Introduction and technological Fundamentals Cellular Principle

Content - Fundamentals - Cellular Principle

- Motivation
- Clustering
- Frequency Reuse and Carrier to Co-channel Interference Ratio (C/I)
- Sectorization

Cellular Principle - Motivation

- **What means “cellular”?**
  - segmentation of the coverage area into zones (so called cells)
- **The maximum cell diameter is limited by**
  - path loss
  - maximum transmitted power / minimal required received power
- **The usable frequency spectrum for mobile communication is limited**
  - therefore: efficient usage is essential
  - thus: reuse of channels at a sufficient distance
- **Properties of first mobile communication systems**
  - large coverage with high radio towers and high transmission power
  - low capacity (low number of concurrent users) per area

Cellular Principle - Technical Background

- **Principle: limitation of the cell coverage area (by transmission power limitation) and frequency reuse in cells at sufficient distance**
  - the received power decreases proportional to the distance between sender and receiver
    - example: Okumura-Hata path loss model, urban environment, base station with 30m height

$$L_{|dB|} = 10\log\left(\frac{P_t}{P_r}\right) = A + B\log\left(d_{|km|}\right) - E$$

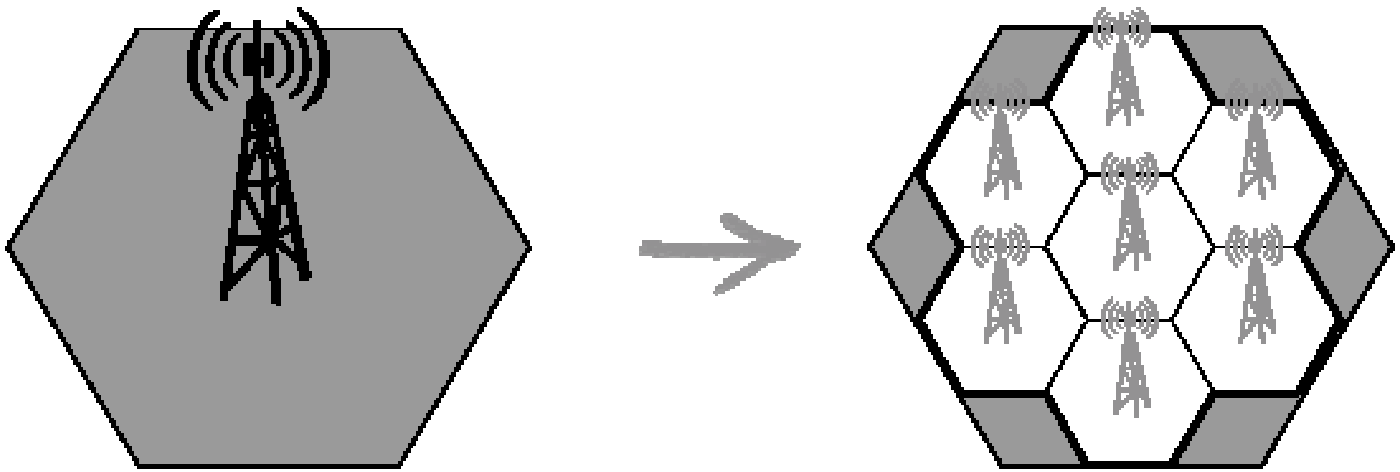
$$B = 44{,}9 - 6{,}55\log\left(h_b\right) = 35{,}22 \quad \text{for } h_b = 30\text{m}$$

$$\Rightarrow P_r \sim d^{-\gamma} \quad \text{here: propagation coefficient } \gamma = 3{,}522$$

  - frequency-reuse in cells at sufficient distance
    - no (or tolerable low) co-channel interference
    - capacity increase of the overall system

Cell Planning with hexagonal Cell Layout

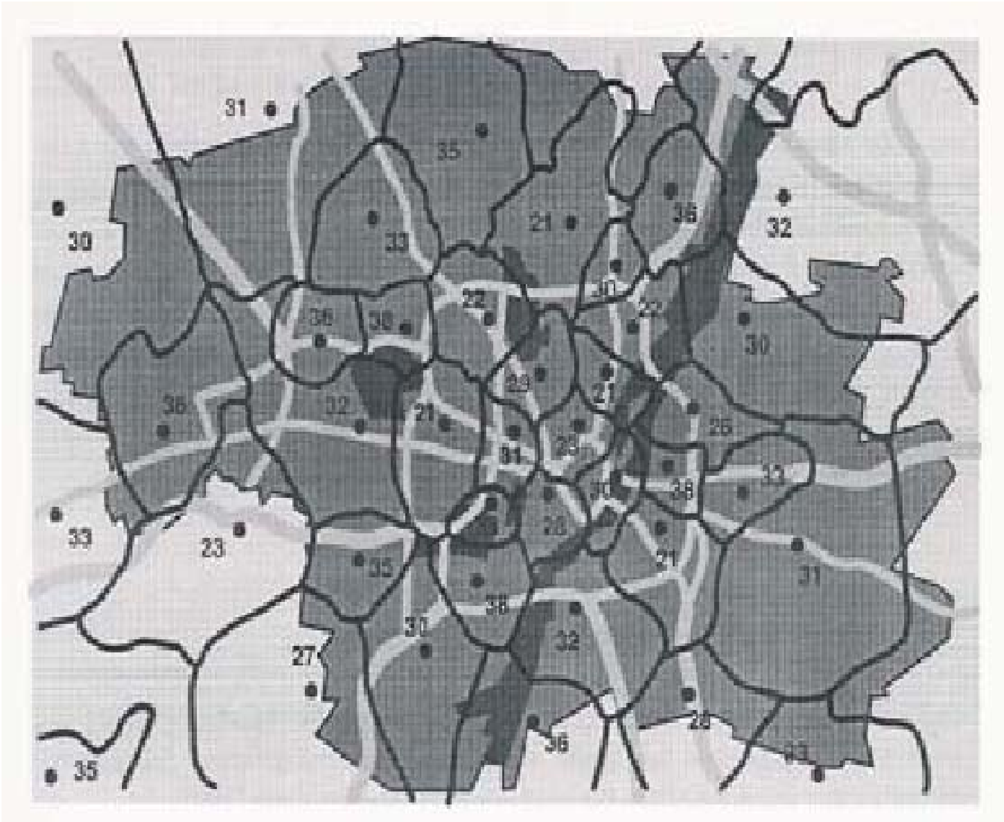
- **Radio cells are usually illustrated via hexagons**
  - this allows a complete and non-overlapping coverage of an area

