Reti cellulari GSM

Reti Avanzate, a.a. 2012/2013

Un. of Rome "La Sapienza"

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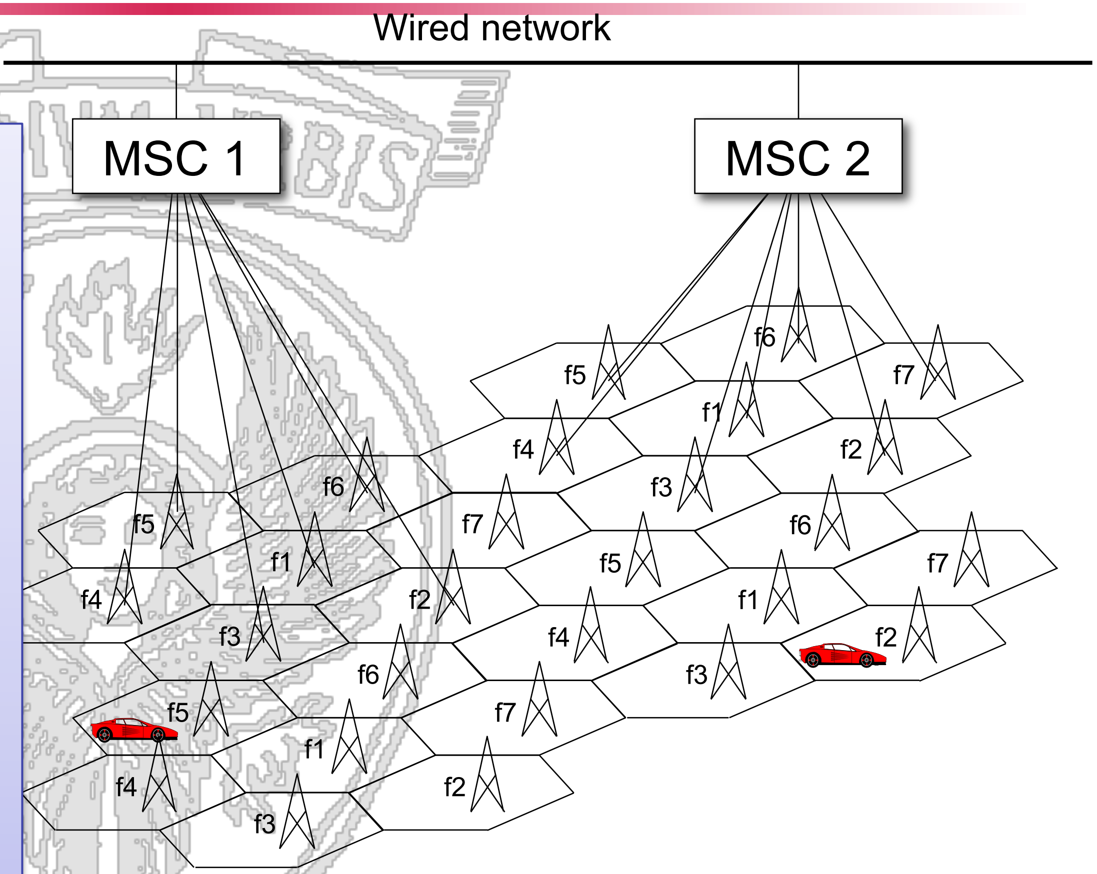
Allocazione delle frequenze: organizzazione a celle

Cellular system architecture

- ➔ 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

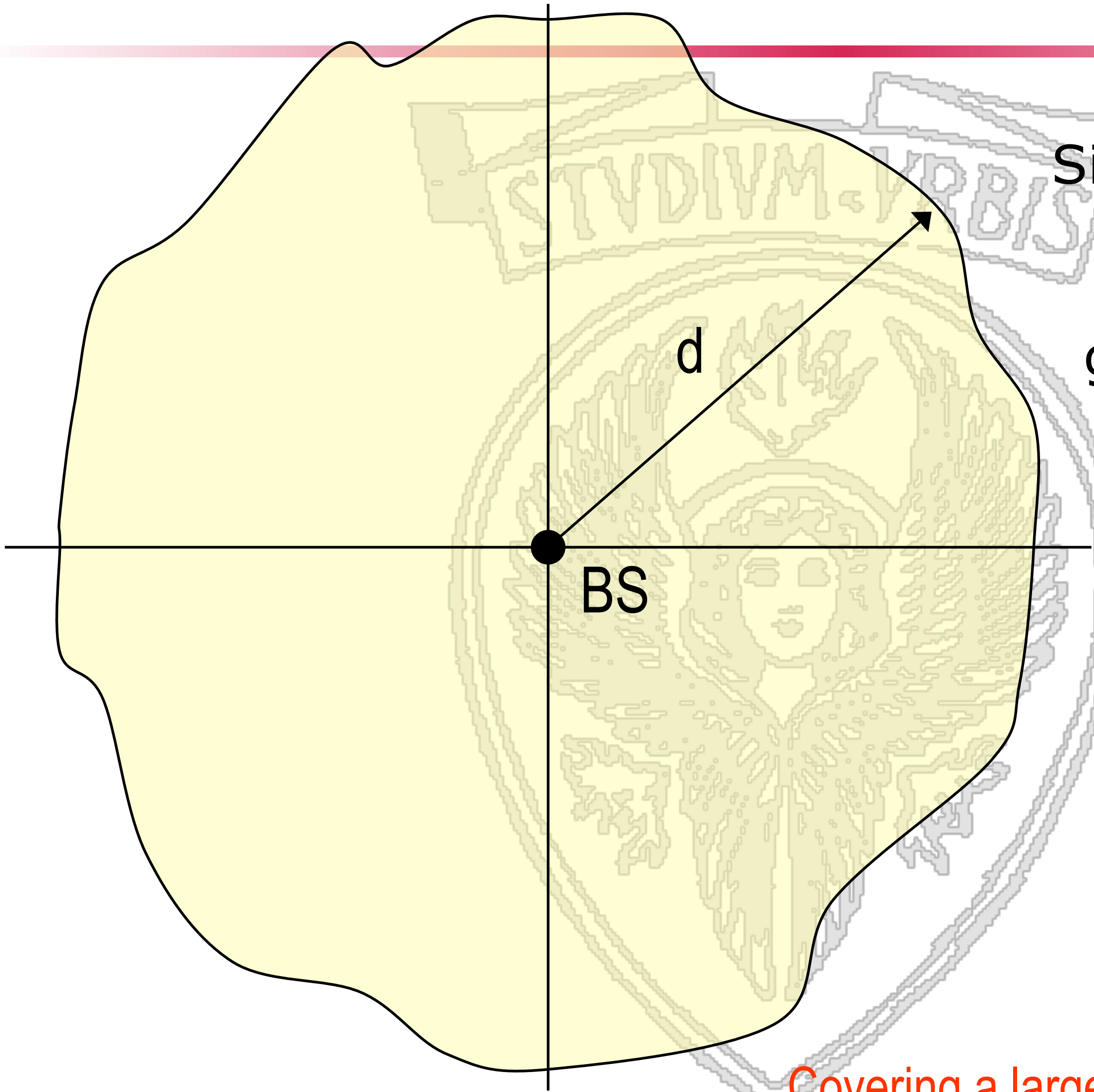


BS = Base Station

MSC = Mobile Switching Centre

PSTN = Public Switching Telephone Network

Coverage for a terrestrial zone



Signal OK if P_{rx} > -X dBm

$P_{rx} = c\, P_{tx}\, d^{-4}$

greater P_{tx} → greater d

1 Base Station

N=12 channels

•(e.g. 1 channel = 1 frequency)

