Cellular Design Fundamentals : Part - II

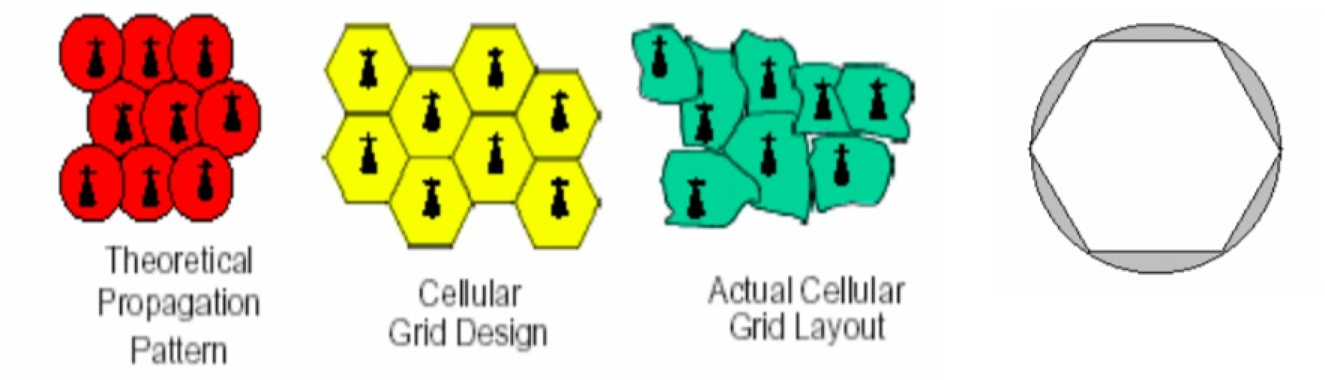
Objectives

① Why we use hexagonal tessellation patterns for characterizing & analyzing behavior of Cellular networks ?

② Explore more about frequency reuse

③ Derive SIR and use it for selecting size of cluster.

- Propagation models represent cell as a circular area
- Approximate cell coverage with a hexagon - allows easier analysis
- Frequency assignment of F MHz for the system
- The multiple access techniques translates F to T traffic channels
- Cluster of cells K = group of adjacent cells which use all of the systems frequency assignment

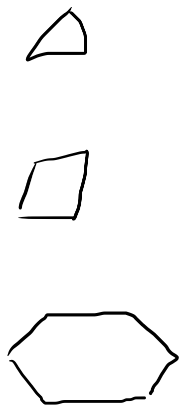


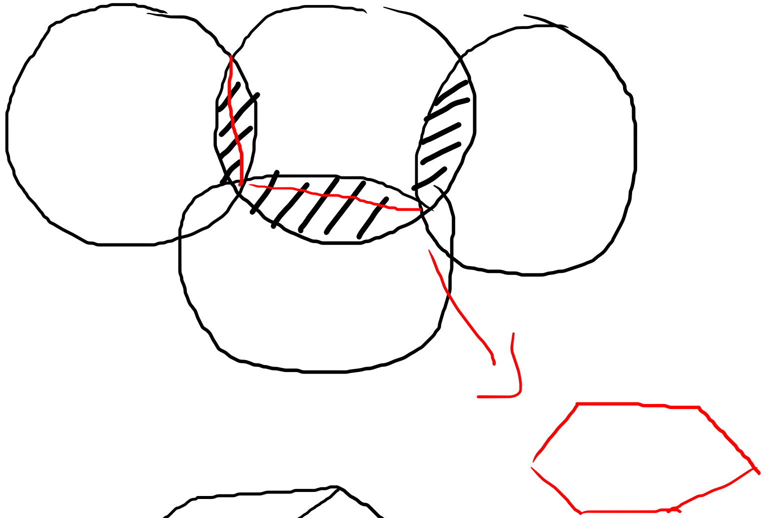
- Cellular concept - small cells with frequency reuse
  - Advantages
    - lower power handsets
    - Increases system capacity with frequency reuse
  - Drawbacks:
    - Cost of cells
    - Handoffs between cells must be supported
    - Need to track user to route incoming call/message

