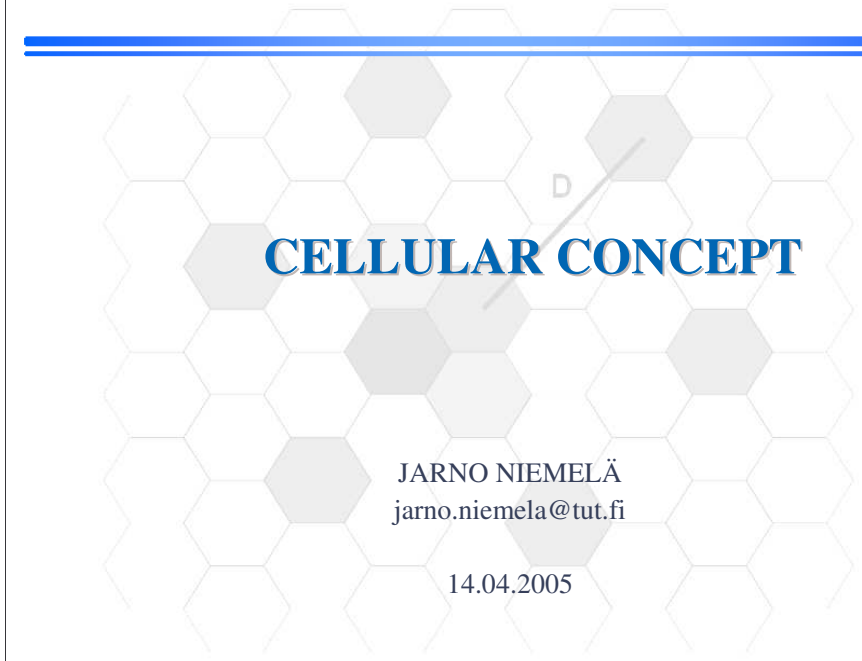


CELLULAR CONCEPT

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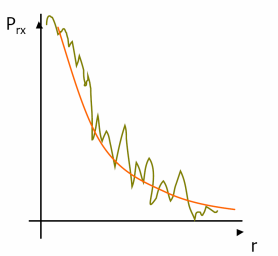
Outline

- Introduction
- Resource reuse (frequency reuse)
- Mobility
- Channel assignment
- Cell capacity
- Capacity enhancement methods
  - Antenna configuration
  - Microcells
  - SW methods
- GSM-planning example



Cellular concept

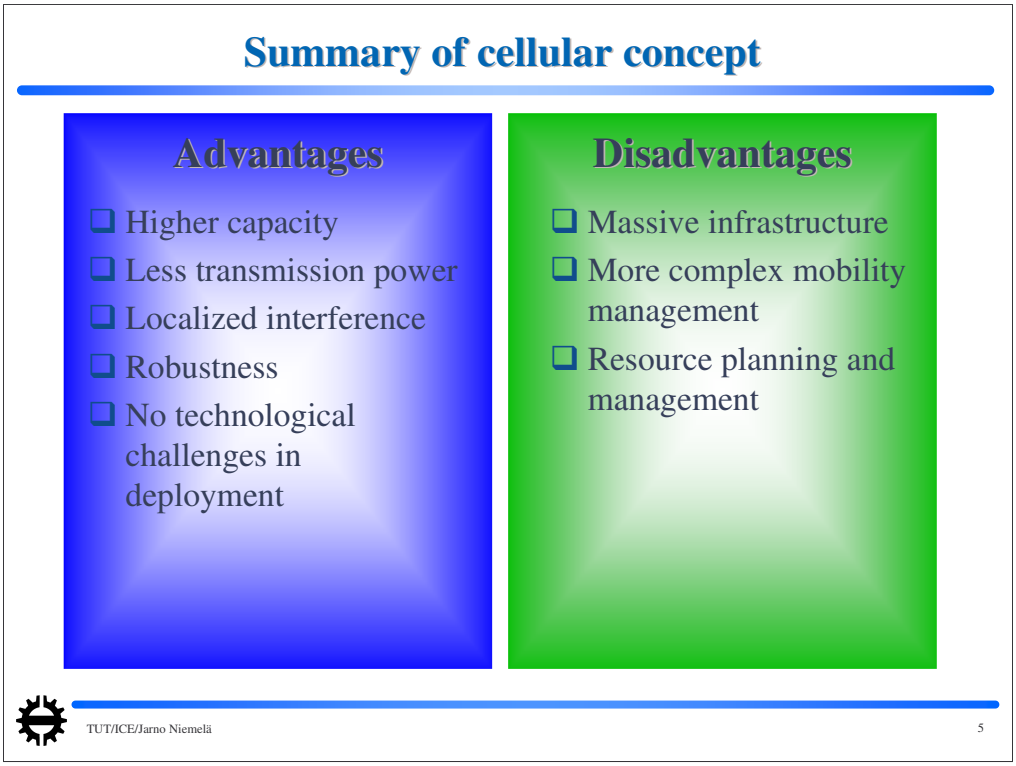
- Motivation: limited radio spectrum.
- The underlying idea of **cellular concept** is to divide the functionality of radio network to geometrically smaller areas; called cells.
- Adjacent/neighboring cells are assigned different resources.
- Radio signal attenuates as a function of distance → same resource (time slot/frequency/code) can be utilized again.
- Cellular concept is not limited to any particular access technology or system.