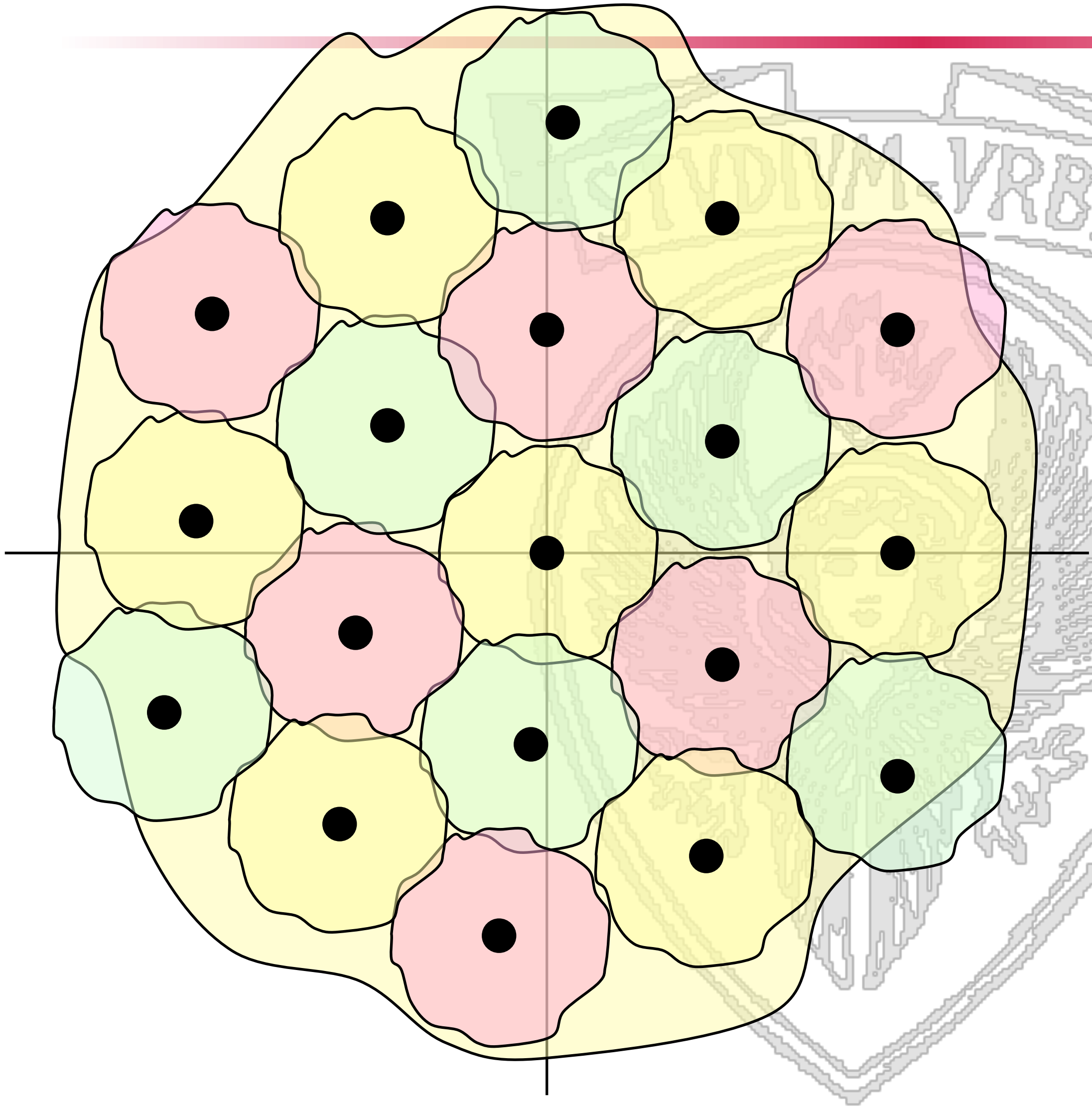
⬇

N=12 simultaneous calls

Covering a large geographical area NOT possible

Cellular coverage

target: cover the same area with a l arger number of BSs



19 Base Station

12 frequencies

4 frequencies/cell

Worst case:

4 calls (all users in same cell)

Best case:

76 calls (4 users per cell, 19 cells)

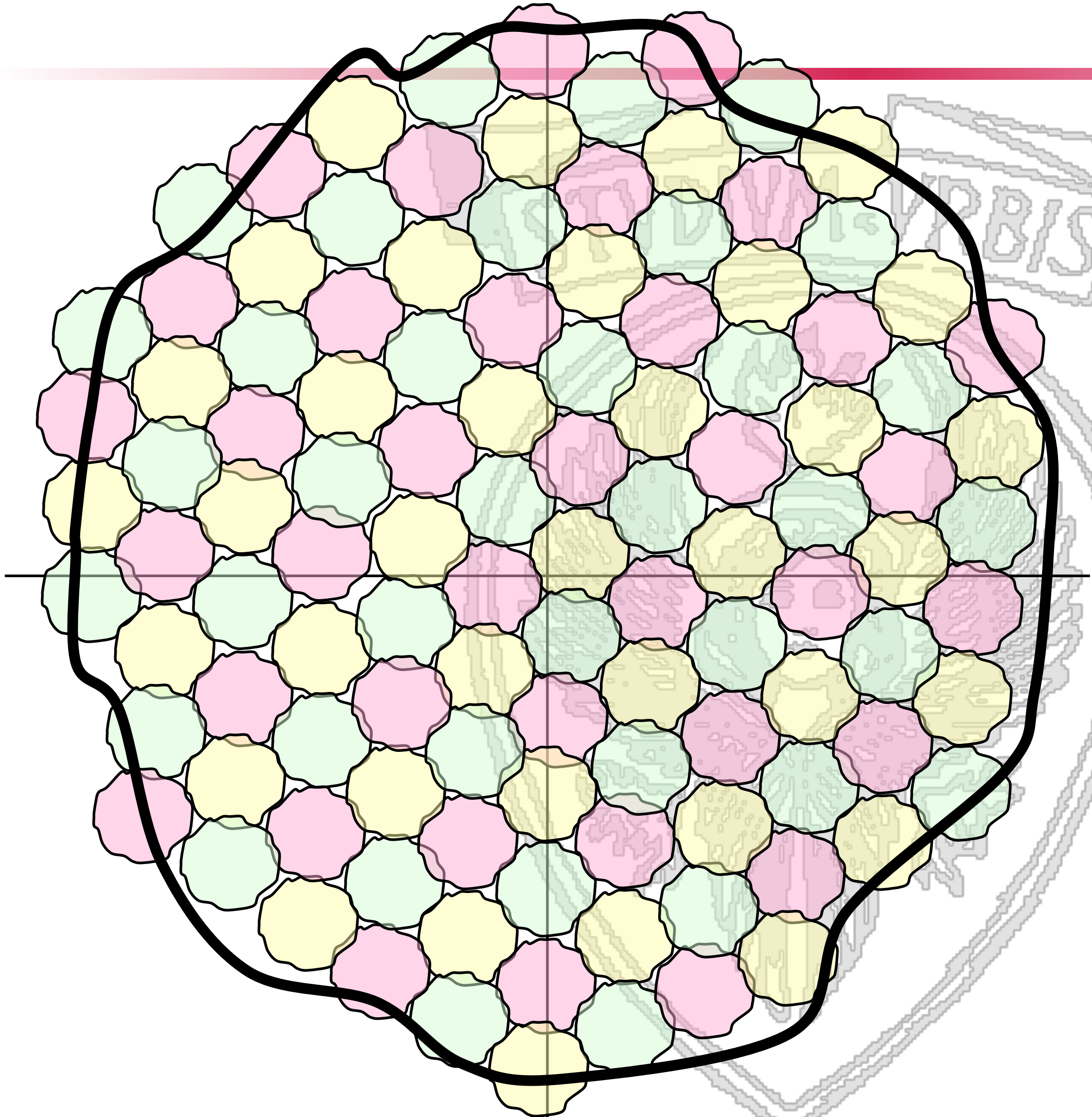
Average case >> 12

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 frequencies)