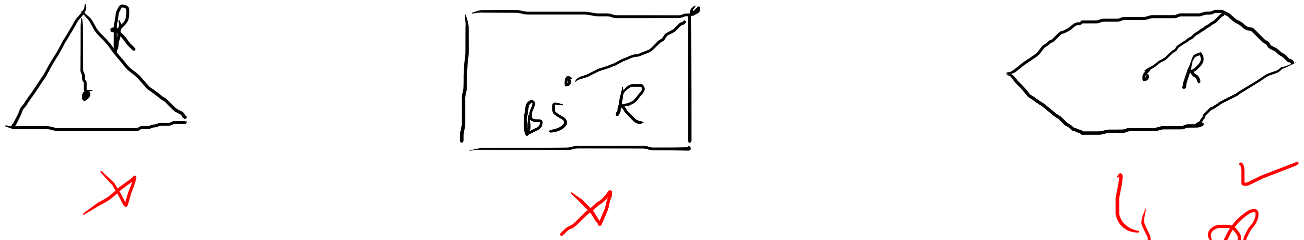
1

a) Omnidirectional antennas

i
ii
iii







Better approximates the circle

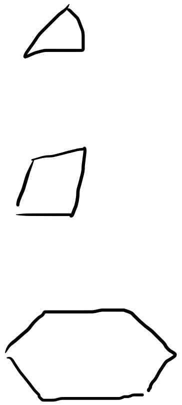
1 Hexagons: why?

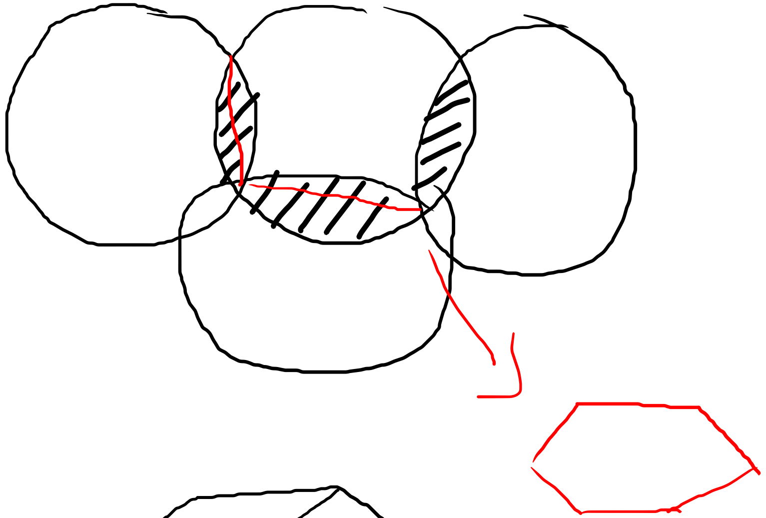
a) Omnidirectional antennas

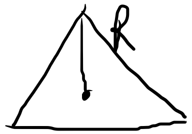
i

ii

iii







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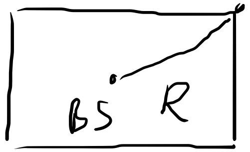

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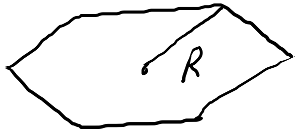
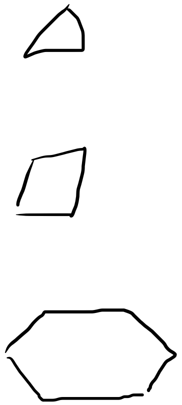