Definitions / terminology

- Resource reuse defines how often the same resource can be used.
- Concerning frequencies, resource reuse refers to **frequency reuse factor** that defines the distance between cells using the same frequency for communication.
- A **cell / sector** is a logical network element that uses given resources.
- A cell site (or site or base station) can include multiple of cells/sectors at the same physical location.
- Cell coverage is defined as geographical area where the cell is likely to serve mobiles.
- Network coverage refers to sum of individual cell coverages.





Advantages

- Higher capacity
  - More frequent resource utilization increases the capacity
- Less transmission power
  - Reduced cell sizes, less power needed to cover the cell area
  - Relaxed power amplifier specs at base stations
  - Longer life-time for mobile station batteries
- Localized interference
  - Due to smaller service areas of cells, interference is as well localized to a smaller area
- Robustness
  - In case that one cell is down, overlapping of cells guarantees that a mobile is able to get connected through other base stations
- No technological challenges in deployment
  - Major problems related to minimizing the implementation and operational expenses of the system
  - Technological challenges related to capacity improvement methods

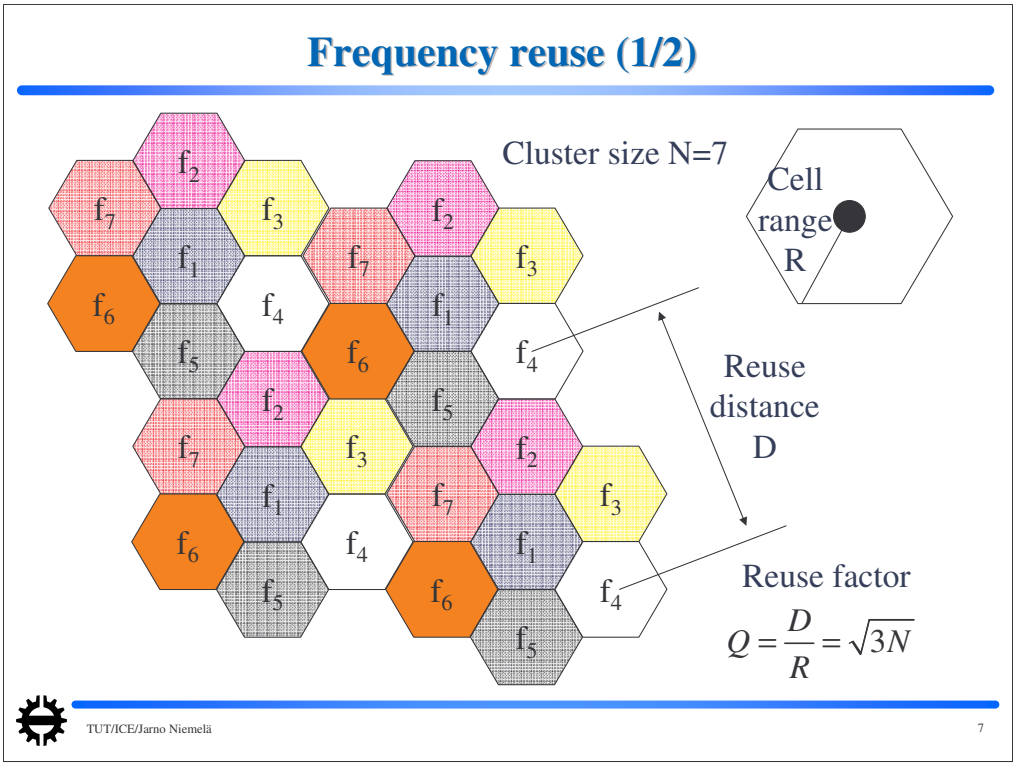
Disadvantages

- Massive infrastructure
  - Number of base stations increases, if more capacity is required
  - Lots of infrastructure needed also after radio air interface (location registers, switches, management servers etc.)
- More complex mobility management
  - Seamless connections throughout the network has to be provided → Handovers needed
  - Management of handover procedures might get complicated
- Resource planning and management
  - Tight resource planning strategy needed (time slots, frequencies)