(4 freq/cell)

Disadvantage:

mobility management

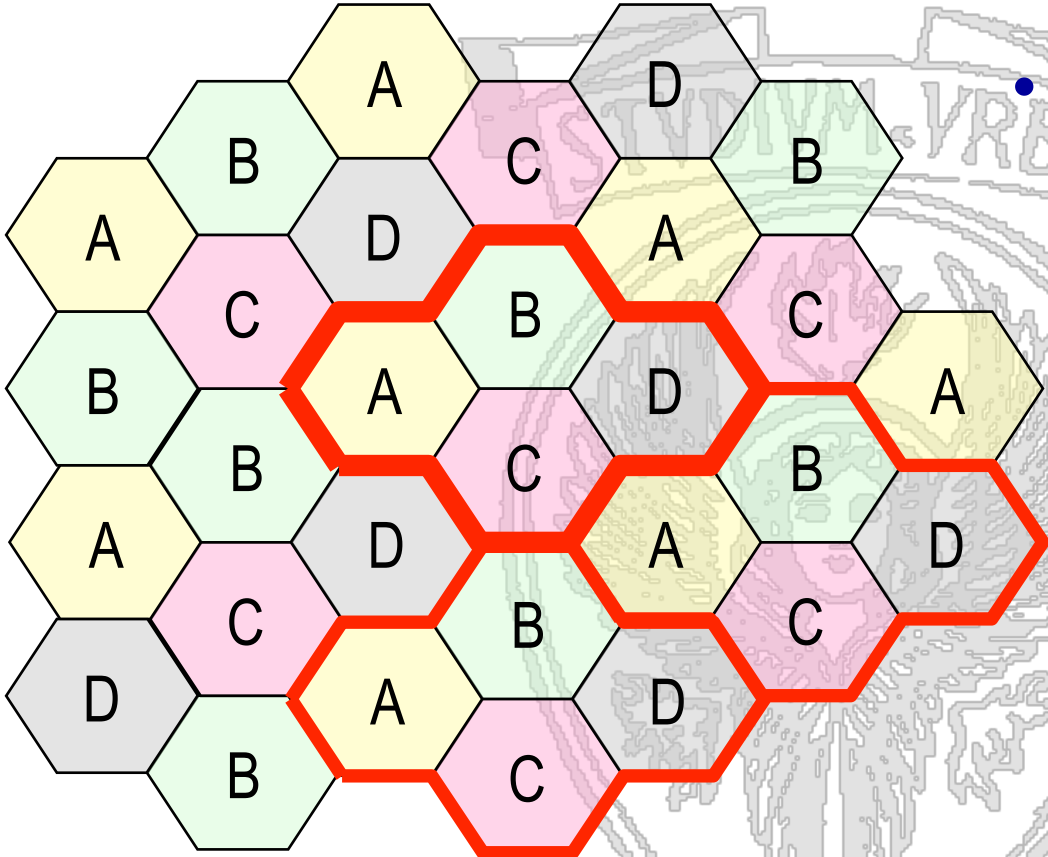
additional infrastructure costs

Cellular capacity

- Increased via frequency reuse
  - Frequency reuse depends on interference
  - need to sufficiently separate cells
    - ✓ reuse pattern = cluster size (7 → 4 → 3): discussed later

- Cellular system capacity: depends on
  - overall number of frequencies
    - ✓ Larger spectrum occupation
  - frequency reuse pattern
  - Cell size
    - ✓ Smaller cell (cell → microcell → picocell→femtocell) = greater capacity
    - ✓ Smaller cell = lower transmission power
    - ✓ Smaller cell = increased handover management burden

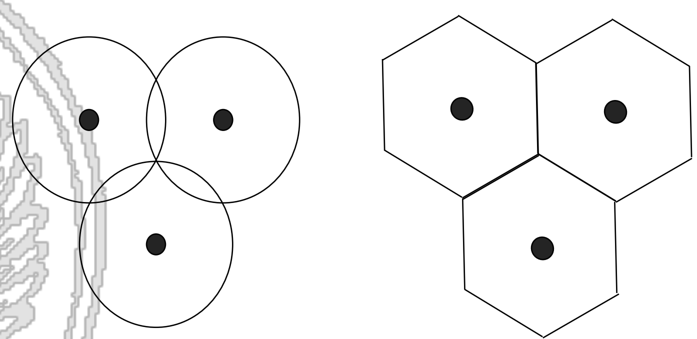
hexagonal cells



➔Example case:

⇨Reuse pattern = 4

- Hexagon:
  - Good approximation for circle



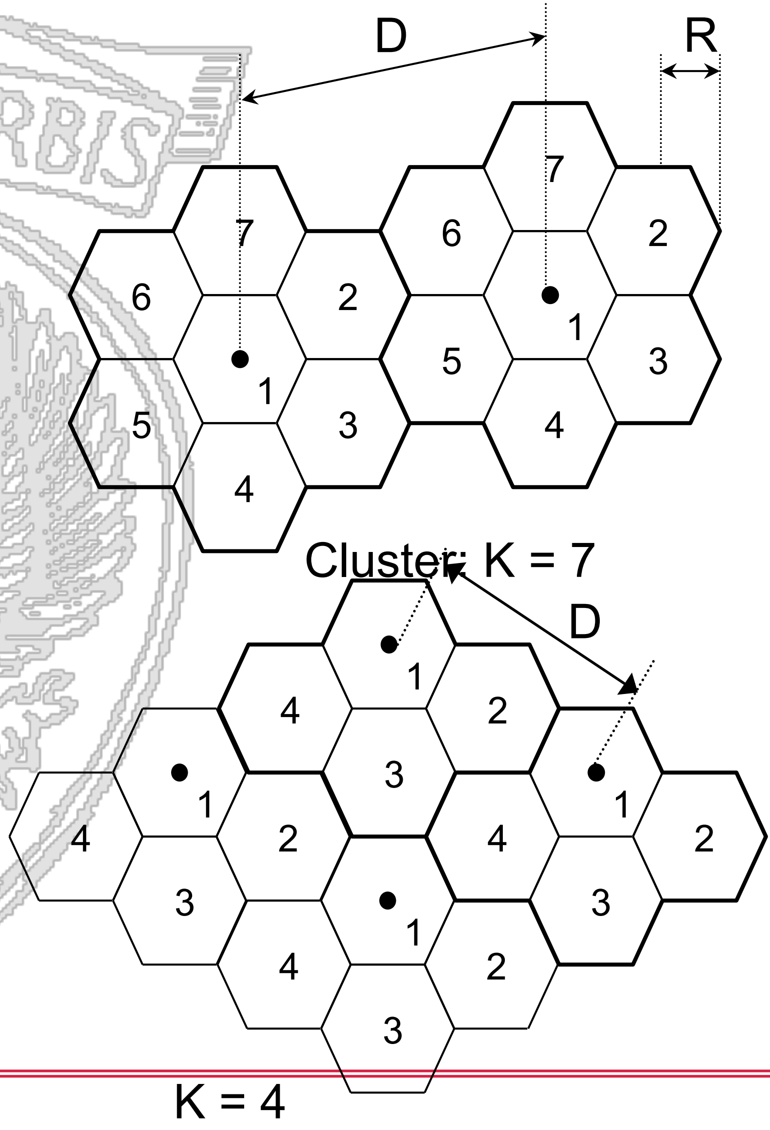
  - Ideal coverage pattern
    - ✓ no "holes"
    - ✓ no cell superposition