✓

Better approximates the circle

1

a) Omnidirectional antennas

i 

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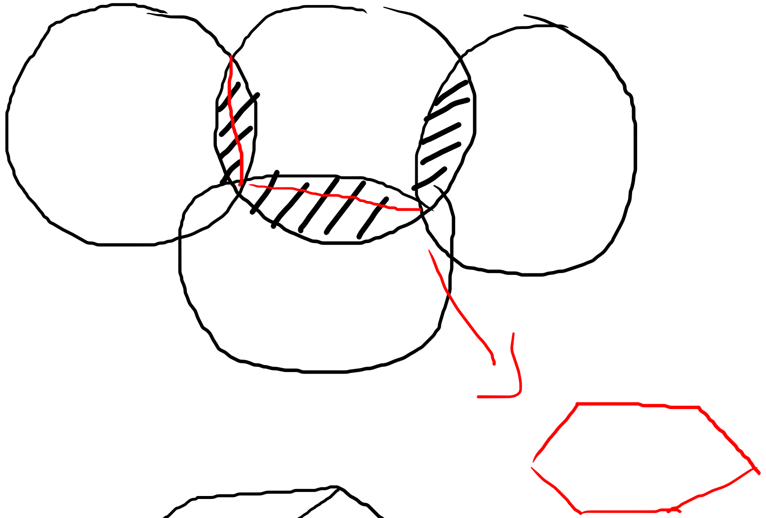
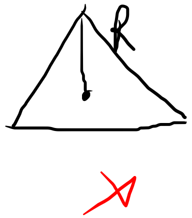
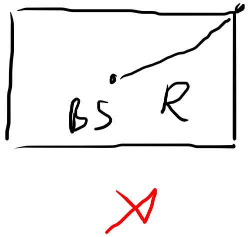
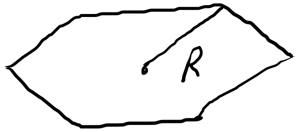




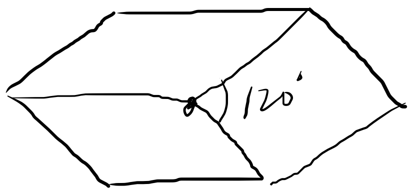


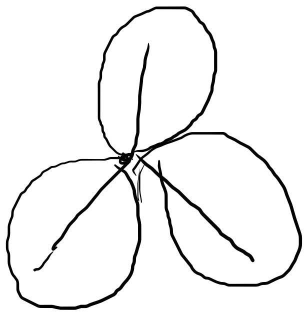


Better approximates the circle

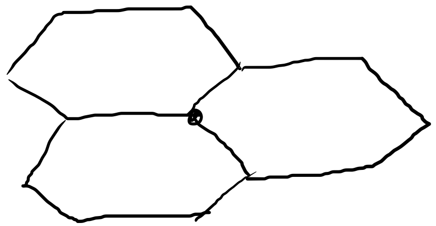
b) Sectorial antennas

(i)





(ii)



(2) Frequency reuse

- Time-division multiplexing
  "Time-domain"
- "Space-domain"
  a) AM/FM Eg: Indore / Mumbai
  b) Cellular Systems
  "freq-reuse in same general area"

Given coverage area - Several Cells - Same set of frequencies or radio channels

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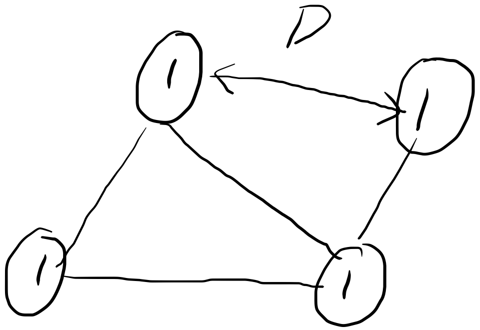
Co-channel Cells.

