

Introduction to cellular systems IoT, a.a. 2018/2019

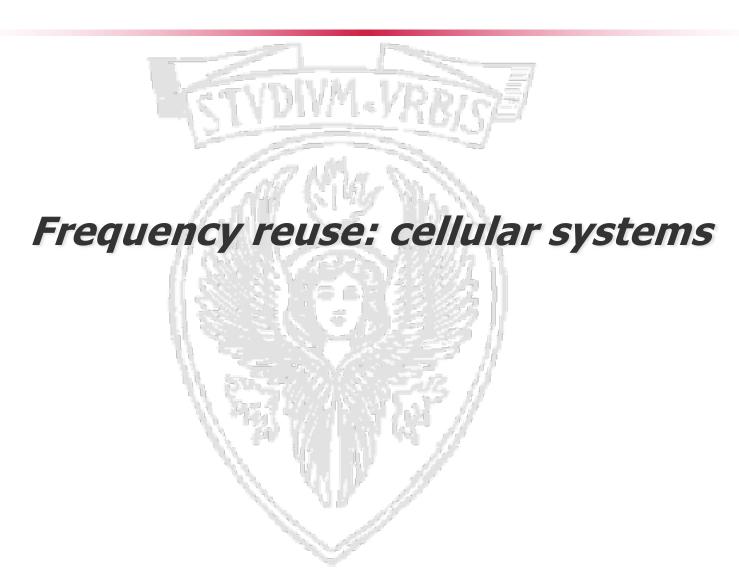
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Frequency reuse

Multi-cell systems

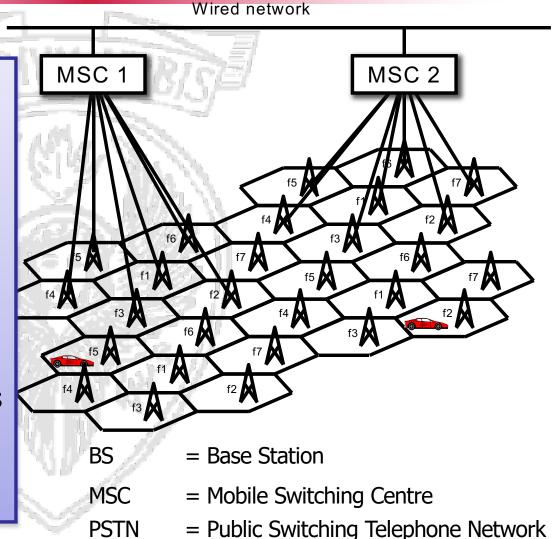
- The radio resource is to be divided among base stations
- The amount of radio resource (bandwidth) is very limited and it is not possible to dedicate it exclusively to a physical channel of a particular cell
- In the division of the radio resource among cells the resource is reused several times in cells that are sufficiently distant so that the mutual interference becomes strongly attenuated (remember path loss)
- The reuse of frequencies is a critical aspect in the design of cellular systems as it determines on one hand the number of channels to assign to each cell and on the other hand the channel quality
- We will devote much attention to the problem!





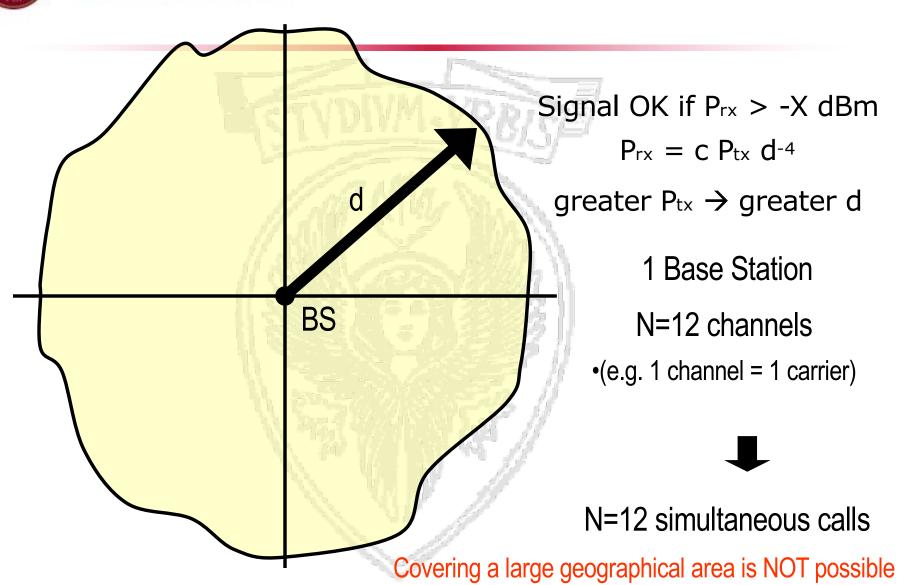
→ 1 BS per cell

- ⇒ Cell: Portion of territory covered by one radio station
- ⇒ One or more carriers (frequencies; channels) per cell
- → Mobile users full-duplex connected with BS
- → 1 MSC controls many BSs
- → MSC connected to PSTN





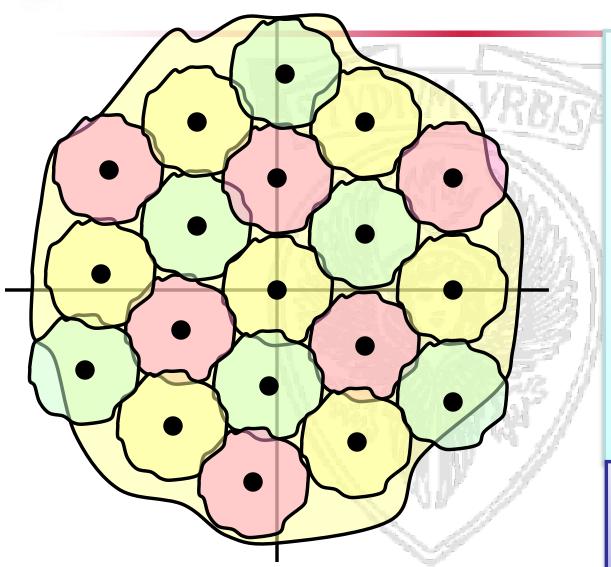
Coverage for a terrestrial zone





Cellular coverage

target: cover the same area with a larger number of BSs



19 Base Station

12 carriers

4 carriers/cell



Worst case:

4 calls (all users in same cell)

Best case:

76 calls (4 users per cell, 19 cells)

Average case >> 12

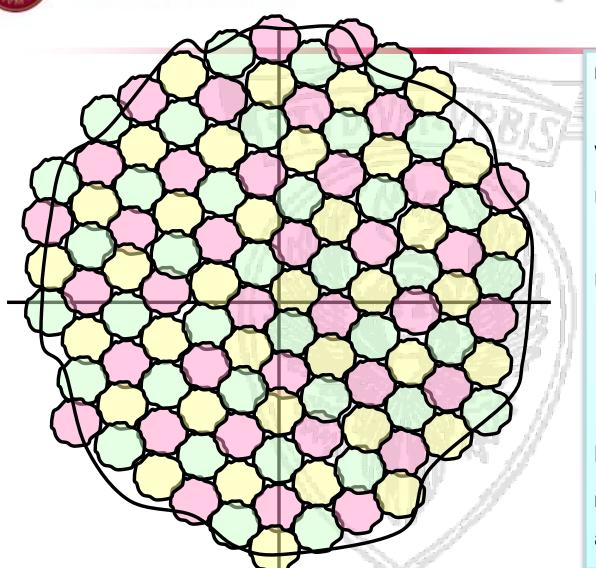
Low transmit power

Key advantages:

- Increased capacity (freq. reuse)
- Decreased tx power



Cellular coverage (microcells)



many BS

Very low power!!