PART 2
Cellular Coverage Concepts
(piu' in dettaglio sull'organizzazione di un sistema cellulare)

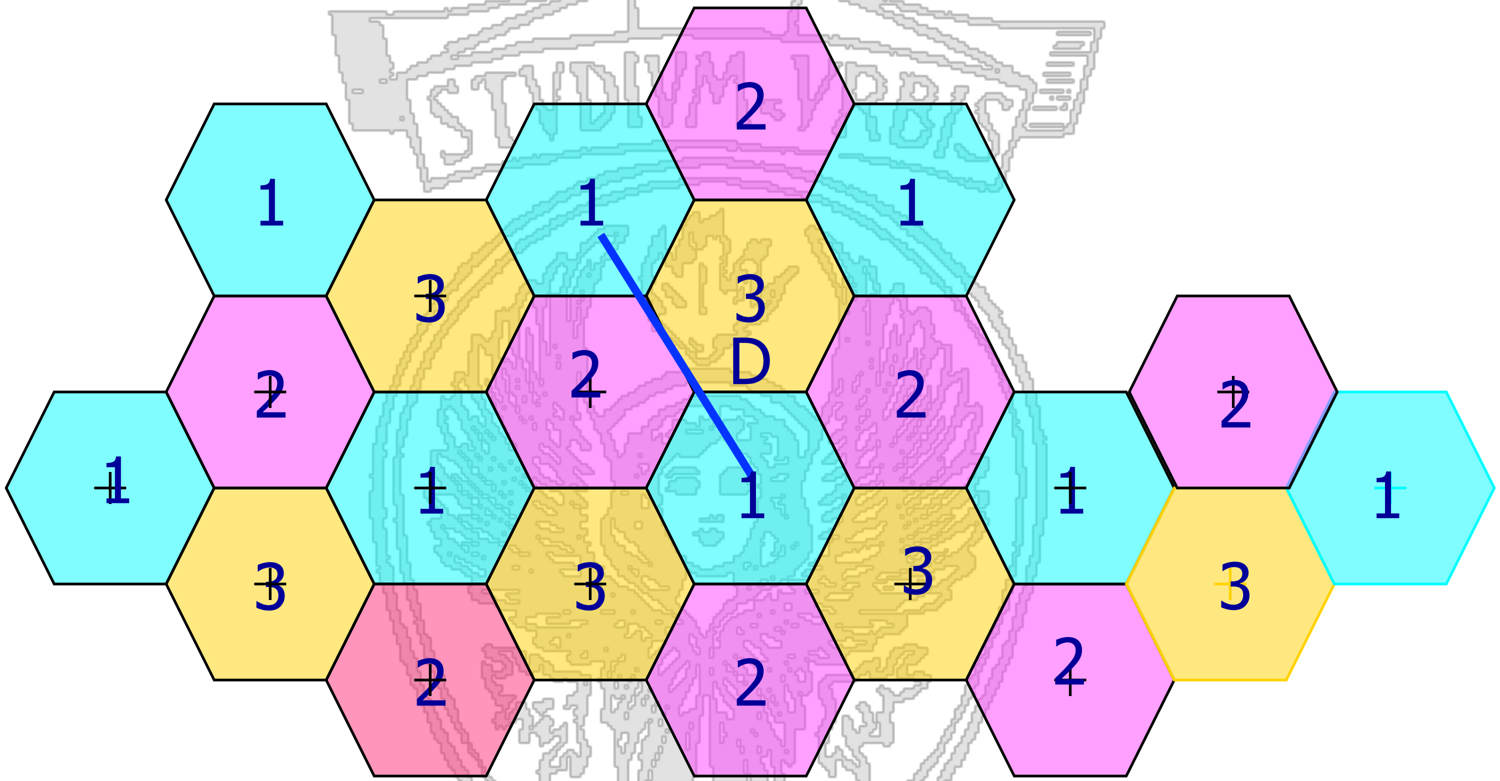
Lecture 2.2
Clusters and CCI

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,…

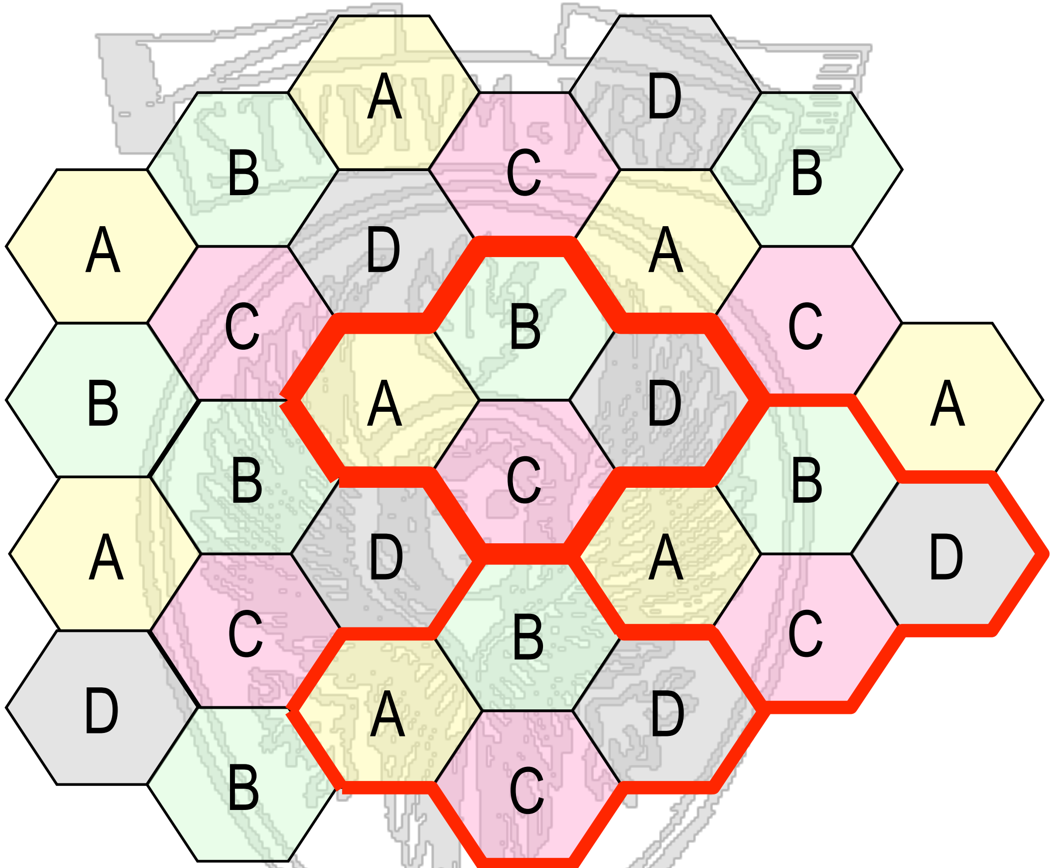