Thermal noise

$S/N \uparrow$ Transmitted power

CCI $\downarrow$



$f_c \uparrow$

CCI $\uparrow$

Co-channels

When, cell size & BS transmitted power are same

then $CCI \neq f$ (transmitted power)

$CCI = f(R, D)$ — dist. b/w centers of the nearest co-channels cells.

radius of cell

Min. distance that allows freq. reuse depends on

a) No. of co-channel cells
b) type of geographic terrain contour
c) Antenna height, & d) Tx power at each cell site.

"min freq reuse distance"

$q = \frac{D}{R}$ "Co-channel reduction factor"

For hexagonal geometry, $q = \frac{D}{R} = \sqrt{3N}$

N - cluster size

(i) q ; smaller $\longrightarrow$ larger capacity $\uparrow$

$S = N k$

(ii) q : large $\rightarrow$ capacity $\rightarrow$ Quality of transmission high

CCI $\uparrow$

Actual Cellular Design

└ Trade-off

b/w

"quality of transmission" & "Capacity"

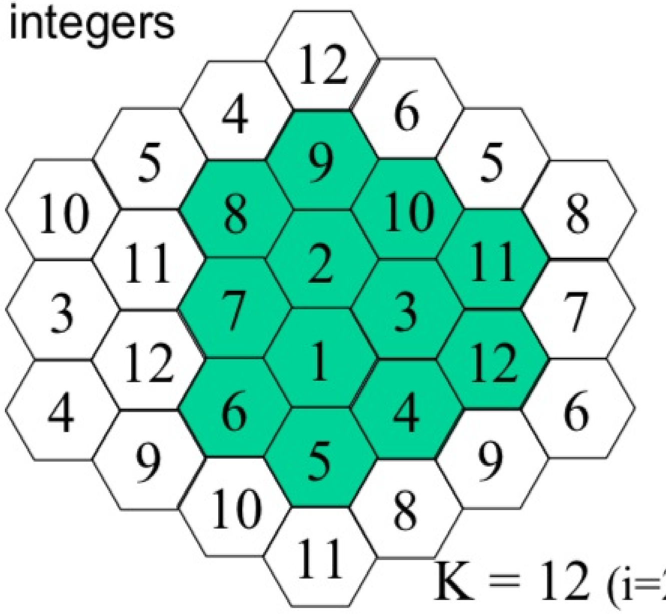
to

set

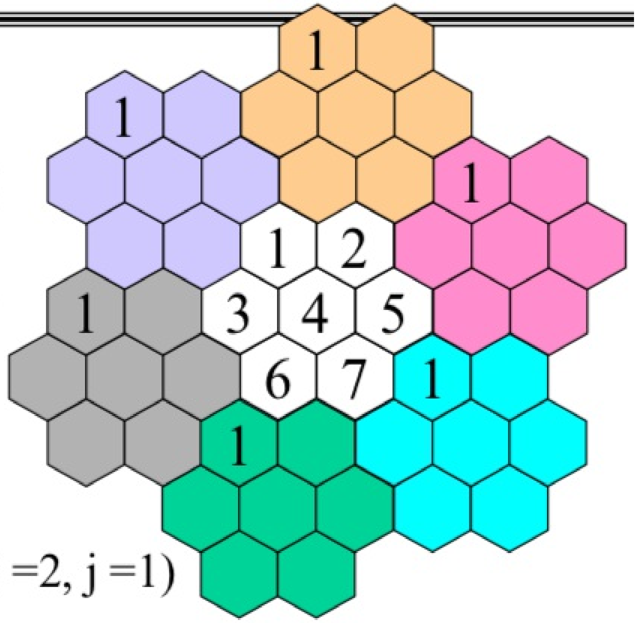
"N"

From geometry of grid of hexagons only certain values of K are possible if replicating cluster with out gaps

