Mobilkommunikation - Mobile Communications

Lecture 3: Cellular Systems

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Outline

Space Division Multiplexing

Cell Geometry

Cochannel Interference

Cell Splitting

Space division multiplexing

Cellular systems implement space division multiplexing

- base stations cover a certain area called cell
- (mobile) stations within a cell communicate with the base station
- cells vary in size
  - from tens of meters, e.g. indoor in buildings
  - hundreds of meters, e.g. in cities
  - up to tens of kilometers, e.g. in rural areas
- ideally cells are circles modeled by non-overlapping hexagons
- in practice cells have complicated shape and overlap depending on
  - the environment, e.g. walls, buildings, mountains, etc.
  - weather conditions
  - even system load, e.g. CDM cells shrink due to interference if many codes are used, cells are said to "breathe"

Frequency reuse with hexagonal cells

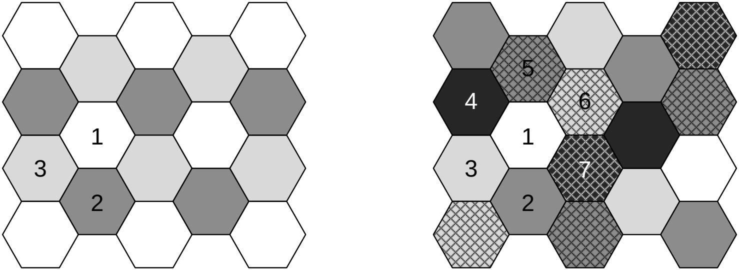


Figure: Ideal model using three resp. seven cell clustering

Cell clustering is done to avoid the reuse of frequencies within the interference range. All cells in a cluster use disjoint frequencies.

Cell size

Small cells achieve

- higher capacity [users/km^2] due to frequency reuse
- less transmission power saves energy in particular in battery operated mobile terminals
- interference is limited to smaller regions
- robustness since failures only affect small cells

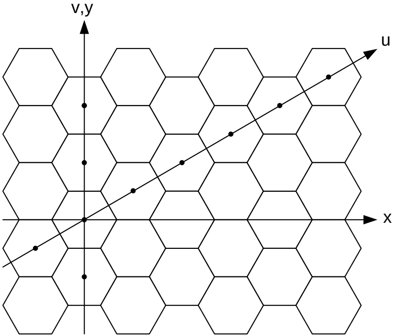
Large cells achieve

- less infrastructure needs, fewer base stations
- fewer handovers between cells

Outline

u-v coordinate system

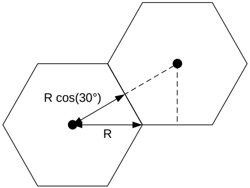
- $\angle$ (x-axis,u-axis) $= 30°$
- $x = u\cos(30°)$
- $y = u\,\sin(30°) + v$
- $\cos(30°) = \sqrt{3}/2$
- $\sin(30°) = \;1/2$
- d = distance from origin



$$
\begin{aligned}
d^2 &= x^2 + y^2 \\
&= (u\cos(30°))^2 + (u\sin(30°) + v)^2 \\
&= u^2 + uv + v^2
\end{aligned}
$$

Distance of cells

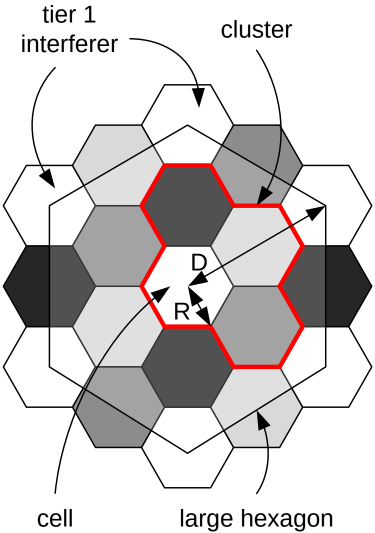
- the normalized center-to-center distance of two adjacent cells is 1, i.e. $(u = 1, v = 0)$ or $(u = 0, v = 1)$
- let $R =$ radius resp. center-to-vertex distance of a cell



- the center-to-center distance of two adjacent cells is $2R\cos(30°) = \sqrt{3}R$
- denote D the distance of a cell from the origin, then $D^2 = 3R^2(u^2 + uv + v^2)$

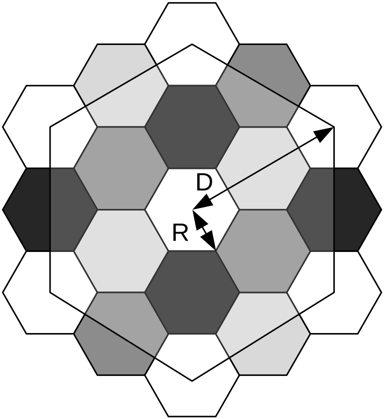
Notation

- N = cluster size
- (u, v) = reuse pattern
- Example: $N = 4$, $(u, v) = (2, 0)$
- Rotational symmetry: 6 tier-1 interferer
- R = cell radius
- D = cochannel separation $D^2 = 3R^2(u^2 + uv + v^2)$
- Goal: compute D as a function of N
- Idea: use the area of the large hexagon