Dim. dei cluster



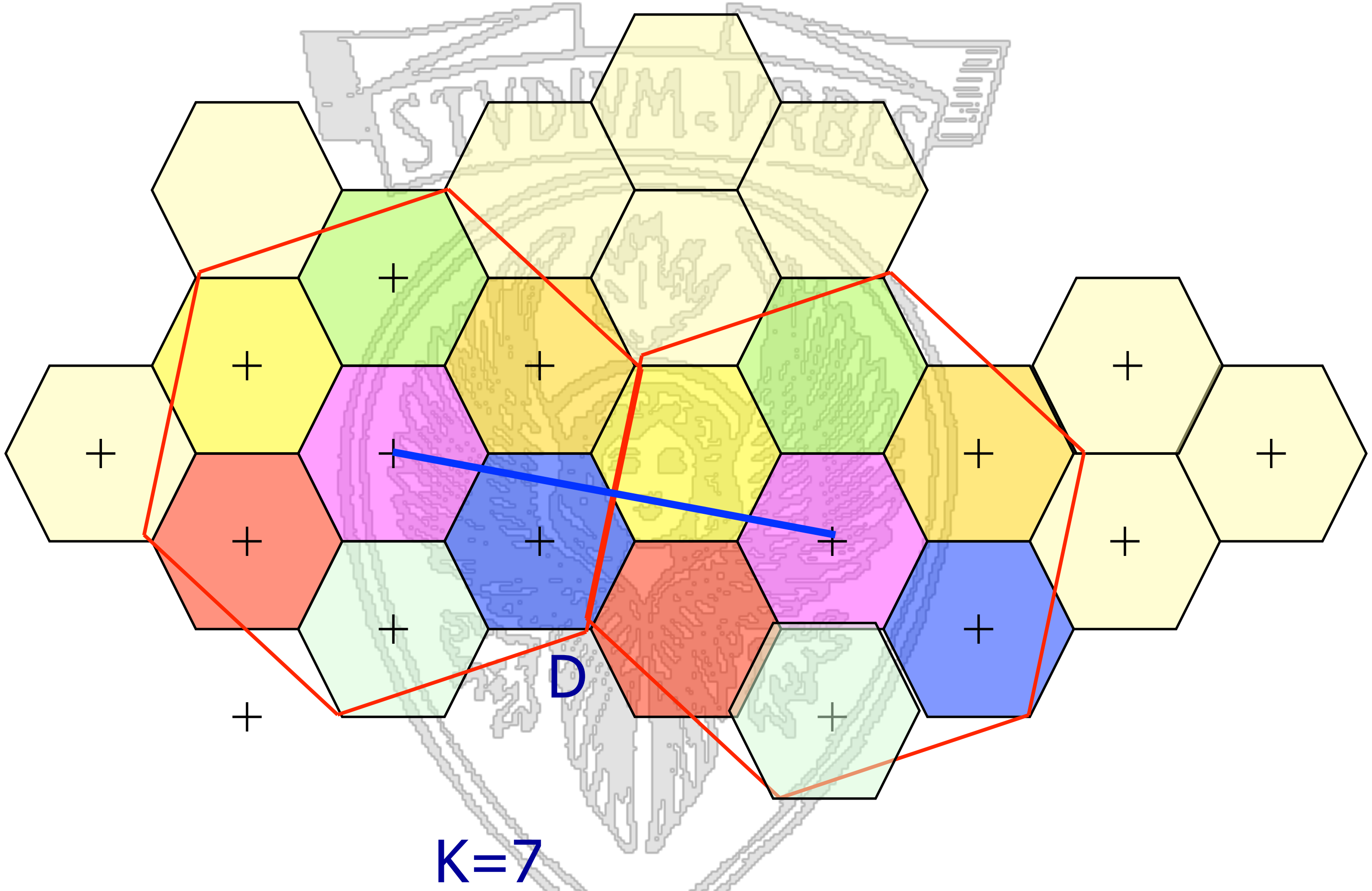
K=3

Dimensione dei cluster



K=4

Dimensione dei cluster

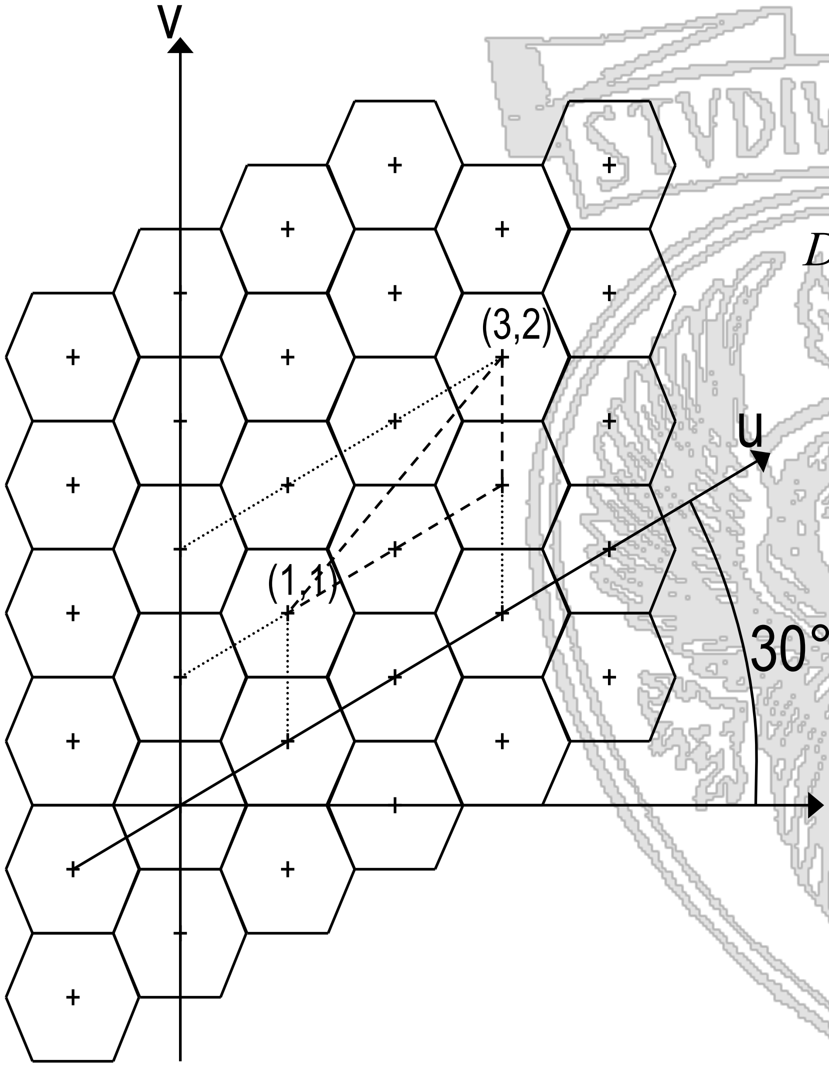


Reuse distance

- 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	3,46
7	4,58
9	5,20
12	6,00
13	6,24