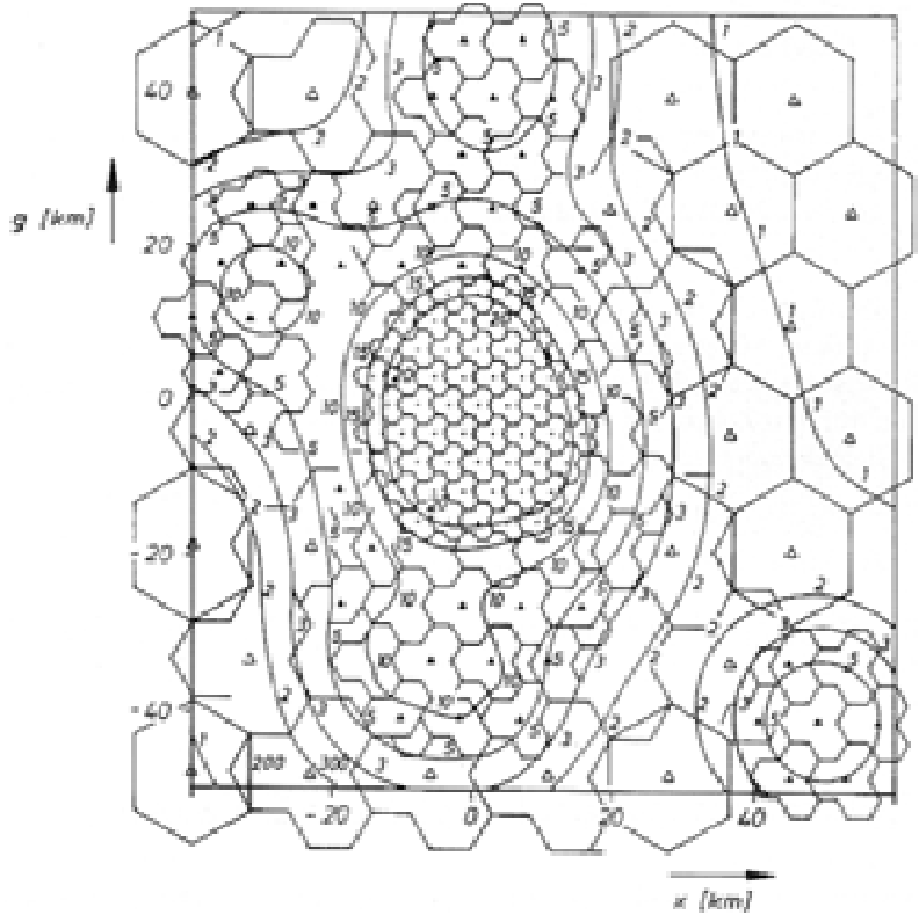


Cell Planning in Reality

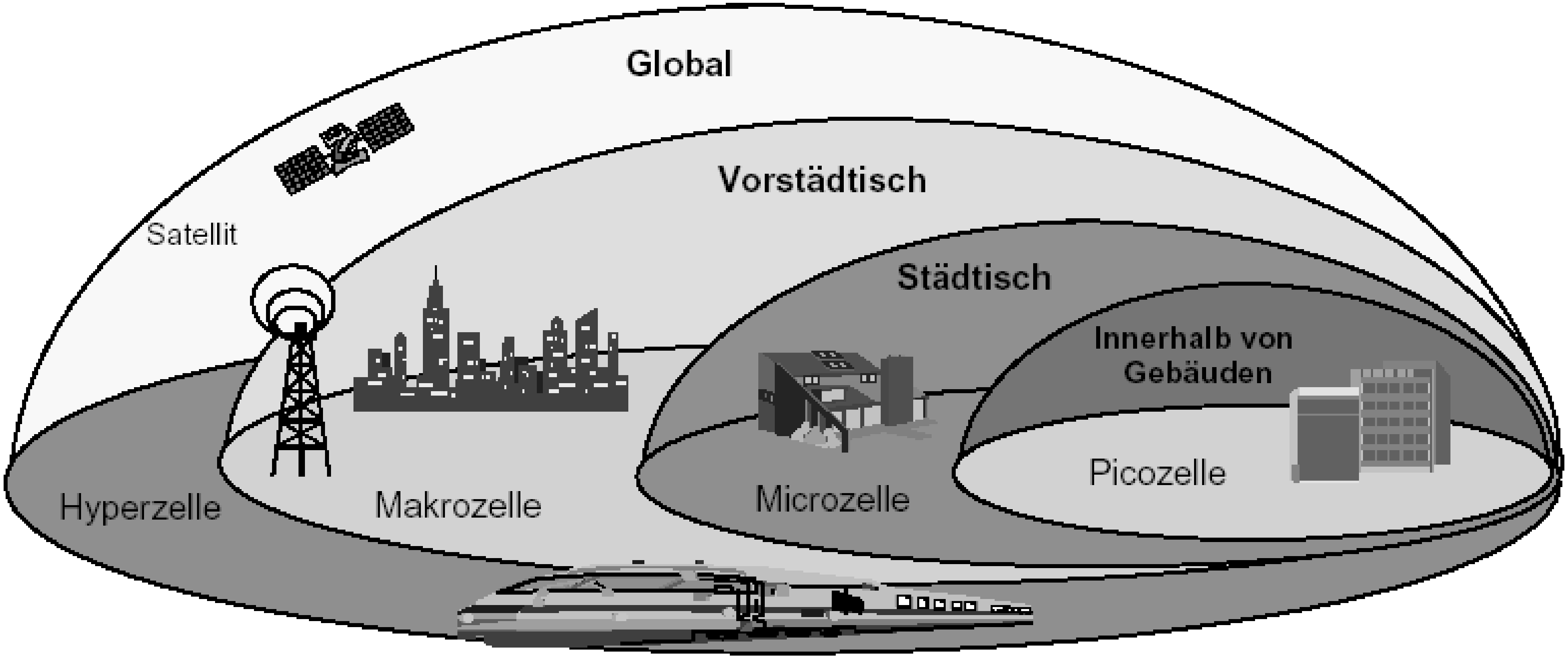
- **In reality:**
  - cells are not circular or hexagonal
  - overlapping cells are desired
    - reason: enables Handover without connection loss
  - the shape and size of a cell depends on the propagation conditions
    - influencing factors: topology of the landscape, building density
  - the subscriber density (and therefore the traffic demand) differs heavily from region to region
    - urban, sub-urban, rural environment
- **Typical approach in cell planning:**