  - Resource management needed to support resource planning

Resource reuse

- The fundamental idea of cellular concept is radio resource reuse.
- Radio resource can be time, frequency, code, space.
- Classical frequency division multiple access (FDMA) system taken as reference (as GSM).
- With a given set of frequencies, a service provider allocates resources such that
  - Frequency reuse factor is maximized (maximum capacity)
  - Mutual interference between the same frequencies at different locations is minimized (target quality)





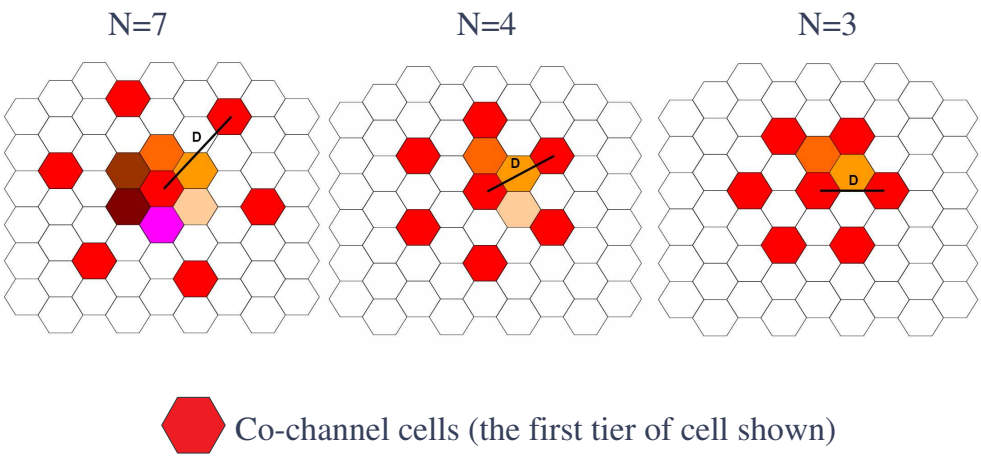
F_n can be a single frequency or a set of frequencies.

Frequency reuse (2/2)

- For each cell, a set of frequencies is allocated.
- A cell that use the same set of frequencies are denoted as **co-channel cells**, and the interference received from co-channel cells is called **co-channel interference**.
- A set of cells can be clustered, and the **cluster** can be repeated.
- One cluster should contain all the available frequencies.
- Reuse distance (Q) depends on the cluster size (N).



Examples of frequency reuse Q



Co-channel cells (the first tier of cell shown)

Interference and system capacity (1/2)

- Interference limits the system capacity and the performance of a single radio link.
- The higher is the interference level, the lower is the system capacity and poorer is the quality of communication links.
- Interference can origin from
  - Mobiles under the same cell
  - Mobile under different cell
  - Base stations operating at the same frequency (or in general using simultaneously the same resources)
  - From non-cellular systems
- Co-channel interference is the most problematic.
- Also adjacent channel interference affect the system capacity.
  - However, adjacent channel interference is also filtering problem, which can be decreased by assigning channels intelligently.