Unlimited capacity!!

Usage of same spectrum

(12 carriers)

(4 carriers/cell)

Disadvantage:

mobility management additional infrastructure costs

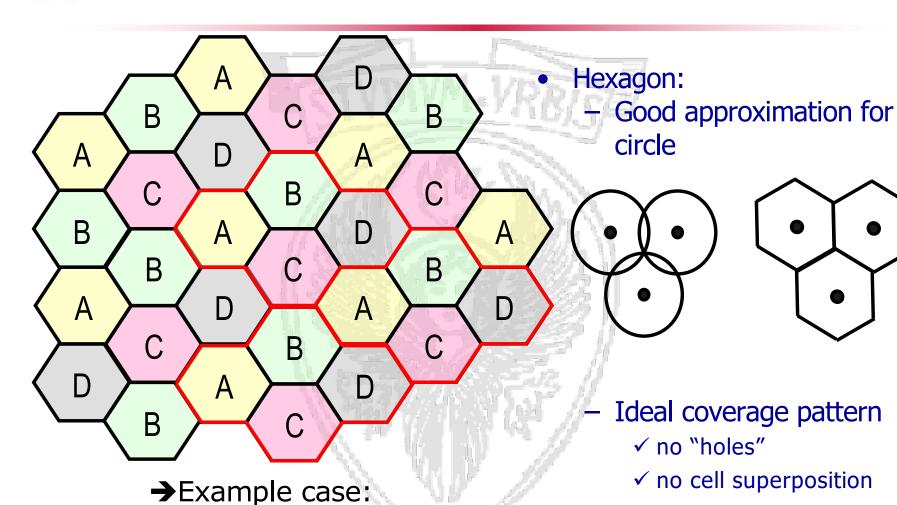


Cellular capacity

- Increased via frequency reuse
 - Frequency reuse depends on interference
 - need to sufficiently separate cells
 - ✓ reuse pattern = cluster size $(7 \rightarrow 4 \rightarrow 3)$: discussed later
- Cellular system capacity: depends on
 - overall number of carriers
 - ✓ Larger spectrum occupation
 - frequency reuse pattern
 - Cell size
 - ✓ Smaller cell (cell → microcell → picocell) = greater capacity
 - √ Smaller cell = lower transmission power
 - √ Smaller cell = increased handover management burden



Hexagonal cells



⇒Reuse pattern = 4



PART 2 Cellular Coverage Concepts

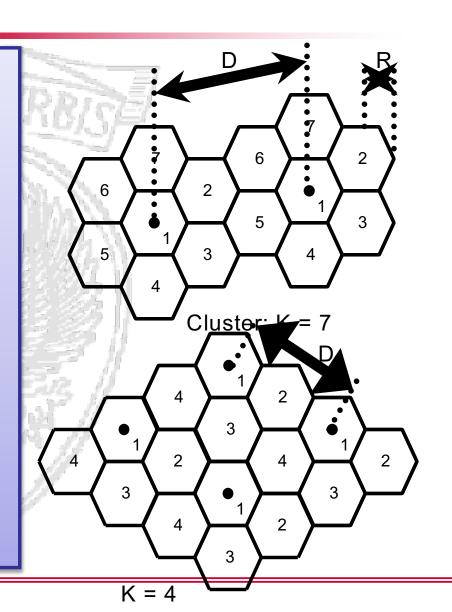
Lecture 2.2 Clusters and CCI



Reuse patterns

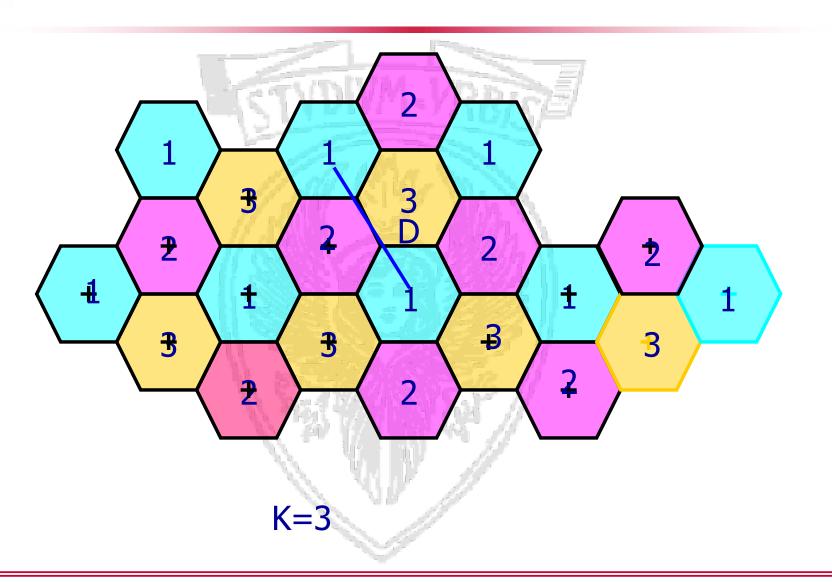
- Reuse distance:
 - Key concept
 - In the real world depends on
 - ✓ Territorial patterns (hills, etc)
 - ✓ Transmitted power
 - and other propagation issues such as antenna directivity, height of transmission antenna, etc
- Simplified hexagonal cells model:
 - reuse distance depends on reuse pattern (cluster size)
 - Possible clusters:

√ 3,4,7,9,12,13,16,19,...