  - starting first with large cells
    - fast coverage with minimal infrastructure (costs) → coverage-driven design
    - but: smaller system capacity
  - downsizing and sectorisation of cells in case of capacity shortage
    - → capacity-driven design

Cell Planning - Real Cell Layout Plan Examples





Cell Planning - Cell Hierarchy

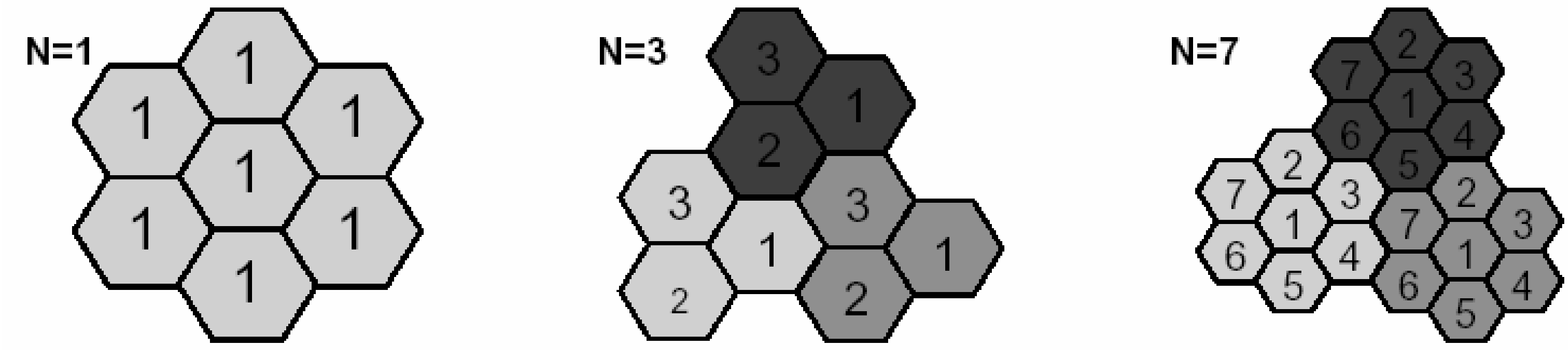


Clustering

- **Motivation: provide sufficient distance between cells that use the same resources (frequency channels) to guaratee an maximum tolerable co-channel interference**

  → grouping of cells into clusters (clustering)