Interference and system capacity (2/2)

- Hence, the target of frequency (or resource) allocation is to plan frequency usage in such a manner that system capacity is maximized (i.e., frequencies should be utilized as frequently as possible).
- However, simultaneously the interference should be kept at adequate level.
- For cellular planning point of view, this can be achieved by providing as much **isolation** as possible between co-channel cells.



SIR (1/3)

- Signal strength from the serving cell is denoted as S and co-channel interference as I. The resulting relation is signal-to-interference ratio (SIR) that defines the quality of the signal.

$$\frac{S}{I} = \frac{S}{\sum_{j=1}^{J} I_j}$$

where I_j is the co-channel interference received from jth co-channel cell. For simplicity, if transmission powers (P) of all cells is assumed to be the same as well as radio signal attenuation equal from all cells, SIR can be written as

$$\frac{S}{I} = \frac{Pd_0^{-n}}{\sum_{j=1}^{J} Pd_j^{-n}} = \frac{d_0^{-n}}{\sum_{j=1}^{J} d_j^{-n}}$$



SIR (2/3)

where d_0 is the distance from the serving cell and d_j from the j[th] co-channel cell.

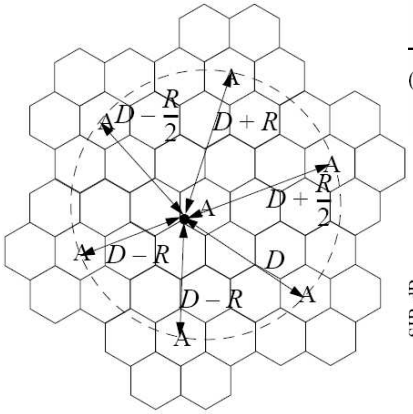
- Propagation exponent (n) varies according to environment (in free space n=2, in dense urban environment n=4)
- In simple scenario, where R is the distance from the serving cell, and D is the distance from the first tier of interfering co-channel cell, SIR can be expressed

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{j=1}^{J} D_j^{-n}} = \frac{\left(\frac{D}{R}\right)^n}{J} = \frac{Q^n}{J} = \frac{\left(\sqrt{3N}\right)^n}{6}$$



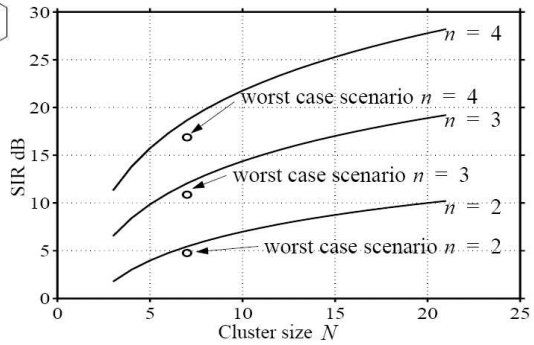
SIR (3/3)

Worst case scenario N=7



$$\frac{S}{I} = \frac{R^{-n}}{2(D-R)^{-n} + \left(D-\frac{R}{2}\right)^{-n} + \left(D+\frac{R}{2}\right)^{-n} + (D+R)^{-n} + D^{-n}}$$

$$\frac{1}{(Q-1)^{-n} + \left(Q-\frac{1}{2}\right)^{-n} + \left(Q+\frac{1}{2}\right)^{-n} + (Q+1)^{-n} + Q^{-n}}$$

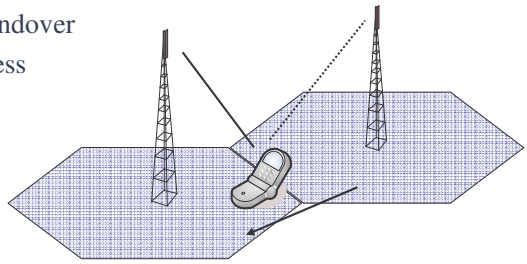


•Continuous line in the figure represent equidistant model for n=2,3,4 (n is propagation exponent)

•Worst case analysis provides 1-2 dB smaller SIR.