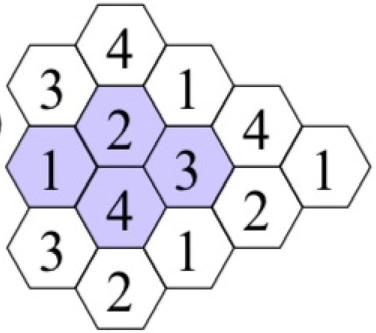
$K = i^2 + ij + j^2$ where i and j are non-negative integers



K = 12 (i=2, j=2)

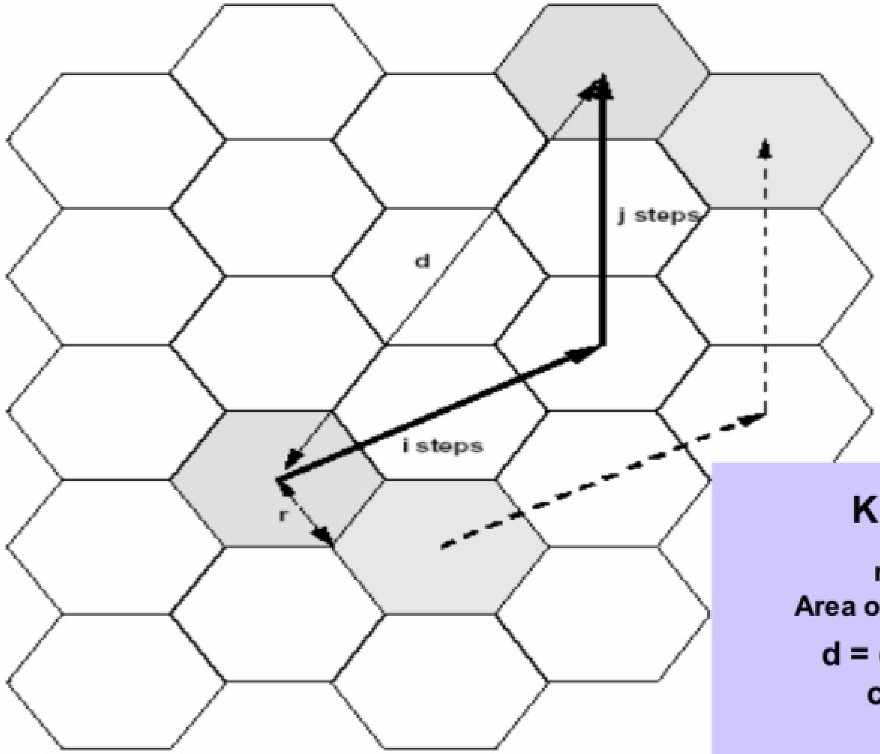


K = 7 (i =2, j =1)



K = 4 (i =2, j=0)

- To find co-channel neighbors of a cell, move i cells along any chain of hexagons, turn 60 degrees counterclockwise, and move j cells (example: i=2, j=2, K=12)