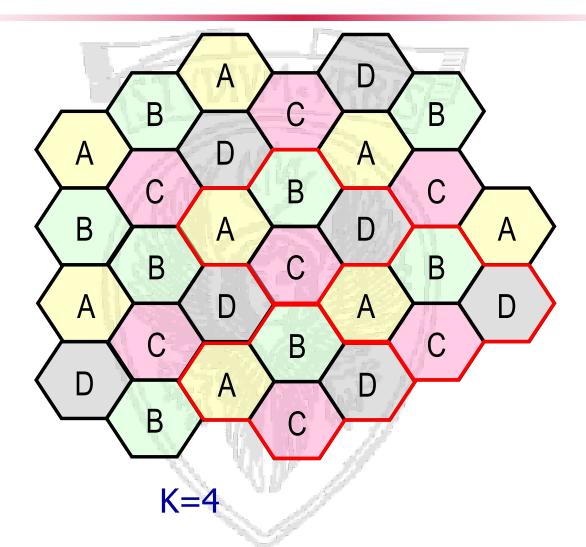


Cluster size



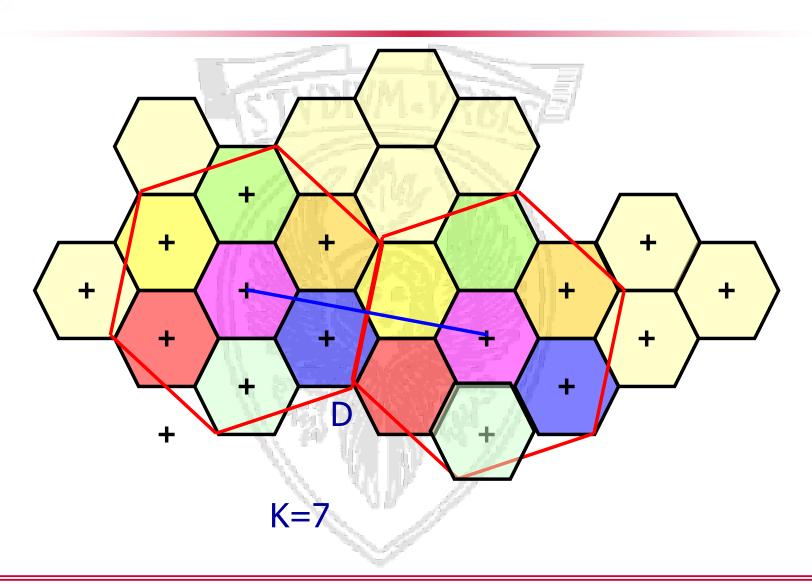


Cluster size





Cluster size





Reuse distance

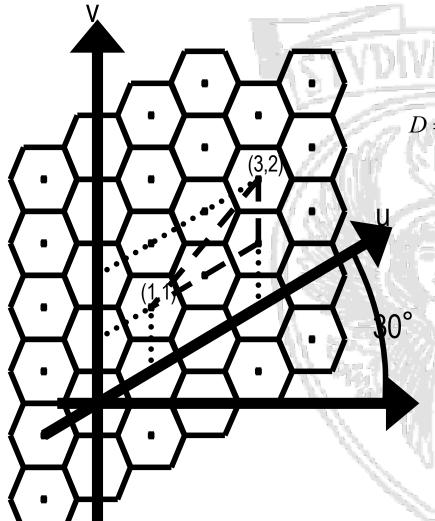
General formula

- $D = R\sqrt{3K}$
- Valid for hexagonal geometry
- D = reuse distance
- R = cell radius
- K=cluster size
- q = D/R = frequency reuse factor

K	q=D/R
3	3,00
4 1	3,46
7	4,58
9	5,20
12	6,00
13	6,24







- Distance between two cell centers:
- $-(u_1,v_1) \longleftrightarrow (u_2,v_2)$

$$D = \sqrt{\left[(u_2 - u_1)\cos 30^{\circ}\right]^2 + \left[(v_2 - v_1) + (u_2 - u_1)\sin 30^{\circ}\right]^2}$$

Simplifies to:

$$D = \sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2 + (u_2 - u_1)(v_2 - v_1)}$$

Distance of cell (i,j) from (0,0):

$$D = \sqrt{i^2 + j^2 + ij} \sqrt{3}R$$

$$D_R = \sqrt{i^2 + j^2 + ij}$$

 $D_R = \sqrt{i^2 + j^2 + ij}$ - Cluster: easy to see that

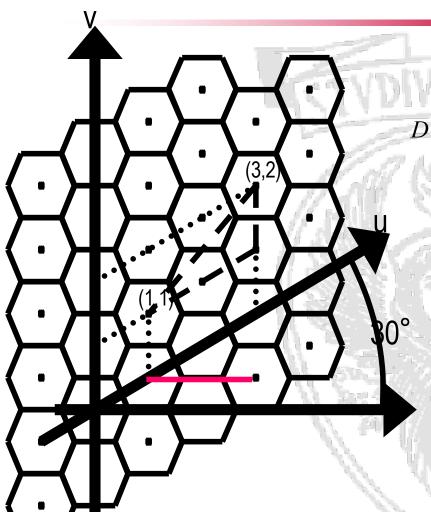
$$K = D_R^2 = i^2 + j^2 + ij$$

hence:

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







- Distance between two cell centers:
 - $(u_1,v_1) \longleftrightarrow (u_2,v_2)$

$$D = \sqrt{\left[u_2 - u_1\right)\cos 30^{\circ}\right]^2 + \left[(v_2 - v_1) + (u_2 - u_1)\sin 30^{\circ}\right]^2}$$

- Simplifies to:

$$D = \sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2 + (u_2 - u_1)(v_2 - v_1)}$$

Distance of cell (i,j) from (0,0):

$$D = \sqrt{i^2 + j^2 + ij} \sqrt{3}R$$

$$D_R = \sqrt{i^2 + j^2 + ij}$$

Cluster: easy to see that

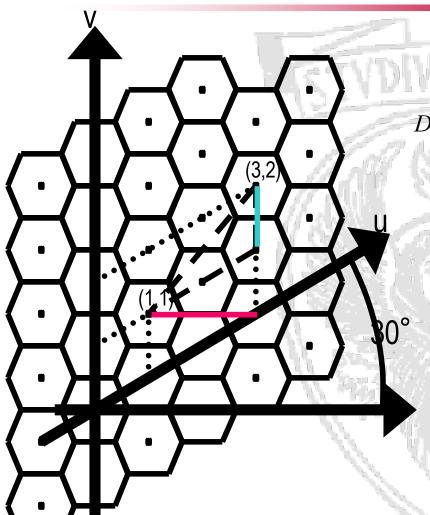
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– hence:

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







- Distance between two cell centers:
 - $-(u_1,v_1) \longleftrightarrow (u_2,v_2)$

$$D = \sqrt{\left[(u_2 - u_1)\cos 30^{\circ} \right]^2 + \left[(v_2 - v_1) + (u_2 - u_1)\sin 30^{\circ} \right]^2}$$

– Simplifies to:

$$D = \sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2 + (u_2 - u_1)(v_2 - v_1)}$$

Distance of cell (i,j) from (0,0):

$$D = \sqrt{i^2 + j^2 + ij} \sqrt{3}R$$

$$D_{R} = \sqrt{i^2 + j^2 + ij}$$

 $D_R = \sqrt{i^2 + j^2 + ij}$ - Cluster: easy to see that

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

hence:

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





Proof



$$D = \sqrt{\left[(u_2 - u_1)\cos 30^{\circ}\right]^2 + \left[(v_2 - v_1) + \left[u_2 - u_1\right)\sin 30^{\circ}\right]^2}$$

Simplifies to:

$$D = \sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2 + (u_2 - u_1)(v_2 - v_1)}$$

Distance of cell (i,j) from (0,0):

$$D = \sqrt{i^2 + j^2 + ij} \sqrt{3}R$$

$$D_R = \sqrt{i^2 + j^2 + ij}$$

- Cluster: easy to see that

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

- hence:

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









 $\left| (R)^2 - \left(\frac{R}{2} \right)^2 \right| = \sqrt{\frac{3}{4}R^2} = R \frac{\sqrt{3}}{2}$

$$D = \sqrt{\left[(u_2 - u_1)\cos 30^{\circ} \right]^2 + \left[(v_2 - v_1) + (u_2 - u_1)\sin 30^{\circ} \right]}$$

Simplifies to:

$$D = \sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2 + (u_2 - u_1)(v_2 - v_1)}$$

 Distance of cell (i,j) from (0,0):

$$D = \sqrt{i^2 + j^2 + i} \sqrt{3}R$$

Distance

Between centers

Of adjacent clusters

$$D_R = \sqrt{i^2 + j^2 + ij}$$
 Cluster: easy to see that

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



Distance between two cell centers:

$$- (u_1,v_1) \longleftrightarrow (u_2,v_2)$$

$$D = \sqrt{\left[(u_2 - u_1)\cos 30^o\right]^2 + \left[(v_2 - v_1) + (u_2 - u_1)\sin 30^o\right]^2}$$

Simplifies to:

$$D = \sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2 + (u_2 - u_1)(v_2 - v_1)}$$

Distance of cell (i,j) from (0,0):

$$D = \sqrt{i^2 + j^2 + ij} \sqrt{3}R$$
 Distance Between centers Of adjacent clusters

If R is the radius of a hexagon, half the distance between two adjacent hexagonal cells is

$$\sqrt{(R)^2 - \left(\frac{R}{2}\right)^2} = \sqrt{\frac{3}{4}R^2} = R\frac{\sqrt{3}}{2}$$

So the distance between two adjacent cells is 2 times this amount!