Areas of the hexagons

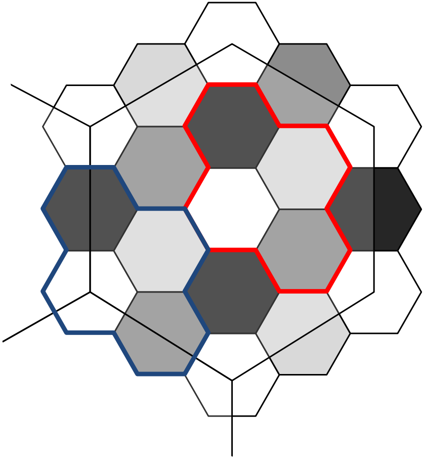
- area of a cell $A_c = kR^2$
- area of the large hexagon $A_h = kD^2$
- $k =$ constant
- $A_h / A_c = D^2 / R^2$



$N = 4, \ (u, v) = (2, 0)$

Reuse ratio

- N cells in the cluster at the center
- $6N$ cells in the 6 clusters of the tier-1 interferer
- the cluster of each interferer contributes to three large hexagons
- due to symmetry $6N/3$ cells are attributed to the hexagon in the center
- it follows that $A_h = 3NA_c$
- with the previous result $D/R = \sqrt{3N}$



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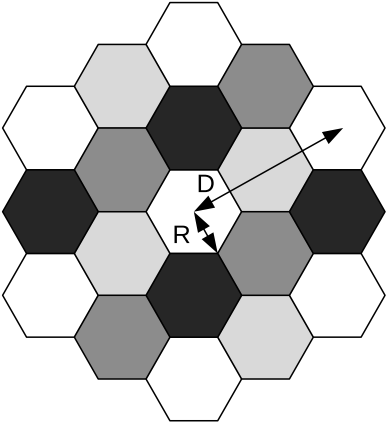
Some typical cluster sizes N and reuse ratios $D/R = \sqrt{3N}$

N	D/R	(u,v)
1	1.7	(1,0)
3	3.0	(1,1)
4	3.5	(2,0)
7	4.6	(2,1)
9	5.2	(3,0)
12	6.0	(2,2)



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Cochannel interference ratio

Using the hexagonal model there are generally six interfering cells that use the same channel in the first tier. Interference from higher tiers is usually comparably small and neglected here.

The signal to interference ratio can be written as

$$\frac{S}{I} = \frac{S}{\sum_{k=1}^{6} I_k}$$

where

- $S =$ signal power
- $I_k =$ power of the k-th interferer

Cochannel interference ratio (2)

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Inserting the path loss formula for signal and interference (assuming similar conditions for both) gives

$$\frac{S}{I} = \frac{\frac{c}{R^\gamma}}{6\frac{c}{D^\gamma}} = \frac{1}{6}\left(\frac{D}{R}\right)^\gamma$$

where

- $c =$ constant
- $\gamma =$ loss coefficient $\in [2 \ldots 5]$ depending on environment

Inserting $D/R = \sqrt{3N}$ it follows after reordering that

$$N = \frac{1}{3}\left(6\,\frac{S}{I}\right)^{2/\gamma}$$

i.e. given a target signal to interference ratio we can compute the minimum cluster size.

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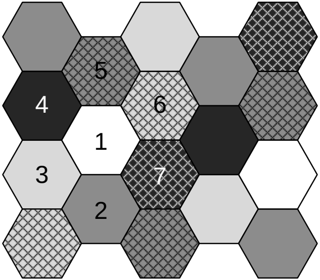
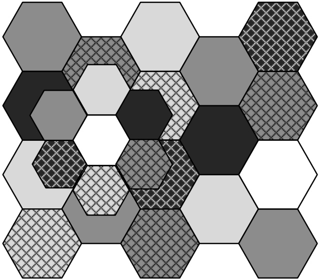
If the traffic load grows in the system, cells can be split to increase the reuse gain of SDM.





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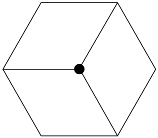
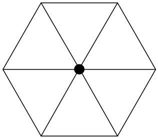
Directional antennas are used

- to split congested cells into smaller cells or
- to sectorize cells to reduce cochannel interference

A sectorized cell is typically divided into

- three 120° sectors
- six 60° sectors





Literature

- Jochen Schiller, Mobile Communications, Second Edition, Addison-Wesley, 2003.
- Vijay Garg, Wireless Communications & Networking, Morgan Kaufmann, 2007.