Proof



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

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

  - 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):

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

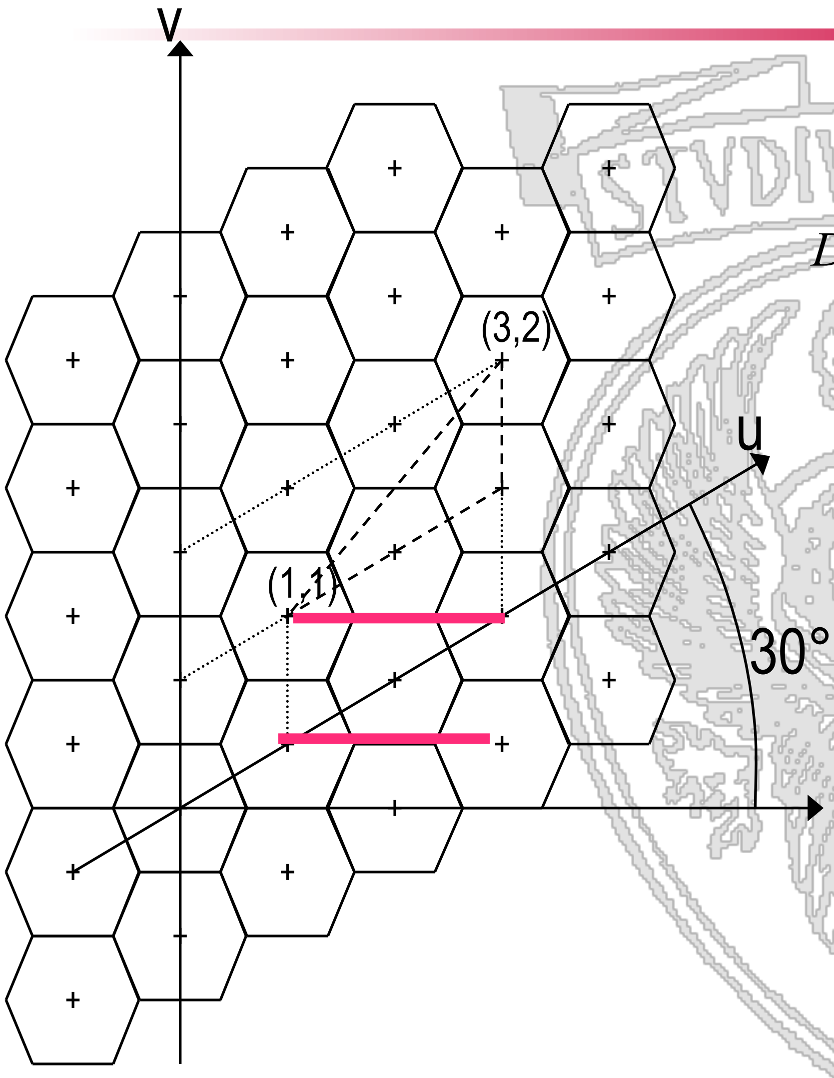
$$D_R = \sqrt{i^2 + j^2 + ij}$$

  - Cluster: easy to see that

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

  - hence: $\boxed{D = R\sqrt{3K}}$

Proof



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

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

  - 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):

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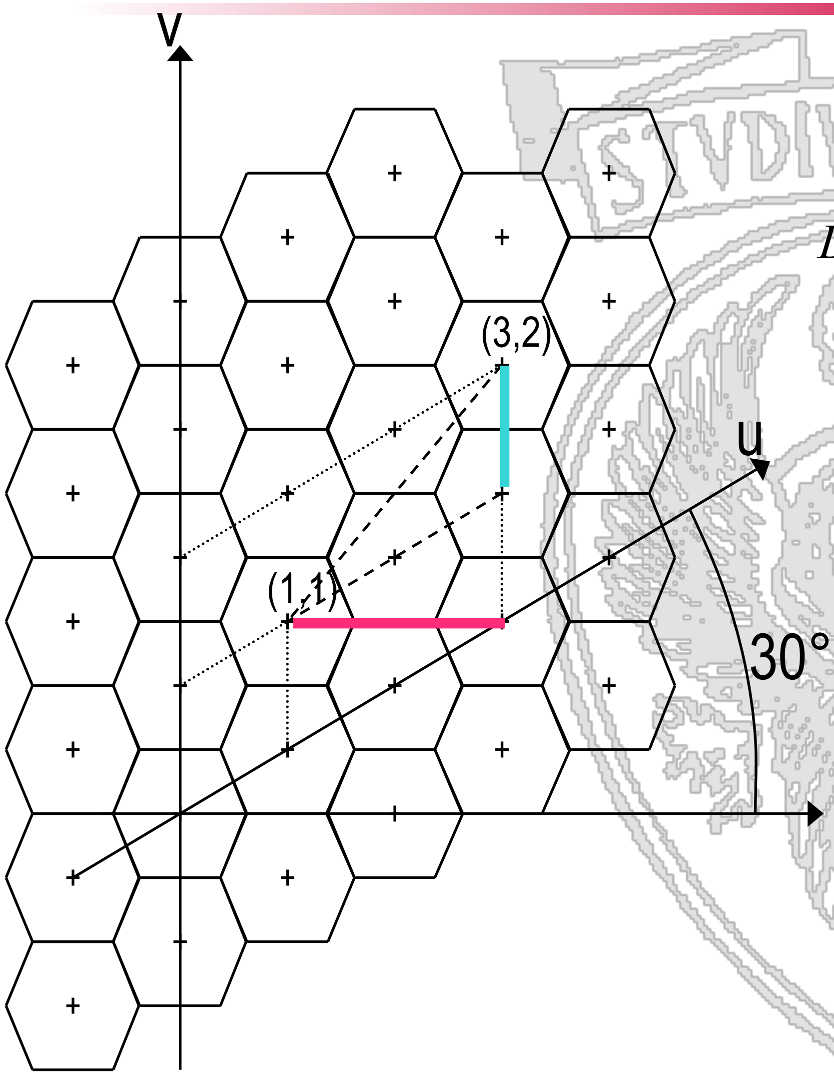

- Distance between two cell centers:
  - $(u_1,v_1) \leftrightarrow (u_2,v_2)$

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  - Simplifies to:

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

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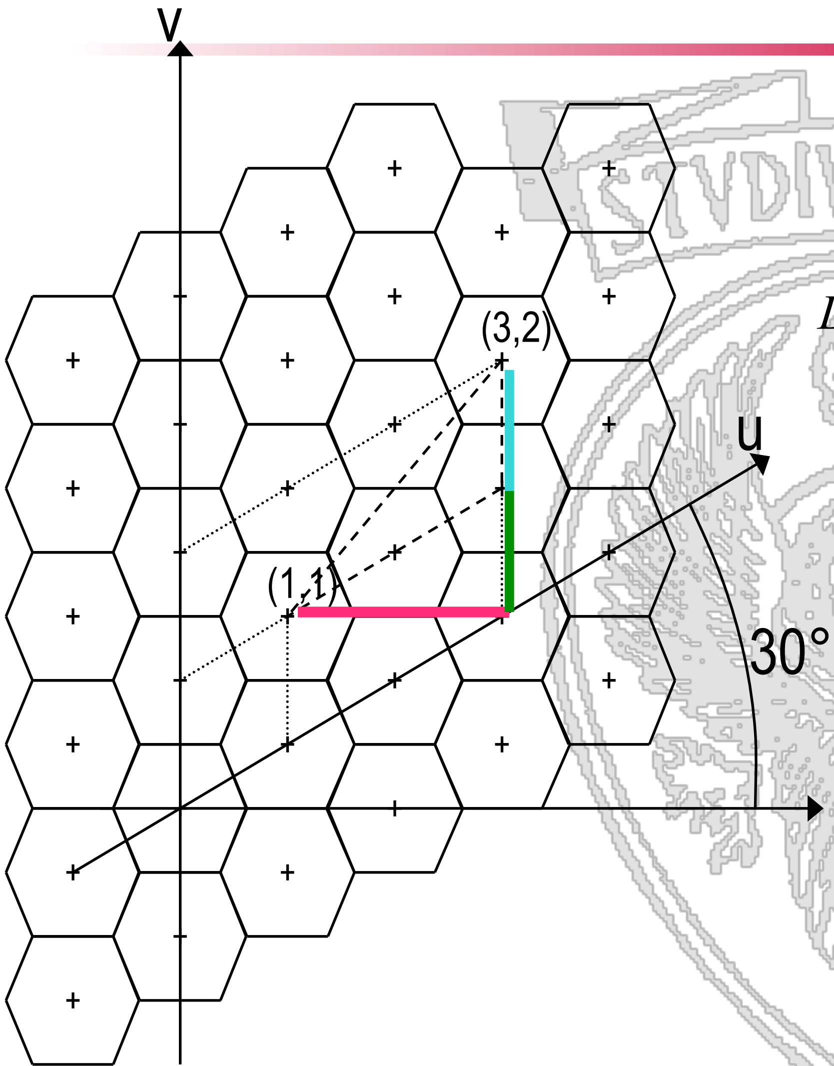
$$K=D_R^2=i^2+j^2+ij$$

  - hence:

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

Proof



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

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

  - 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):

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

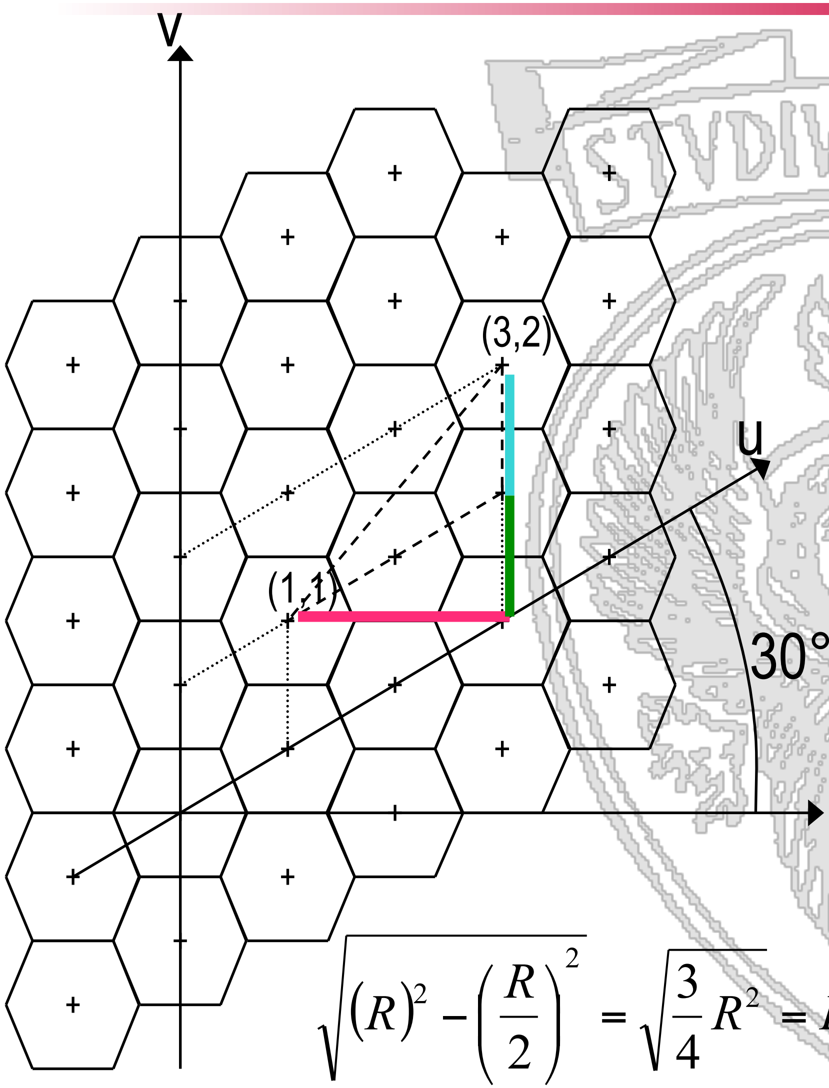
$$D_R = \sqrt{i^2 + j^2 + ij}$$

  - Cluster: easy to see that

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

  - hence: $\boxed{D = R\sqrt{3K}}$

Proof



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

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

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

  - 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):

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

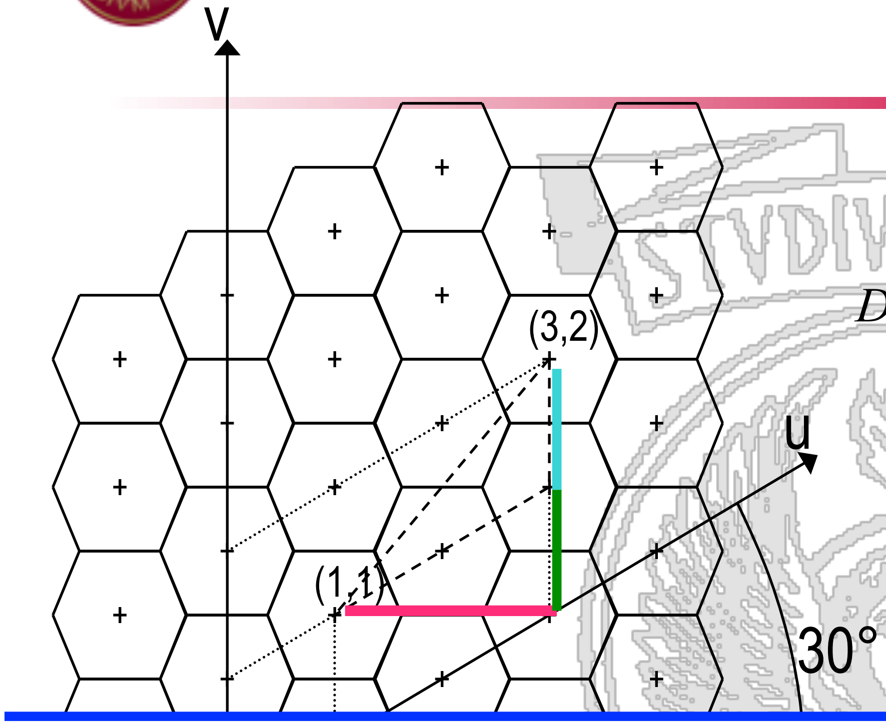
Distanza tra i centri di celle adiacenti