Distance between two cell centers:

 $-(u_1,v_1) \longleftrightarrow (u_2,v_2)$

$$D = \sqrt{\left[(u_2 - u_1)\cos 30^{\circ}\right]^2 + \left[(v_2 - v_1) + (u_2 - u_1)\sin 30^{\circ}\right]^2}$$

Simplifies to:

$$D = \sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2 + (u_2 - u_1)(v_2 - v_1)}$$

Distance of cell (i,j) from (0,0):

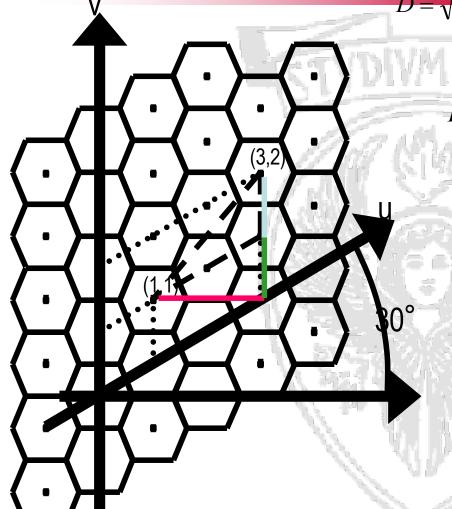
$$D = \sqrt{i^2 + j^2 + ij} \sqrt{3}R$$

 $D_R = \sqrt{i^2 + j^2 + ij}$ (we are defining DR) – Cluster: possible to see

that

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

hence: $K = D^2 / 3R^2$

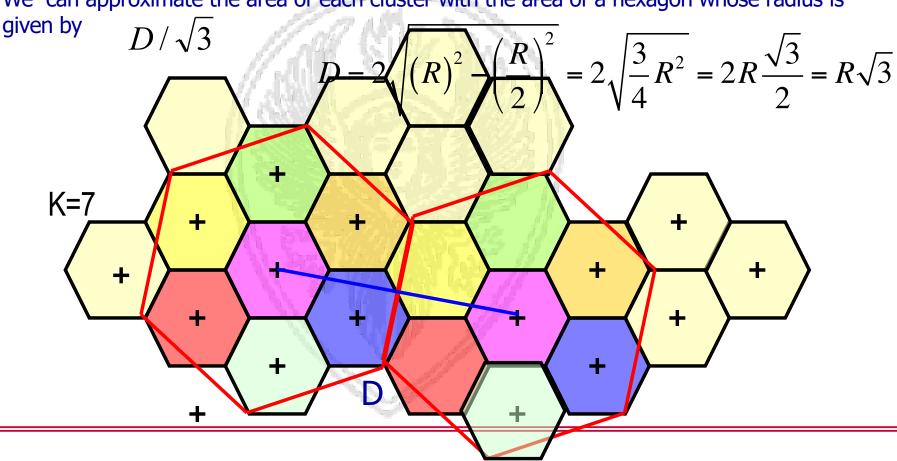




Proof

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

- Let us focus on a cell using a set of carriers A
- We cover the area with "clusters of cells" providing the pattern for frequency reuse
- Let D be the fixed distance between the centers of interfering cells in adjacent clusters
- We can approximate the area of each cluster with the area of a hexagon whose radius is

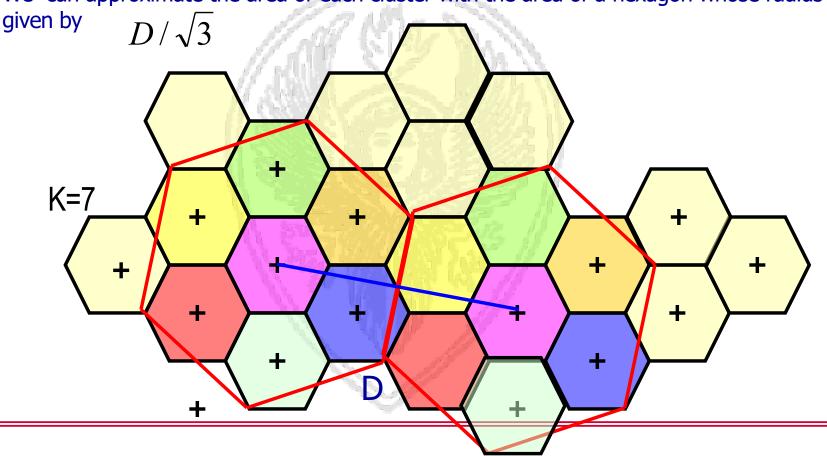




Proof

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

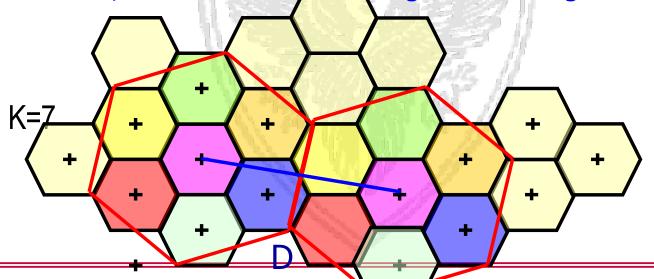
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- We cover the area with "clusters of cells" providing the pattern for frequency reuse
- Let D be the fixed distance between the centers of interfering cells in adjacent clusters
- We can approximate the area of each cluster with the area of a hexagon whose radius is







- We can approximate the area of each cluster with the area of a hexagon whose radius is given by $D/\sqrt{3}$
- if the radius of a hexagonal cell is r, the distance between the centers of two adjacent hexagons is $d=\sqrt{3}r$
- The distance between the centers of adjacent clusters is defined as D
- Therefore, the radius r of the hexagon containing the cluster is



 $D/\sqrt{3}$





by: $\frac{3}{2} \left(\frac{D}{\sqrt{3}}\right)^2 \sqrt{3}$

• How many hexagons of area $\frac{3}{2}(R)^2\sqrt{3}$

may be in an area equal to $\frac{3}{2} \left(\frac{D}{\sqrt{3}} \right)^2 \sqrt{3}$

Answer:

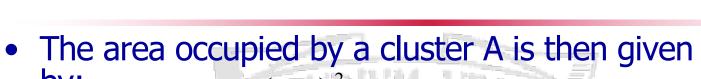
$$K = \frac{A_{cluster}}{A_{cella}} = \frac{\frac{3}{2} \left(\frac{D}{\sqrt{3}}\right)^2 \sqrt{3}}{\frac{3}{2} \left(R\right)^2 \sqrt{3}} = \left(\frac{D}{R\sqrt{3}}\right)^2 = (D_R)^2$$

$$K = \left(\frac{D}{R\sqrt{3}}\right)^2 = \frac{D^2}{3R^2}$$



$$D = \sqrt{3KR^2} = R\sqrt{3K}$$





by: by: $\frac{3}{2} \left(\frac{D}{\sqrt{3}}\right)^2 \sqrt{3}$ • How many hexagons of area

may be in an area equal to $\frac{3}{2} \left(\frac{D}{\sqrt{3}}\right)^2 \sqrt{3}$?