Mobility (1/2)

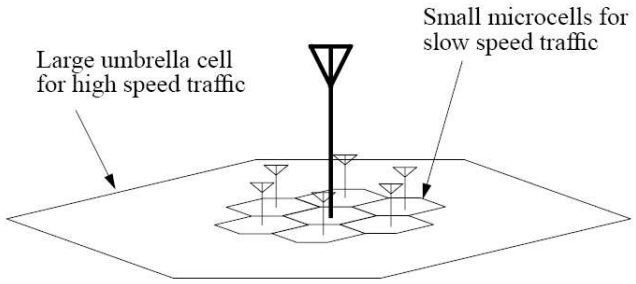
- Mobility within a cellular network is guaranteed with handovers.
- A **handover** (or handoff) refers to a situation where all radio resources of a connection are handed to another base station.
- A handover decision can be based either on power level or quality measurements according to some handover function.
- Parameters needed in handover process
  - Triggering method (power level, quality level, other reasons)
  - Thresholds for making handover
  - Target cell selection process





Mobility (2/2)

- A classical example of an 'umbrella cell', which can be used to serve high mobility users.
  - Note that this approach can be used only in FDMA/TDMA networks!
  - Also the frequency reuse factor of umbrella cell is larger.





Channel assignment (1/2)

- Within a certain frequency band (also called channel), users can be separated also in time-domain (this is actually the approach in GSM).
- One GSM channel includes 8 time slots.
- Channel assignment strategies include:

1) Fixed channel allocation (FCA)
   - Channels allocated permanently for each cell (predefined).
   - If all the channels are occupied, all new connection requests are blocked.

2) Dynamic channel allocation (DCA)
   - Channel are allocated on demand fashion from some centralized management function. This management function then decides according to an algorithm that when channels are allocated.
   - DCA can reduce the blocking probability, but the implementation is more complex.



Channel assignment (2/2)

3) Hybrid channel allocation (HCA)

- Part of the channels are permanently allocated, but the rest of the channels may be allocated dynamically
- For example in GSM/GPRS, certain channels reserved purely for voice (i.e., GSM) and the rest for GPRS.
- Another example is in UTRA TDD, where HCA can be utilized between uplink and downlink channels.



GPRS (General Packet Radio System)

UTRA TDD = UMTS terrestrial radio access frequency division duplex

•Time division version of 3rd generation UMTS system.

•Uplink and downlink direction uses the same frequency, but during different time slots.

•Depending on the traffic asymmetry between uplink and downlink, channels may be allocated dynamically.

•However, at least one uplink time slot and two downlink time slots out of 15 have to be allocated in FCA –fashion.

Capacity of cell (1/3)

- For circuit-switched traffic (such as regular voice call), required number of channels (and frequencies) of a cell can be defined using Erlang formulas.
- If $1/\lambda$ is the average lenght of a call (channel holding time) and $1/\mu$ is call interval time, the probability that a call is blocked/delayed is

Erlang B (without queuing)

$$p_B = \frac{\left(\frac{\lambda}{\mu}\right)^M}{\sum_{i=0}^{M} \frac{\left(\frac{\lambda}{\mu}\right)^i}{i!}}$$

Erlang C (with queuing)

$$p_C = \frac{\frac{\left(\frac{\lambda}{\mu}\right)^M}{(M-1)!\left[M-\left(\frac{\lambda}{\mu}\right)\right]}}{\frac{\left(\frac{\lambda}{\mu}\right)^M}{(M-1)!\left[M-\left(\frac{\lambda}{\mu}\right)\right]} + \sum_{i=0}^{M-1} \frac{\left(\frac{\lambda}{\mu}\right)^i}{i!}}$$

where M is the number of traffic channels.