  - area coverage is achieved by repeating the clusters



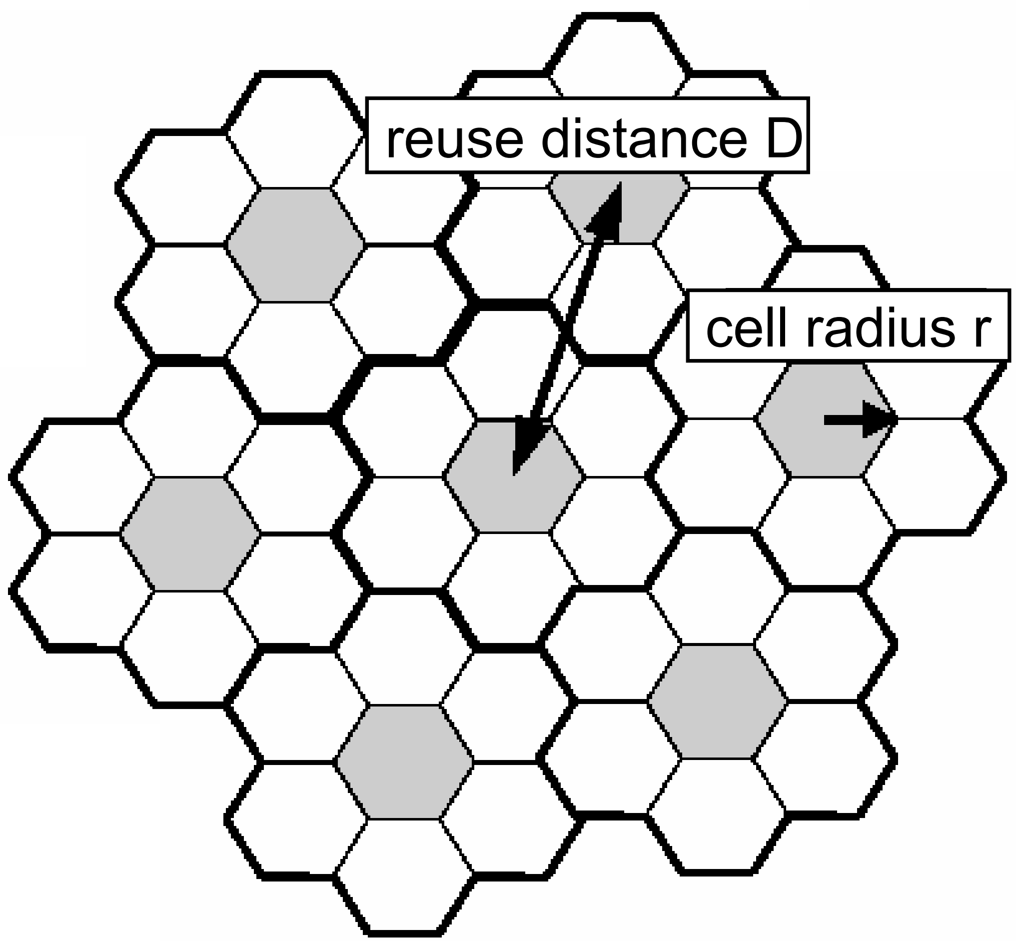
  - possible cluster sizes N:

    $N = i^2 + ij + j^2$ with $i, j \in \{0,1,2,3,\ldots\}$ and $i + j \neq 0$

Clustering - Reuse of Frequency Channels

- **Reuse distance D** in a uniform hexagonal layout:

$$D = r\sqrt{3 \cdot N}$$



- **Reuse factor q** in a hexagonal layout:

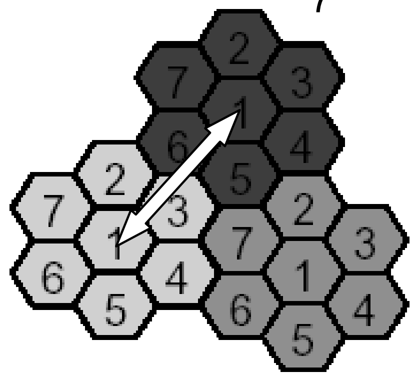
$$q = \frac{D}{r} = \sqrt{3 \cdot N}$$

- **Examples:**
  - N=7: reuse factor q=4,583
  - N=3: reuse factor q=3

Competing Goals of Clustering

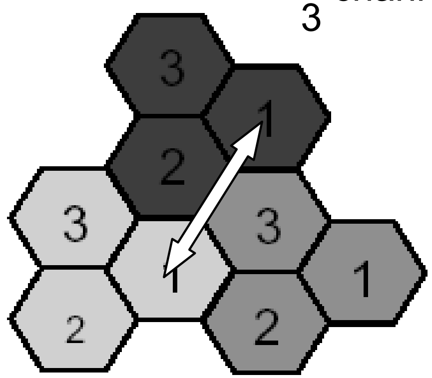
- **Goal: low co-channel interference (good decoupling)**
  - is achieved with large clusters (high reuse factor)
  - disadvantage: partitioning of the available cluster resources into many cells → decreasing share of the available system capacity per cell → "bundling" loss

$\frac{k}{7}$ channels per cell



- **Goal: high spectral efficiency** (i.e. serving as many subscribers as possible with the available spectrum)
  - is achieved through small clusters → big share of the available system capacity per cell → "bundling" gain
  - disadvantage: small clusters have a small reuse factor → higher co-channel interference (bad decoupling)