Answer:

$$K = \frac{A_{cluster}}{A_{cella}} = \frac{\frac{3}{2} \left(\frac{D}{\sqrt{3}}\right)^2 \sqrt{3}}{\frac{3}{2} (R)^2 \sqrt{3}} = \left(\frac{D}{R\sqrt{3}}\right)^2 = (D_R)^2$$

$$K = \left(\frac{D}{R\sqrt{3}}\right)^2 = \frac{D^2}{3R^2}$$



$$D = \sqrt{3KR^2} = R\sqrt{3K}$$

Since:

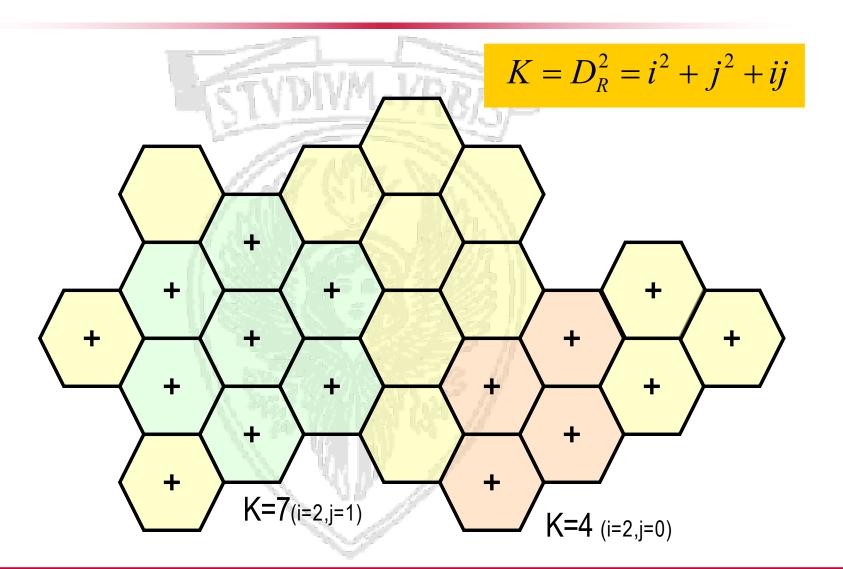
Since:

$$D = \sqrt{i^2 + j^2 + ij} \sqrt{3}R$$

$$D_R = \sqrt{i^2 + j^2 + ij}$$



Clusters





Possible clusters all integer i j values

		K=ii+jj+ij	q=D/R
1.4.1	0) \/ .1 /1	1,73
11	1	3	3,00
2	0 -	4	3,46
2	1.	7 / 7	4,58
2	2	12	6,00
3	0	9	5,20
3	1 1	13	6,24
3	2	19	7,55
3_	3	27	9,00
4	0	16	6,93
4	<u>.</u> 1	21	7,94
4	2	28	9,17
4	3-	37	10,54
4	4	48	12,00
5	0	25	8,66
5	1	31	9,64
	70.70	Wall ARE	

Feasible cluster sizes: 1,3,4,7,9,12,13,16,...



Co-Channel Interference



- Frequency reuse implies that remote cells interfere with tagged one
- Co-Channel Interference (CCI)
 - sum of interference from remote cells

signal power (S)

noise power (N_s) + interfering signal power (I)

$$\frac{S}{I} = \frac{\text{signal power (S)}}{\text{interfering signal power (I)}}$$

$$\frac{S}{N} \approx \frac{S}{I}$$
 as N_S small



CCI Computation – assumptions

Assumptions

- N_I=6 interfering cells
 - ✓ NI=6: first ring interferers only
 - ✓ we neglect second-ring interferers
- Negligible Noise Ns
 - √ S/N ~ S/I
- d¬¬ propagation law
 - $\checkmark \eta = 4$ (in general)
- Same parameters for all BSs
 - √ Same Ptx, antenna gains, etc.

- Key simplification
 - Signal for MS at distanceR
 - Signal from BS interferers at distance D





CCI computation

$$\frac{S}{N} \approx \frac{S}{I} = \frac{\cos t \cdot R^{-\eta}}{\sum_{k=1}^{N_I} \cos t \cdot D^{-\eta}} =$$

By using the assumptions of same cost and same D:

Results depend

$$= \frac{1}{N_I} \left(\frac{R}{D}\right)^{-\eta} = \frac{1}{N_I} \left(\frac{D}{R}\right)^{\eta} = \frac{1}{N_I} q^{\eta} \quad \text{on ratio q=D/R}$$
 (q=frequency reuse factor)

Alternative expression: recalling that $D = R\sqrt{3K}$

$$\frac{S}{N} \approx \frac{S}{I} = \frac{1}{N_I} \left(\frac{R}{R\sqrt{3K}} \right)^{-\eta} = \frac{1}{N_I} (3K)^{\eta/2} = \frac{(3K)^{\eta/2}}{6}$$

Ni=6,
$$\eta$$
=4 $\Rightarrow \frac{S}{I} = \frac{(3K)^2}{6} = \frac{3}{2}K^2$

USAGE: Given an S/I target, cluster size K is obtained



Examples
$$\frac{S}{N} \approx \frac{S}{I} = \frac{(3K)^{\frac{\eta}{2}}}{6}$$

- target conditions:
 - S/I=9 dB
 - $-\eta=4$
- Solution:

$$\frac{S}{I} = 10^{0.9} = 7.94 \approx 8$$

$$\frac{S}{I} = \frac{(3K)^{\eta/2}}{6} \bigg|_{\eta=4} \implies K = \sqrt{\frac{2 \cdot S}{3 \cdot I}}$$

$$K \ge 2.3 \implies K = 3$$

- target conditions:
 - S/I= 18dB
 - $-\eta = 4.2$
- Solution:

$$\frac{S}{I}[dB] = 5\eta \log(3K) - 10\log 6$$

$$\log(3K) = \frac{18 + 7.78}{21} = 1.23$$

$$K \ge \frac{10^{1.23}}{3} = 5.63 \implies K = 7$$



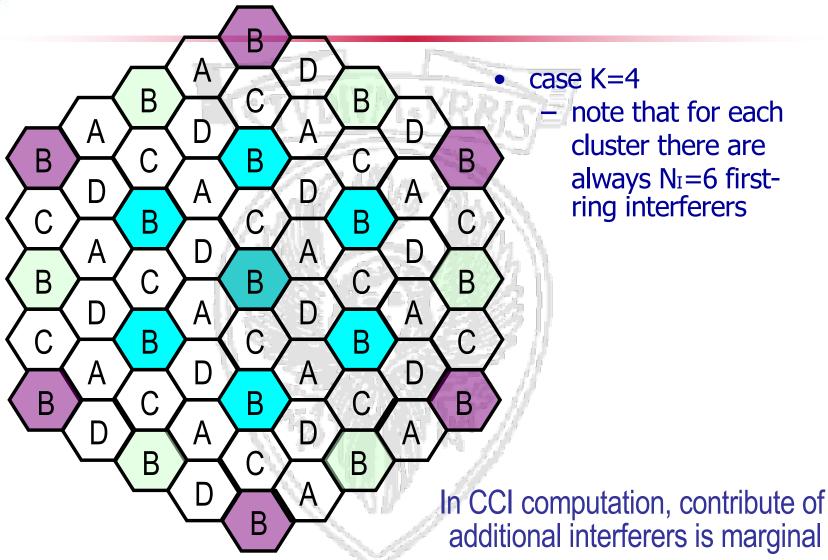
S/I computation

assuming 6 interferers only (first ring)

