_2 = \left(\sqrt{3K}\right)^{\alpha} \frac{1}{C(\alpha) + \underbrace{\frac{N}{P} r^{\alpha}}_{\gamma^{-1}} \left(\sqrt{3K}\right)^{\alpha}}$$

$$K = \frac{1}{\sqrt{3}} \left(\frac{\Gamma_2 C(\alpha)}{1 - \Gamma_2 \gamma^{-1}}\right)^{\frac{1}{\alpha}} \approx 15.75 \Rightarrow K = 16$$

Frequency reuse example



- Frequency plan
  $C=256$
  $K_1c_1+K_2c_2=C$
  $c_2=(C-c_1)/K_2$
- Feasible allocations
  - No reuse partitioning:
    $c=c_2=C/K_2$ = 16 channels per cell
  - Reuse partitioning:
    $c_2=(C-c_1)/K_2$ = 1,2,…,15 channels per zone and cell
    c_1=240, 224,…, 16 channels per zone and cell

Frequency reuse example