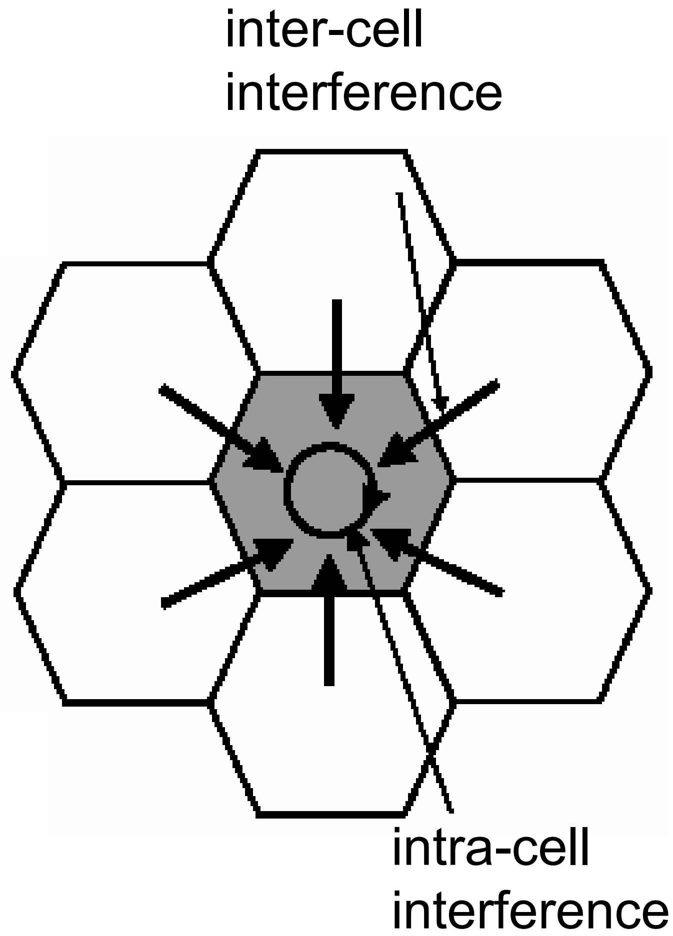
$\frac{k}{3}$ channels per cell



Inter- and Intra-Cell Interference

- **Uplink (to base station):**
  - **Inter-cell interference** is caused be mobile stations in neighboring cells. The interference is the sum of all received signals originating from users in other cells.
  - **Intra-cell interference** is caused by users in the same cell. The interference is the sum of the energy emitted by all mobile stations in the cell, except the energy emitted by the mobile station considered.

- **Downlink (to mobile station):**
  - **Inter-cell interference** is caused by base stations of neighboring cells. The interference is the sum of all received signals from base stations of other cells.
  - **Intra-cell interference** is caused by the energy emitted by the base station to serve all mobile stations except the considered mobile station in the cell. The interference is the sum of the energy received by the mobile station except the energy of the signal destined to the mobile station.

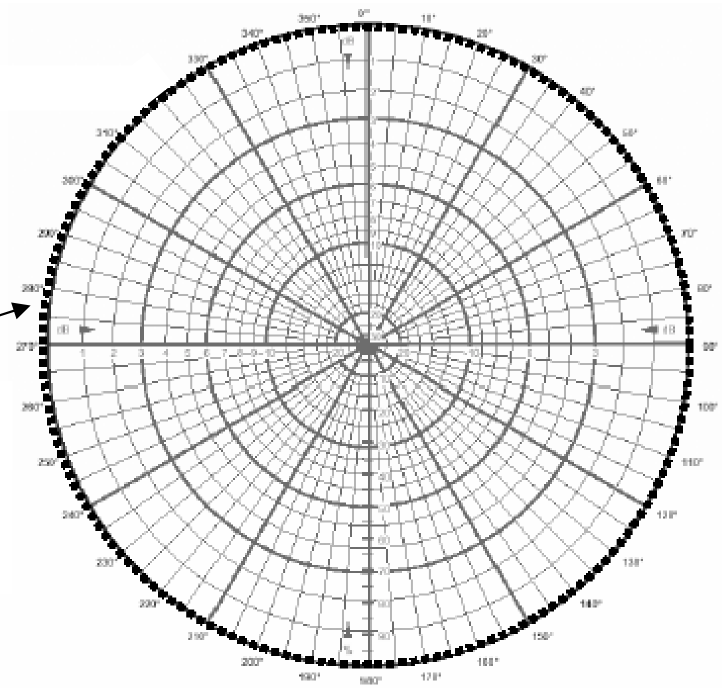


Cells with omnidirectional Antennas (hexagonal Layout)

- Uniform power radiation (by the base station)
- Equal received power in all directions

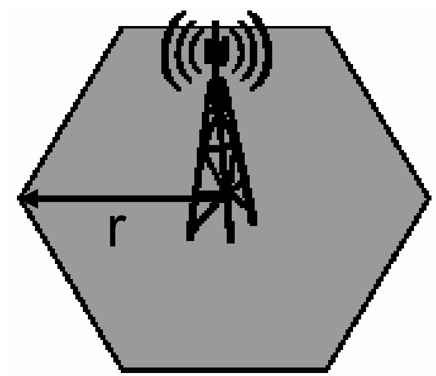
- Antenna diagram (omnidir. antenna):