K	q=D/R	S/I	S/I dB
3	3,00	13,5	11,3
4	3,46	24,0	13,8
7	4,58	73,5	18,7
9	5,20	121,5	20,8
12	6,00	216,0	23,3
113	6,24	253,5	24,0
16	6,93	384,0	25,8
19	7,55	541,5	27,3
21	7,94	661,5	28,2
25	8,66	937,5	29,7
Vi. VL 10cc		10.00	



Additional interferers



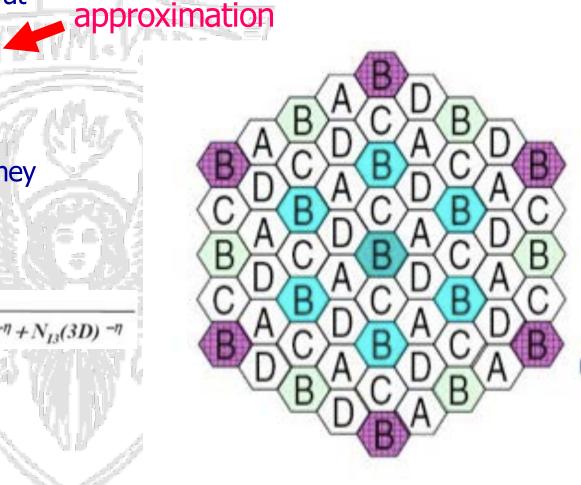


Multiple Tiers of Interferers

- First tier of interferers are at distance D; secondtier at distance 2D; third tier at distance 3D etc.
- Often interferers have a significant impact only if they belong to the first tier
- General formula:

$$SIR = \frac{R^{-\eta}}{N_{II}(D)^{-\eta} + N_{I2}(2D)^{-\eta} + N_{I3}(3D)^{-\eta}}$$

 NIi=number of interefers belonging to the i-th tier





Special case of co-channel interference

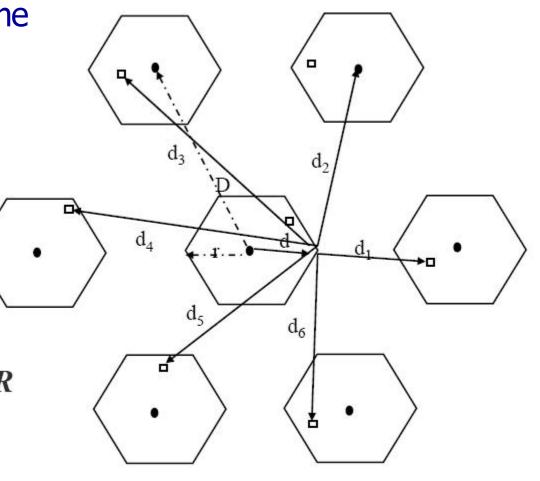
Same antennas and same power

$$SIR = \frac{P_t \cdot G \cdot d^{-\eta}}{\sum_{i=1}^6 P_t \cdot G \cdot d_i^{-\eta}} = \frac{d^{-\eta}}{\sum_{i=1}^6 d_i^{-\eta}}$$



• Approximation: $d_i = D - R$

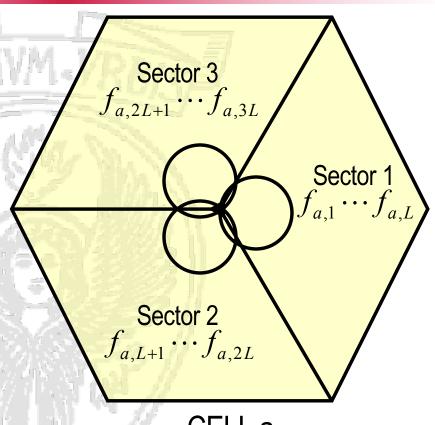
$$SIR = \frac{R^{-\eta}}{6(D-R)^{-\eta}}$$





Sectorization

- Directional antennas
- Cell divided into sectors
- Each sector uses different frequencies
 - To avoid interference at sector borders
- PROS:
 - CCI reduction
- CONS:
 - Increased handover rate
 - Less effective "trunking" leads to performnce impairments



CELL a



SAPIENZA CCI reduction via sectorization three sectors case

- Inferference from 2 cells, only
 - Instead of 6 cells

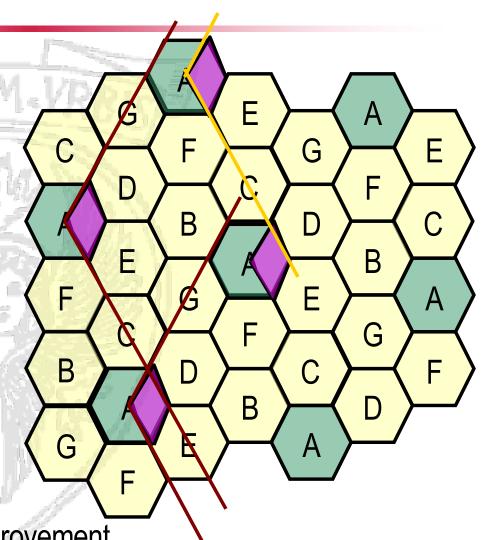
With usual approxs

(specifically, Dint ~ D)

$$\left[\frac{S}{I}\right]_{120^{o}} = \frac{R^{-\eta}}{2D^{-\eta}} = 3 \cdot \left[\frac{S}{I}\right]_{omni}$$

$$\left[\frac{S}{I}\right]_{120^{\circ}} dB = \left[\frac{S}{I}\right]_{\text{count}} dB + 4.77$$

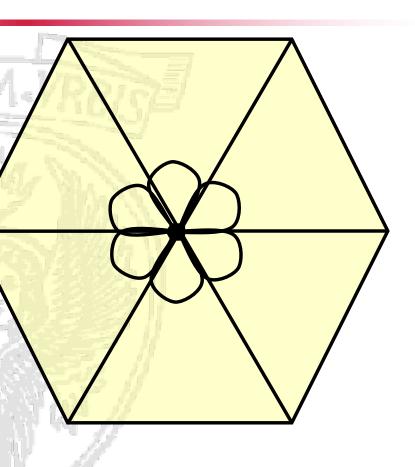
Conclusion: 3 sectors = 4.77 dB improvement







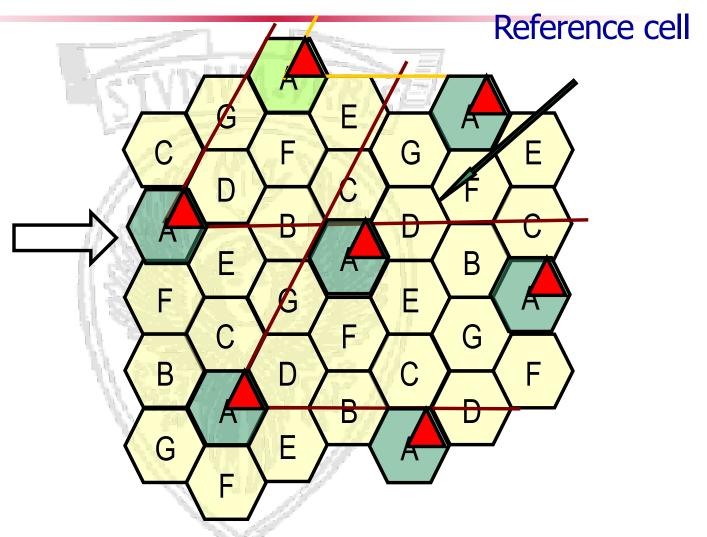
- 60° Directional antennas
- CCI reduction:
 - 1 interfereer only
 - 6 x S/I in the omni case
 - Improvement: 7.78 dB