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

r = cell radius
Area of hexagon = 2.61 r^2

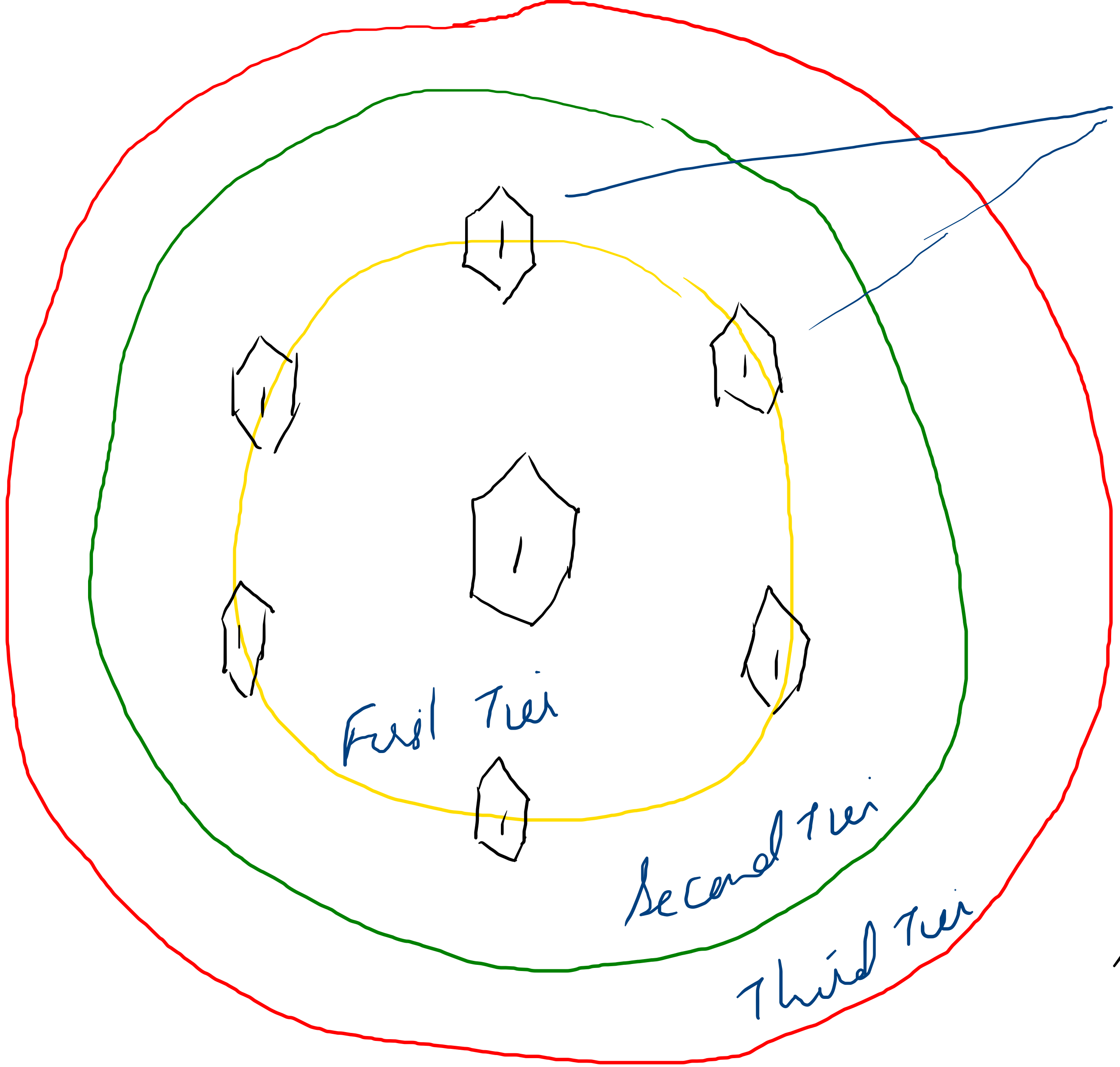
d = distance to co-channel cell

In other words, $\underline{N} \uparrow$

$S = \Uparrow k \downarrow$ drastically $\Rightarrow$ trunking inefficiency or spectral inefficiency

Note: CCI experienced

- at cell site "BS"
- at mobile unit (MS)



$$\frac{2\pi D}{D} = 6$$

Six effective interfering cells of Cell 1

$$q = \frac{P}{R}$$

$$D = f\left(K_I, \frac{S}{I}\right)$$

Received carrier to interference ratio at the desired mobile receiver

K_I → Co-channel interfering cells "First tier"

$\frac{S}{I}$ $\xrightarrow{\text{knowing this}}$ D $\xrightarrow{\text{we will get}}$ $\underline{\underline{N}}$ "Finally"

We know that from propagation measurements in radio channels,

Avg. received signal strength

$$\boxed{P_r = P_0 \left(\frac{d}{d_0}\right)^{-n}}$$

where,

n = path loss exponent

→ 2 to 4

Urban Cellular System

P_0 at ref. point in far field at dist d_0.