antenna gain vs. direction angle



- **Cell area for hexagonal layout and one cell per base station:**

$$\boxed{A_{cell,omni} = \frac{3}{2}\sqrt{3}\cdot r^2}$$

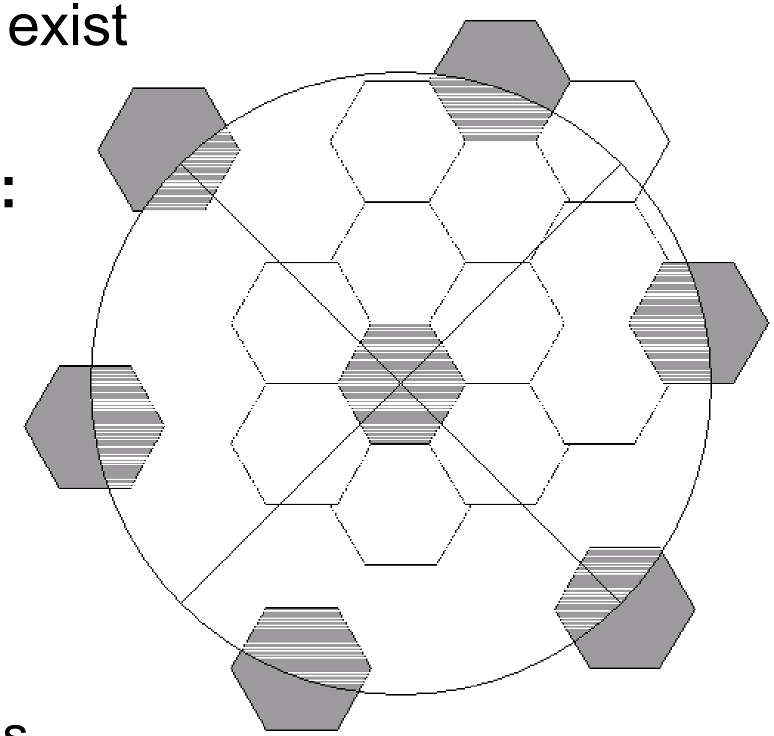


Carrier to Interference Ratio (C/I) for omnidirect. Antennas

- **Basic assumption: uniform hexagonal cell layout**

  → always exactly 6 close co-channel cells exist (independently of the cluster size)

- **Carrier to Co-channel Interference Ratio:**
  (C/I = CIR)

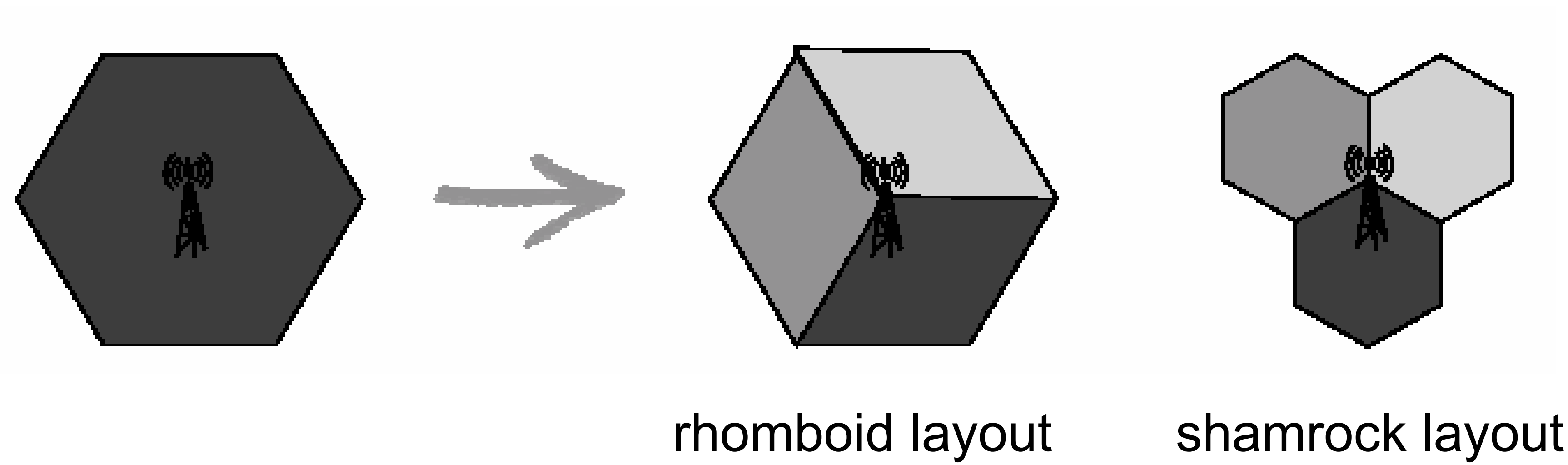


$$\frac{P_r}{P_{\text{co-channel interference}}} = \frac{C}{I} \approx \frac{1}{6} q^{\gamma}$$

- **Assumptions:**
  - D >> r
  - equal transmission power of all base stations
  - only the interference of the first-order co-channel cells is considered
- **Note:** the co-channel interference cannot be decreased by increasing the transmission power