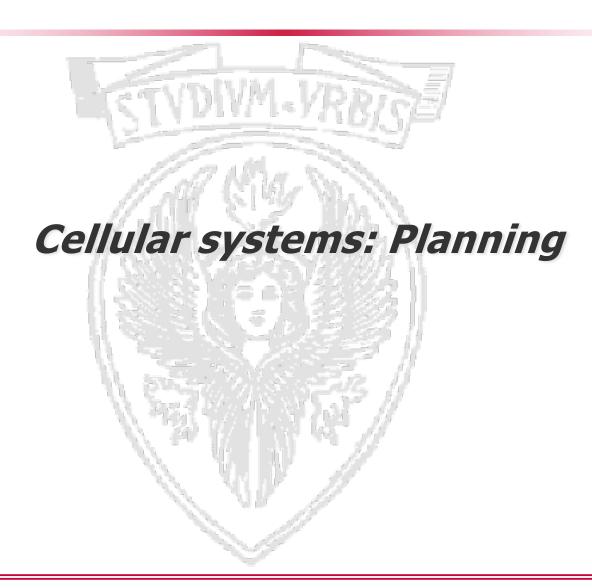


Only BS which disturbs receptions / transmissions to / from MU in the reference cell











Performance of cellular systems

- Regardless of the manner with which the resource is divided the number of channels that we can assign to each cell is limited
- Apart for special cases (which we will see, as those of dynamic allocation) the number of channels is fixed
- The number of **simultaneous conversations per cell is limited** and it is therefore possible that upon arrival of a new call that requires to establish a circuit (eg. Voice) there are no more available channels in the radio access network (resulting in **call blocking**)
- To evaluate the performance in terms of call blocking probability we need to characterize the traffic
 - Process of arrivals (voice calls are well modeled by the Poisson process)
 - Rate of arrivals
 - Average call duration



Arrival process

- In the case of a queue system that represents the management of calls in a cell
- The probability that the number of arrivals N (t, t + τ) in a time interval between t and t + τ is equal to k is given by:

$$P[N(t,t+\tau)=k] = \frac{(\lambda \tau)^k}{k!} e^{-\lambda \tau}$$

Poisson arrival process



Traffic engineering



 $A = \lambda X$

Average traffic (active calls)

in an interval of size T

A is adimensional

Traffic is measured in Erlang

 λ Arrival rate of calls(call/s)

X average duration of calls (s)



Traffic theory

- To model the arrival of calls in a cell with n channels we can use a queueing system with n serving units and a queue length equal to zero
- If the process of arrivals is Poisson, the probability of rejecting a call is given y the Erlang B equation:

$$B(n, A) = \frac{\frac{A^n}{n!}}{\sum_{k=0}^n \frac{A^k}{k!}}$$

- where A=λT (in Erlang), λ is the average arrival rate (call/s), T is the average call duration
 - NOTE: it works for any call duration distribution



The blocked traffic which is not served is:

$$A_p = A \cdot B(n, A)$$

Carried traffic:

$$A_s = A \cdot (1 - B(n, A)) = A - A_p$$

Channel utilization coefficient is given by:

$$\rho = \frac{A_s}{n} = \frac{A \cdot (1 - B(n, A))}{n}, \quad 0 \le \rho \le 1$$





- Fundamental formula for telephone networks planning
 - A₀=offered traffic in Erlangs

→ Efficient recursive computation available

$$E_{1,C}(A_o) = \frac{A_o E_{1,C-1}(A_o)}{C + A_o E_{1,C-1}(A_o)}$$

offered load (erlangs)

$$\Pi_{block} = \frac{\frac{A_o^C}{C!}}{\sum\limits_{j=0}^{C} \frac{A_o^j}{j!}} = E_{1,C}(A_o) \lim_{\substack{\text{ling eq out} \\ \text{0,01}\%}} 100,00\%$$



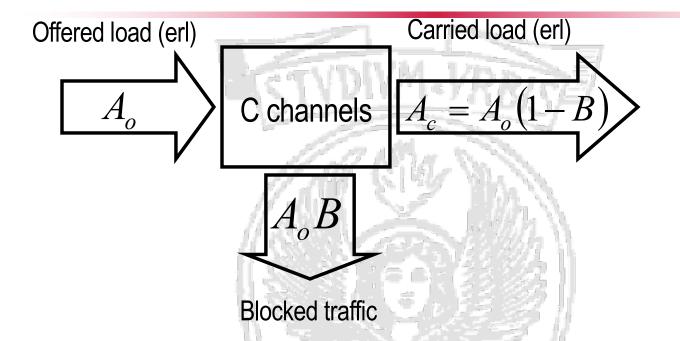


- Target: support users with a given Grade Of Service (GOS)
 - GOS expressed in terms of upper-bound for the blocking probability
 - ✓ GOS example: subscribers should find a line available in the 99% of the cases, i.e. they should be blocked in no more than 1% of the attempts
- Given:
 - √ Offered load A₀
 - √ Target GOS B_{target}
 - C (number of channels) is obtained from numerical inversion of

$$B_{\text{target}} = E_{1,C}(A_o)$$



Channel usage efficiency

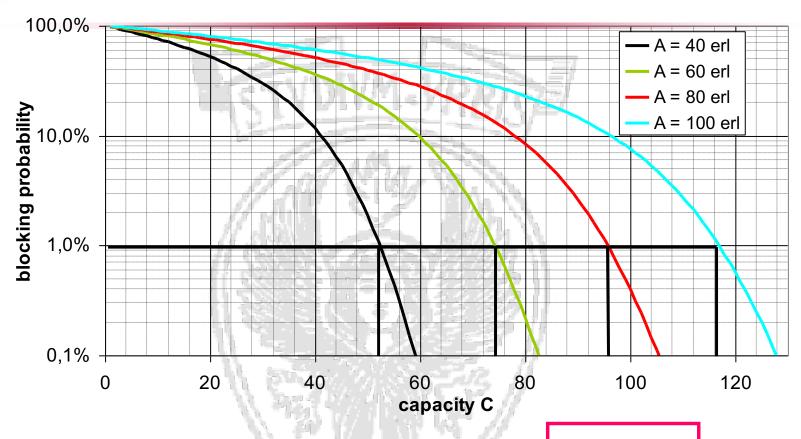


efficiency:
$$\rho = \frac{A_c}{C} = \frac{A_o (1 - E_{1,C}(A_o))}{C}$$
 $\approx \frac{A_o}{C}$ if small blocking

Fundamental property: for same GOS, efficiency increases as C grows!!



example ...



GOS = 1% maximum blocking.