We know that from propagation measurements in radio channels,

Avg. received signal strength

$$\boxed{P_r = \underset{\sim}{P_0} \left(\frac{d}{d_0}\right)^{-n}}$$

P_0 at ref. point in far field at dist d_0.

where,

n = path loss exponent

→ 2 to 4

Urban

Cellular System

If i_0 be the no. of co-channel cells interfering

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i}$$

"SIR" for a mobile receiver which is monitoring forward channel

I_i : Interfering power due to i^{th} co-channel cell "Base Station"

Note; a) Effect of BS on MS

b) local noise neglected.

c) First Tier only.

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}} = \frac{(D/R)^{n}}{i_0}$$

for equidistance i_0-channels

$$= \frac{(\sqrt{3N})^{n}}{i_0}$$

For U.S. AMPS Cellular System, uses FM & 30 KHz Channels

$$\frac{S}{I} \geq 18\,dB.$$

$N \approx 6.49$ or 7

$\boxed{n = 4}$

Assumed.

Example ①: For given path loss exponent

a) $n = 4$ &

b) $n = 3$, find the freq. reuse factor

and cluster size that should be used for max capacity.

The S/N of 15 dB is min. required for satisfactory forward channel performance of a cellular system. Assume first tier cells with equal distance b/w them.

Sol^n

a) $n = 4$

Lets Consider that Seven-Cell reuse pattern

$$\underline{\underline{N = 7}}$$

$$Q = D/R = \sqrt{3N} = \sqrt{21} = 4.583$$

$$\frac{S}{I}\bigg|_{dB} = \frac{(\sqrt{3N})^4}{i_0}\bigg|_{dB} = \frac{(4.583)^4}{6} = \underline{18.66\,dB}$$

"SIR"

This justifies that N can be selected as 7.

(b) $n = 3$

Assume: $N = 7$

$$\frac{S}{I} = \frac{(4.583)^3}{6} = 12.05\,dB \quad (< 15\,dB \text{ required})$$

change $\underline{\underline{N = 12}}$

$$\frac{D}{R} = 6.$$

$$\frac{S}{I} = \frac{6^3}{6} = 36 = \underline{15.56}\,dB.$$

$\Rightarrow$ $N = 12$ can be selected!

Example ②: Compare interference from the first tier of 6 interferers with that from 12 interferers.

"first plus second"

First tier:

$$\frac{2\pi D}{D} \simeq 6.$$

Assume $\boxed{n = 4}$

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{6} I_i} = \frac{R_1^{-4}}{6 D_1^{-4}} = \frac{a_1^{4}}{6}.$$

where, $a_1 = \frac{D_1}{R_1}$

$$\left(\frac{S}{I}\right)_{\text{first tier}} = \underline{\underline{18.72\ dB}}.$$

First & Second tier:

$$\frac{S}{I} = \frac{S}{\underbrace{\sum_{i=1}^{6} \left(I_{1i} + I_{2i} \right)}_{12 \text{ elements}}} = \frac{1}{6\left(a_1^{-4} + a_2^{-4}\right)}$$

$$a_2 = \frac{D_2}{R_1} = \frac{2D_1}{R_1}$$

$$\left(\frac{S}{I}\right)_{\text{first + second tier}} = 18.46\,dB$$

$2a_1 = 9.2 = a_2$

because $\overline{a_1 = 4.6}$ for hexagonal geo.

First & Second tier:

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{6} \underbrace{(I_{1i} + I_{2i})}_{12\ \text{elements}}} = \frac{1}{6(a_1^{-4} + a_2^{-4})}$$

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$$\left(\frac{S}{I}\right)_{\text{first + second tier}} = \underline{18.46\,dB}$$

$2a_1 = 9.2$

because $\underline{\underline{a_1 = 4.6}}$