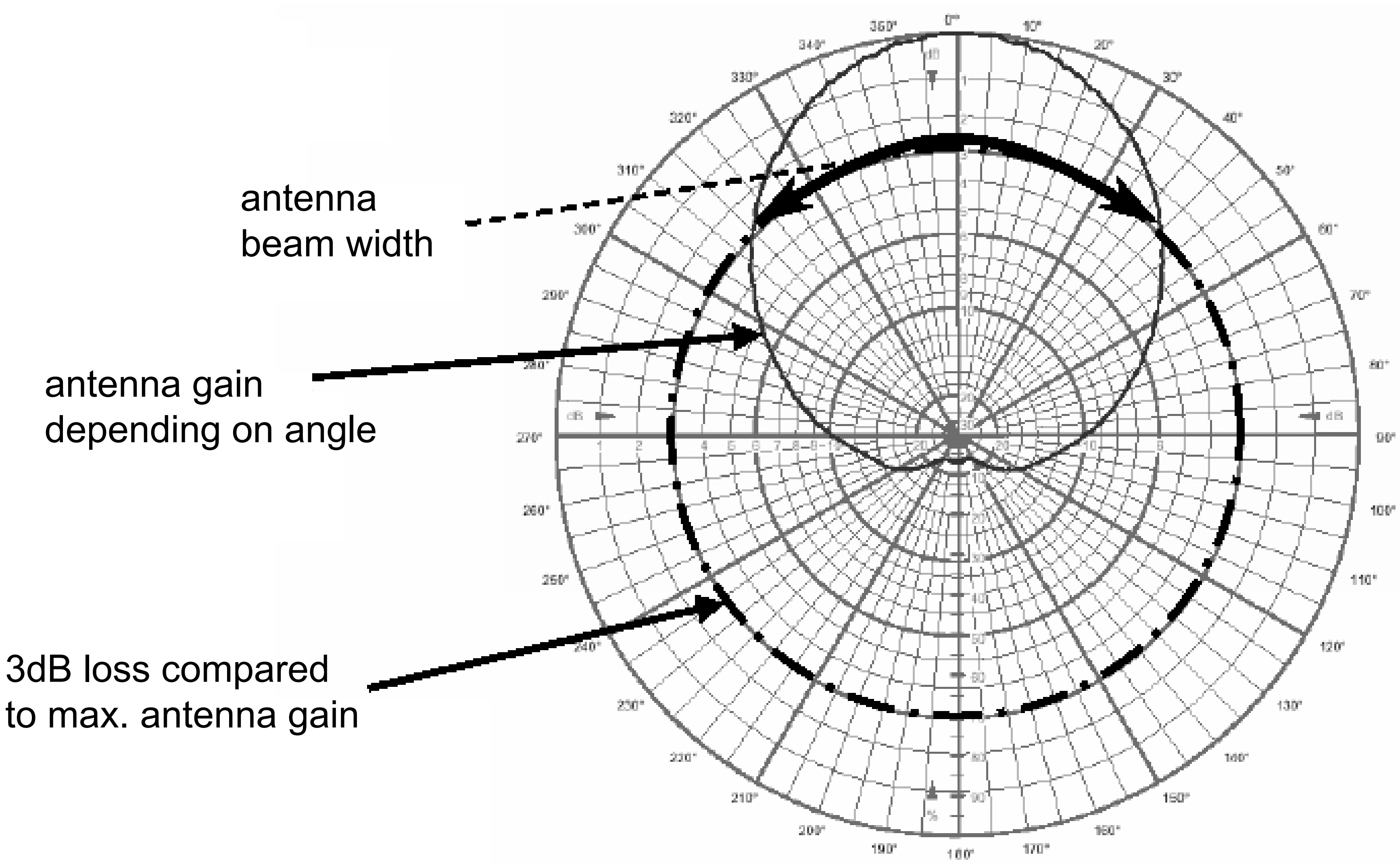
Cells with directional Antennas - Sectorization

- **Sectorization:** partitioning of the coverage area of a base station into several sectors by using directional antennas
- In practice: three (sometimes also four or six) sectors per base station
- **Advantage: interference reduction**
- **Sectors can be illustrated in two different ways:**
  - three rhomboid-shaped sectors per base station (**“rhomboid layout”**)
  - three hexagonal cells per base station (**“shamrock layout”**)



Directional Antennas

- Antenna diagram (directional antenna):



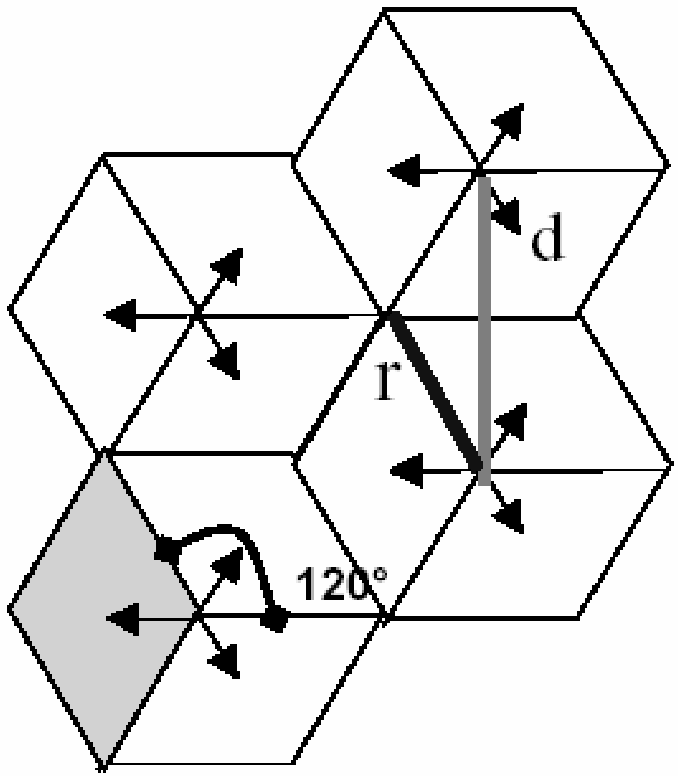
Sectorization and Rhomboid Layout

- **Distance d between two base stations (site-to-site distance) for a rhomboid layout and 3 cells per base station:**