Capacity of cell (2/3)

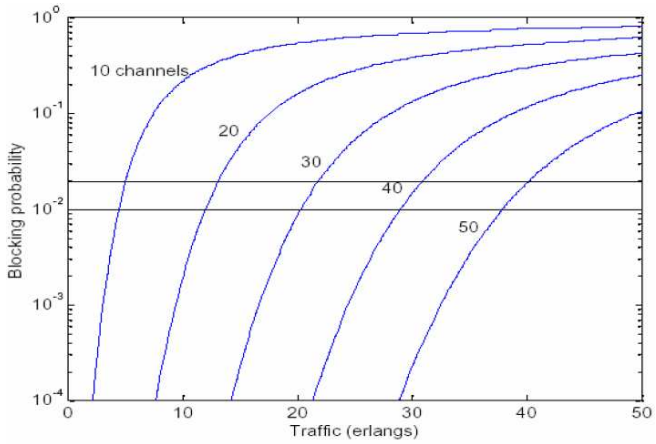
- Average call length is typically exponential function, whereas call arrival process is Poisson distributed.
- (λ/μ) is the normalized load in Erlangs.
- 1 Erlang is that one channel is occupied for an hour. For example, 100 users having an average call length of 90 s, the traffic generated from one user is 25 mErl (90s/3600s), and the total traffic 2.5 Erl.

CHs	1%	2%	3%	5%
1	0.01	0.02	0.03	0.05
2	0.15	0.22	0.28	0.38
3	0.46	0.60	0.72	0.90
4	0.87	1.09	1.26	1.52
5	1.36	1.66	1.88	2.22
6	1.91	2.28	2.54	2.96
7	2.50	2.94	3.25	3.75
8	3.13	3.63	3.99	4.54
9	3.78	4.34	4.75	5.37
10	4.46	5.08	5.53	6.22
11	5.16	5.84	6.33	7.08
12	5.88	6.61	7.14	7.95
13	6.61	7.40	7.97	8.83
14	7.35	8.20	8.80	9.73
15	8.11	9.01	9.65	10.60
16	8.88	9.83	10.50	11.50
17	9.65	10.70	11.40	12.50
18	10.40	11.50	12.20	13.40
19	11.20	12.30	13.10	14.30
20	12.00	13.20	14.00	15.20

CHs	1%	2%	3%	5%
21	12.80	14.00	14.90	16.20
22	13.70	14.90	15.80	17.10
23	14.50	15.80	16.70	18.10
24	15.30	16.60	17.60	19.00
25	16.10	17.50	18.50	20.00
26	17.00	18.40	19.40	20.90
27	17.80	19.30	20.30	21.90
28	18.60	20.20	21.20	22.90
29	19.50	21.00	22.10	23.80
30	20.30	21.90	23.10	24.80
31	21.20	22.80	24.00	25.80
32	22.00	23.70	24.90	26.70
33	22.90	24.60	25.80	27.70
34	23.80	25.50	26.80	28.70
35	24.60	26.40	27.70	29.70
36	25.50	27.30	28.60	30.70
37	26.40	28.30	29.60	31.60
38	27.30	29.20	30.50	32.60
39	28.10	30.10	31.50	33.60
40	29.00	31.00	32.40	34.60



Capacity of cell (3/3)





Example of capacity planning (1/2)

- The starting situation is to evaluate the number of base station required to support for a certain area depending on the traffic needs.
- An example plan for Hervanta
- What is possible capacity need?
  - 25 000 inhabitants
  - An operator has 40 % market share
  - 10000 potential customers
  - Every user is assumed to use 25 mErl
  - **Channel requirements** have to be dimensioned for 250 Erl
- How many frequencies can be used per cell (frequency reuse factor?)
  - An operator has **40 frequencies** in use



Example of capacity planning (2/2)

- C/I requirement for GSM (12 dB in specifications, lets use 14 dB)
- **Propagation exponent** for Hervanta (n=3)
- From slide 14, the required cluster size has to be 10. Hence, 10 is selected for frequency reuse factor
- This means that 40/10 = 4 frequencies can be used in each cell

❑ How many cell is needed?

- 4 frequencies mean in total 32 channel (lets reserve 2 for **signalling**)
- 30 **traffic channels** can support 20.30 Erl of traffic with 1% blocking probability (slide 19)
- Hence, 250 Erl / 20.30 Erl/cell = 12.3 cells → **13 cells** are required for Hervanta area.