Resulting system dimensioning and efficiency:

111	3017	
40 erl	C >= 53	ρ = 74.9%
60 erl	C >= 75	ρ = 79.3%
80 erl	C >= 96	ρ = 82.6%
100 erl	C >= 117	ρ = 84.6%



Trunking Efficiency

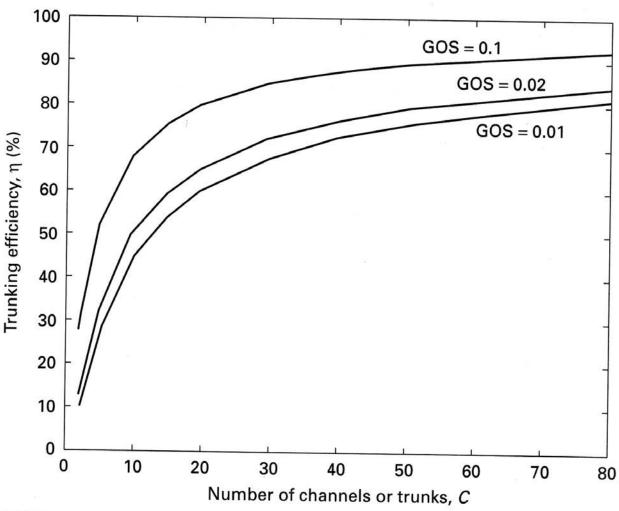


FIGURE 4.21 Trunking efficiency plots.



Erlang B calculation - tables

Example: How many channels are required to support 100 users with a GOS of 2% if the average traffic per user is 30 mE?

100x30mE = 3 Erlangs 3 Erlangs @ 2% GOS =

8 channels

Trunks	0.01	0.015	(0.02)	0.03
P(B)=	TOTATE		1	
1-	0.010	0.015	0.020	0.031
2	0.153	0.190	0.223	0.282
18	0.465	0.536	0.603	0.715
	0.870	0.992	1.092	1.259
-5	1.361	1.524	1.657	1.877
- 6-	1.913	2.114	2.277	2.544
-1	2.503	2.743	2.936	3.250
(8)	3.129	3.405	(3.627)	3.987
9	3.783	4.095	4.345	4.748
10	4.462	4.808	5.084	5.529

ErlangB Online calculator:

http://mmc.et.tudelft.nl/~frits/Erlang.htm



Application to cellular networks

Cell size (radius R) may be determined on the basis of traffic considerations

Given a provider with 50 channels available, how many users can be supported If each user makes an average of 4 calls/hour, each call lasting on average 2 minutes?

- First step:
 - Given num channels and GOS
 - C=50 available channels in a cell
 - Blocking probability<=2%
 - Evaluate maximum cell (offered) load
 - From Erlang-B inversion(tables)
 A=40.25 erl
- Second step
 - Given traffic generated by each user
 - Each user: 4 calls/busy-hour
 - Each call: 2 min on average
 - A_i=4x2/60=0.1333 erl/user
 - Evaluate max num of users in cell
 - M=40.25/0.1333 ~ 302

Second question: if the user density Is 500 users/km2 how should we

Set the cell radius?

$$\delta = \frac{M}{\pi R^2} \implies R = \sqrt{\frac{M}{\pi \delta}}$$

- → Third step:
 - ⇒ Given lensity of users $\rightarrow \delta = 5$ 0 users/km²
 - ⇒ Evaluate radius

⇒ R~438m

It is preferrable
To approximate
With hexagons





- Three service providers are planning to provide cellular service for an urban area. The target GOS is 2% blocking. Users make 3 calls/busy-hour, each lasting 3 minutes in average (A_i=3/20=0.15)
 - Question: how many users can support each provider?
- Provider A configuration: 20 cells, each with 40 channels
- Provider B configuration: 30 cells, each with 30 channels
- Provider C configuration: 40 cells, each with 20 channels

→ Provider A:

→ Provider B:

→ Provider C:

- ⇒ 40 channels/cell
- ⇒ at 2%: A₀=30.99 erl/cell
- ⇒ 619.8 erl-total (20 cells)
- ⇒ M=4132 overall users

- ⇒ 30 channels/cell
- ⇒ at 2%: A₀=21.93 erl/cell
- \Rightarrow 657.9 erl-total (30 cells)
- ⇒ M=4386 overall users

- ⇒ 20 channels/cell
- \Rightarrow at 2%: A_o=13.18 erl/cell
- ⇒ 527.2 erl-total (40 cells)
- ⇒ M=3515 overall users

Compare case A with C! The reason is the lower efficiency of 20 channels versus 40





- Three service providers are planning to provide cellular service for an urban area. The target GOS is 2% blocking. Users make 3 calls/busy-hour, each lasting 3 minutes in average (A_i=3/20=0.15)
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- ⇒ 30 channels/cell
- \Rightarrow at 2%: A₀=21.93 erl/cell
- ⇒ 657.9 erl-total (30 cells)
- ⇒ M=4386 overall users

to have more cells
with a few channels
(for example, because
we have selected a
different K)
does not port an

the fact

advantage in terms
of system capacity

Compare case A with C! The reason is the lower efficiency of 20



Sectorization and traffic

- Assume cluster K=7
- Omnidirectional antennas: S/I=18.7 dB
- 120° sectors: S/I=23.4 dB
- 60° sectors: S/I=26.4 dB
- Sectorization yields to better S/I
- BUT: the price to pay is a much lower trunking efficiency!
- With 60 channels/cell, GOS=1%,
 - Omni: 60 channels ρ =77.46%
 - 120 \circ : 60/3=20 channels ρ =59.54%
 - 60°: 60/6=10 channels ρ =44.15%

$$A_0 = 3 \times 12.03 = 36.09 \text{erl}$$

$$A_0 = 6x4.46 = 26.76erl$$

Erlang supported per sector =



Sectorization and traffic

Assume cluster K=7

Omnidirectional antennas: S/I=18.7 dB

• 120° sectors: S/I=23.4 dB

• 60° sectors: S/I=26.4 dB

On the other hand

Lower CCI can allow

To select a smaller K

- Sectorization yields to better S/I
- BUT: the price to pay is a much lower trunking efficiency!
- With 60 channels/cell, GOS=1%,
 - Omni: 60 channels ρ =77.46%
 - 120 \circ : 60/3=20 channels ρ =59.54%
 - 60°: 60/6=10 channels ρ =44.15%

A₀=1x46.95= 46.95 erl

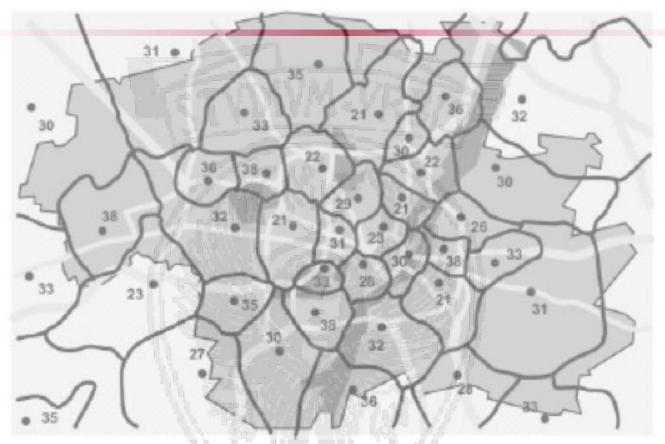
 $A_0 = 3 \times 12.03 = 36.09 \text{erl}$

 $A_0 = 6x4.46 = 26.76erl$

Erlang supported per sector =



Cells in réal world



Shaped by terrain, shadowing, etc

Cell border: local threshold, beyond which neighboring BS signal is received stronger than current one