$$d_{rhomboid} = 2 \cdot r \cdot \cos(30°) = 1{,}732 \cdot r$$

- **Cell area for a rhomboid layout and 3 cells per base station:**

$$A_{cell,\,rhomboid} = \frac{1}{2}\sqrt{3} \cdot r^2$$



note: the direction of the antenna main lobe is depicted by an arrow

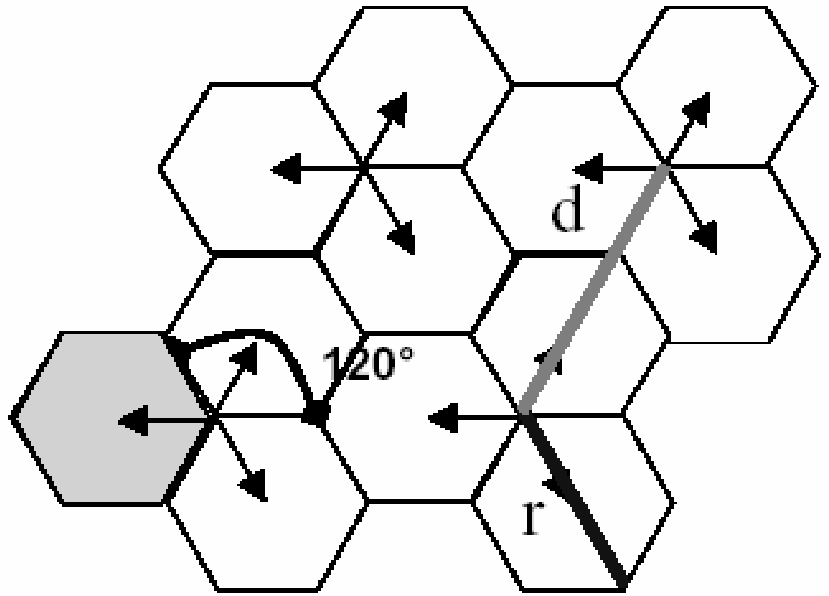
Sectorization and Shamrock Layout

- **Distance d between two base stations (site-to-site distance) for a shamrock layout and 3 cells per base station:**

$$\boxed{d_{shamrock} = 1{,}5 \cdot r}$$

- **Cell area for a shamrock layout and 3 cells per base station:**

$$\boxed{A_{cell,\,shamrock} = \frac{3 \cdot \sqrt{3}}{8} \cdot r^2}$$

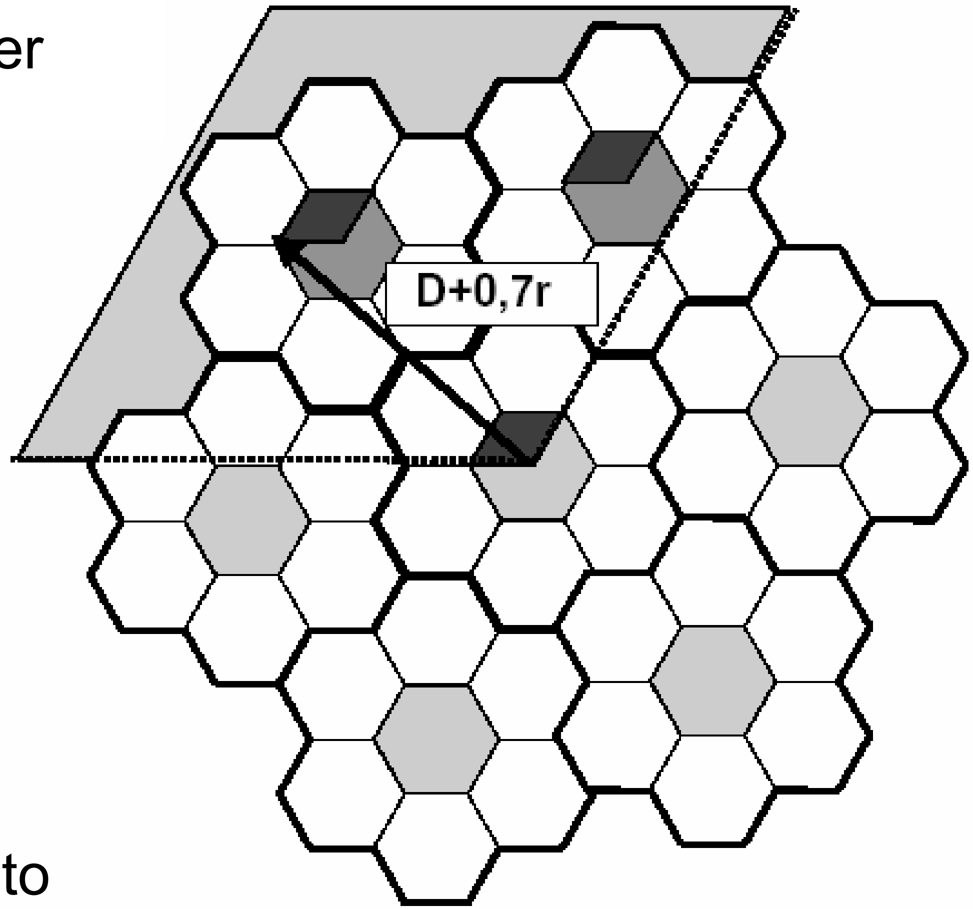


Carrier to Interference Ratio (C/I) for Sectorization

- The sectorized cell only causes interference to two of the six first order co-channel cells

- **Carrier to Co-channel Interference Ratio (C/I = CIR):**

$$\frac{P_r}{P_{\text{co-channel interference}}} = \frac{C}{I} \approx \frac{1}{(q+0{,}7)^{-\gamma} + q^{-\gamma}}$$



- **Example:** N=7, $\gamma = 3{,}522$

  the C/I improves by 5,7dB compared to the omnidirectional case