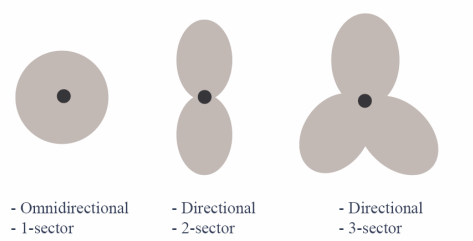
Capacity and quality enhancement methods

- System capacity can be improved by decreasing the frequency reuse factor and quality by improving SIR.
- System capacity or SIR can be improved by
  - Introducing multiple antennas at the base station site → sectoring
  - Minimization of out-of-cell interference (base station antenna characteristics)
  - Decreasing antenna height
  - Microcell deployment
  - SW methods
    - Frequency hopping
    - Underlay-overlay concept
    - Transmitter power control (only required TX power is used)
    - DTX



Sectoring (1/2)

- Sectoring implies to increasing the number of logical cells belonging to a single base station.
- Hence, one physical location (base station) includes multiple of antennas of the cells.
- Co-channel interference can be thus reduced.
- However, omni-directional antennas (1-sectored base station) has to be changed into directional ones.
- More intra-cell handovers



- Omnidirectional
- 1-sector

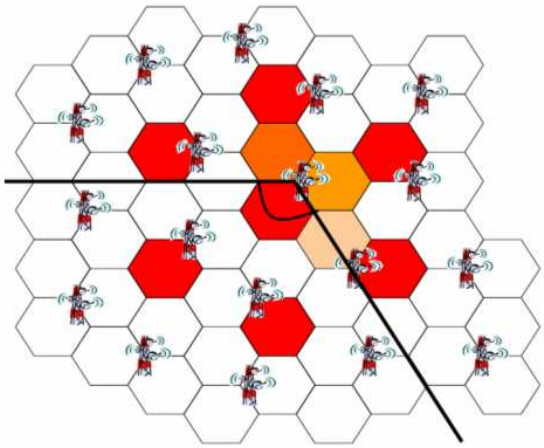
- Directional
- 2-sector

- Directional
- 3-sector



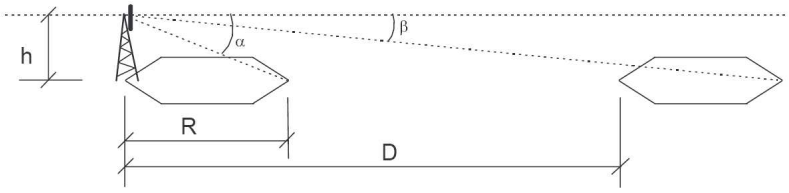
Sectoring (2/2)

- Illustration of reduction of co-channel interference in N=4 using 3-sectored base stations.



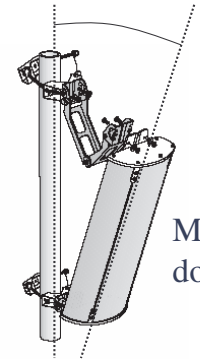
Antenna downtilt (1/2)

- The vertical radiation pattern of a base station antenna can be directed towards the ground in order to **reduce the power of co-channel interference**.
- This way most the radiated energy can be focused more clearly towards the users under the cell coverage are, instead of focusing the maximum power towards the horizon.
- Parameters as shape of vertical radiation pattern, antenna height, cell coverage area (length) affect on the selected downtilt angle.

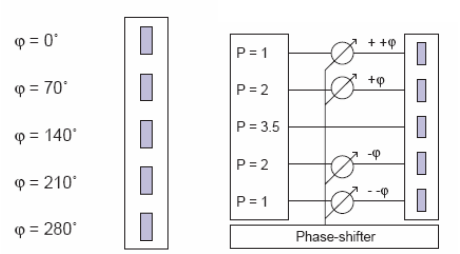


Antenna downtilt (2/2)

- Downtilt can be performed either **mechanically** or **electrically**.
- Mechanical downtilt relies on physical movement of an antenna, whereas electrical downtilt relies on relative phase shifts of different antenna elements in an antenna array.



Mechanical downtilt



Electrical downtilt

Source: *Basic antenna principles for mobile communications*; online catalogue; Kathrein.

Antenna horizontal beamwidth

- The radiation characteristics of a directional base station antenna affect the level of co-channel interference.
  - For example, in 3-sectored base stations, the cell serving area is 120º.
- Naturally, the selection of antenna depends on the applied sectoring scheme.

Slope 4	C/I	
Interferers	**120**	**65**
I1	19.2	20.3
I1, I2	18.8	19.8
I1, I2, I3	16.1	18.6
I1, I2, I3, I4	15.8	18.5
I1, I2, I3, I4, I5	15.6	18.2
I1, I2, I3, I4, I5, I6	15.6	18.1

	C/I [dB]	
Slope	**120**	**65**
2	4.2	6.2
2.5	7.2	9.3
3	**10.0**	**12.3**
3.5	12.8	15.3
4	15.6	18.1
4.5	18.2	20.9

Frequency reuse factor 9

Slope 4	C/I	
Interferers	**120**	**65**
I1	24.1	24.1
I1, I2	19.4	21.6
I1, I2, I3	18.9	21.1
I1, I2, I3, I4	18.8	20.9
I1, I2, I3, I4, I5	18.6	20.7
I1, I2, I3, I4, I5, I6	18.4	20.7

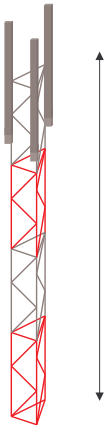
	C/I [dB]	
Slope	**120**	**65**
2	5.6	7.7
2.5	8.9	11.0
3	12.1	14.3
3.5	15.3	17.5
4	18.4	20.7
4.5	21.4	23.8

Frequency reuse factor 12

Tables provide information how the resulting C/I values for 120º and 65º antennas (horizontal half-power beamwidht) in different environment (n=slope=2..4.5). Moreover, for n=4, C/I is shown as a function of increasing number of interferers.

Antenna height

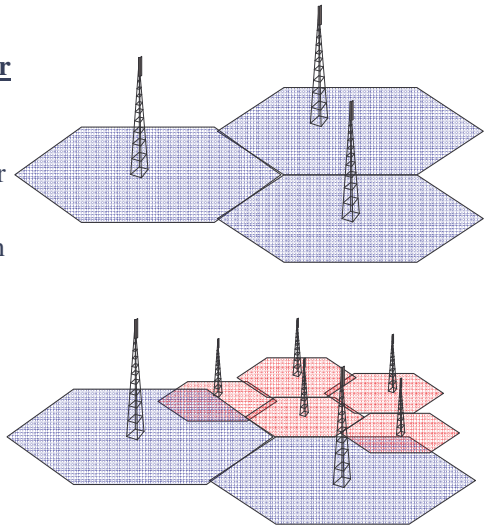
- Antenna position (height) affects the propagation characteristics of signal (mean propagation exponent).
- Moreover, with lower antenna position, a signal is more likely shadowed from mobile point of view.
- Higher antenna positions improve the coverage from the serving cell (i.e., *S* is higher).
- However, simultaneously co-channel interference (i.e., *I*) will increase.
- Hence, in the final deployment of a cellular network, antenna heights have to be optimized together with frequency reuse distance.





Microcell deployment

- A network having antennas above roof top level is referred to as **macrocellular** network.
- Deploying antennas below roof top level reduces the frequency reuse factor → **microcellular** network.
- Building prevent the signal propagation → co-channel interference reduced significantly.
- Simultaneously, cell coverage is reduced and more cells are needed to cover certain area.
- Frequency reuse factor can be 5-7.
- Microcell deployment is **expensive** solution.



SW methods

- Frequency hopping
  - Frequency hopping is based the usage of several frequencies
  - It reduces co-channel (and adjacent channel) through **interference averaging** (interference diversity)
- Overlay-underlay concept
  - Intelligent utilization of frequencies between macro and microlayer
  - Overlay frequencies for coverage, underlay frequencies capacity
- Power control
  - Transmission power controlled
  - Reduces interference
- Discontinuous transmission (DTX)
  - Transmission occurs only during speech
  - Average interference reduced