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

  - Cluster: easy to see that

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

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



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

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

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

Distanza tra i centri di celle adiacenti

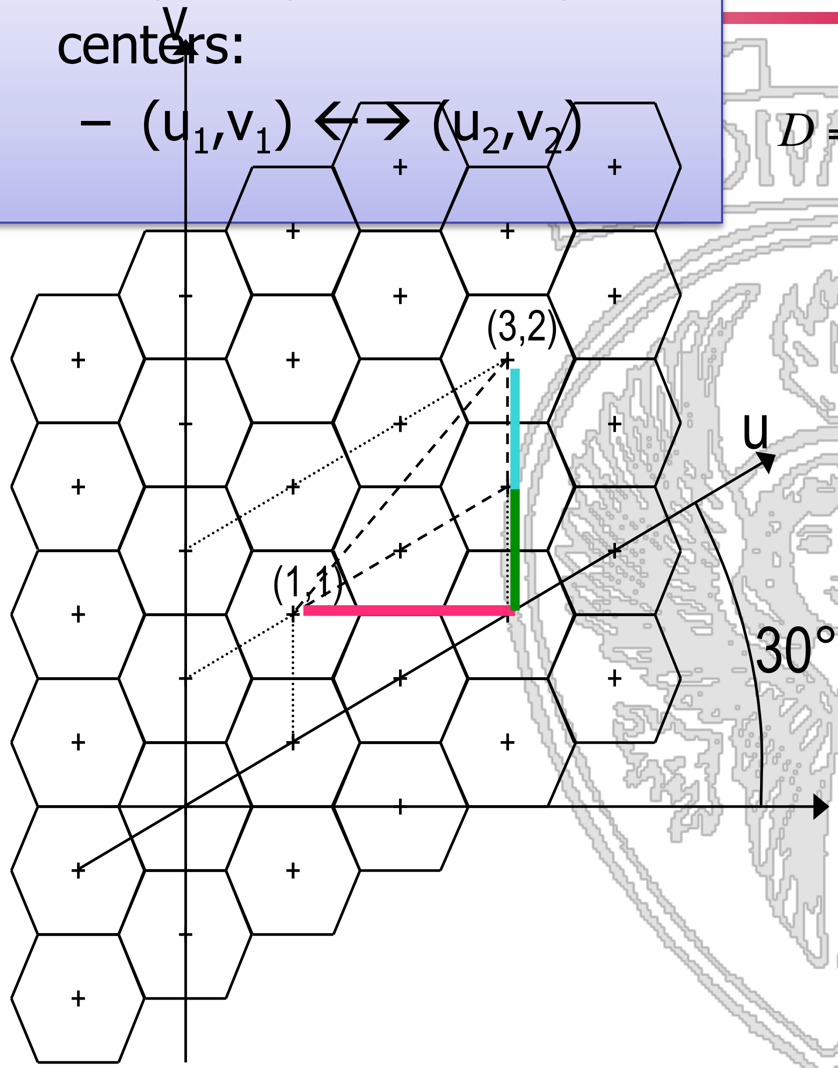
Se R è il raggio di un esagono la metà della distanza tra due celle adiacenti è

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

Quindi la distanza tra due celle adiacenti è 2 volte questa quantità!

Proof

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



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

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

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

$$D_R = \sqrt{i^2 + j^2 + ij}$$ (definizione di D_R)

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

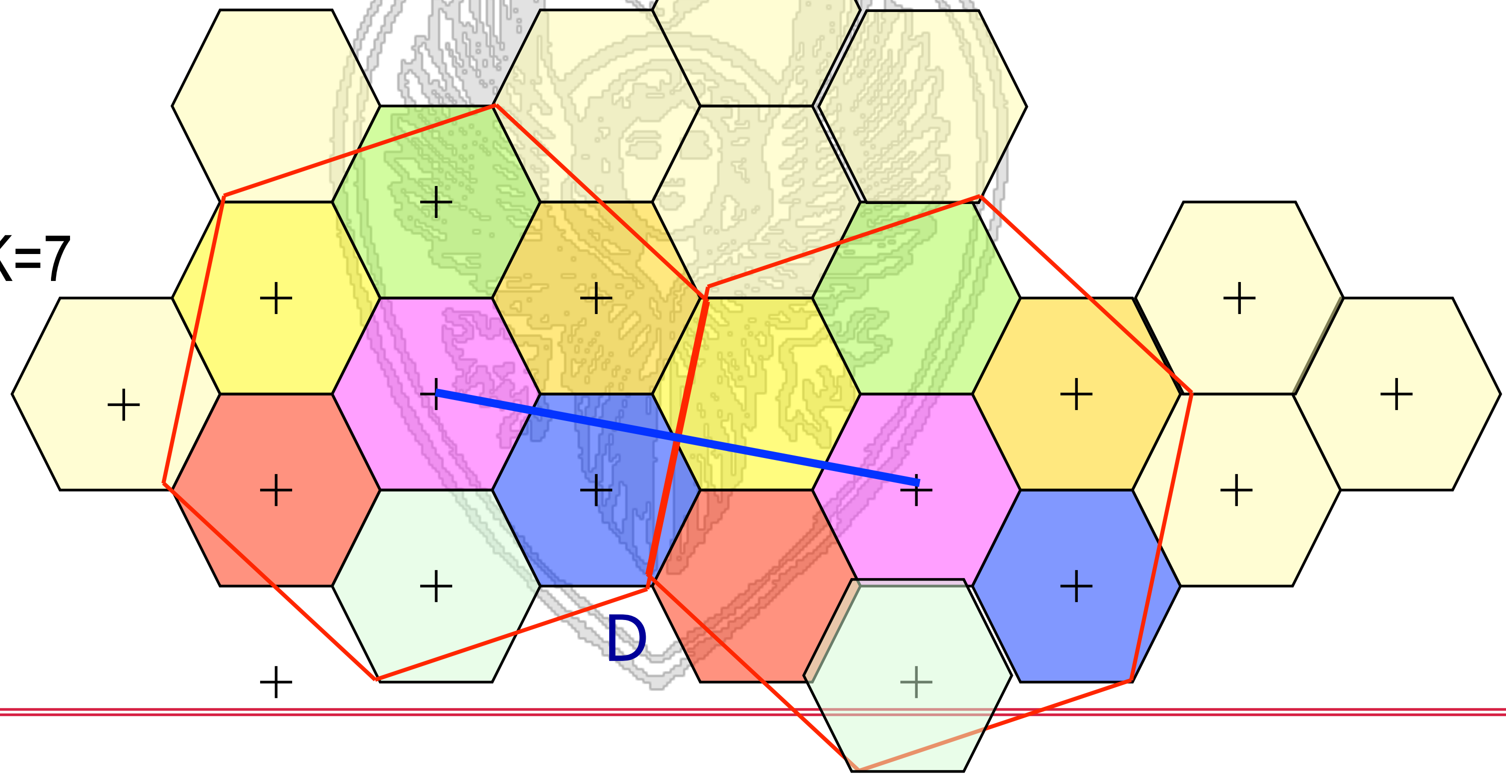
$$K = D^2 / 3R^2$$

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

Proof

- Se considero una cella che usa un determinato gruppo di frequenze A dato che voglio ricoprire l'area con cluster i centri delle celle interferenti saranno a distanza D
- Posso approssimare l'area di ciascun cluster con l'area di un esagono il cui raggio e' dato da $D/\sqrt{3}$

K=7



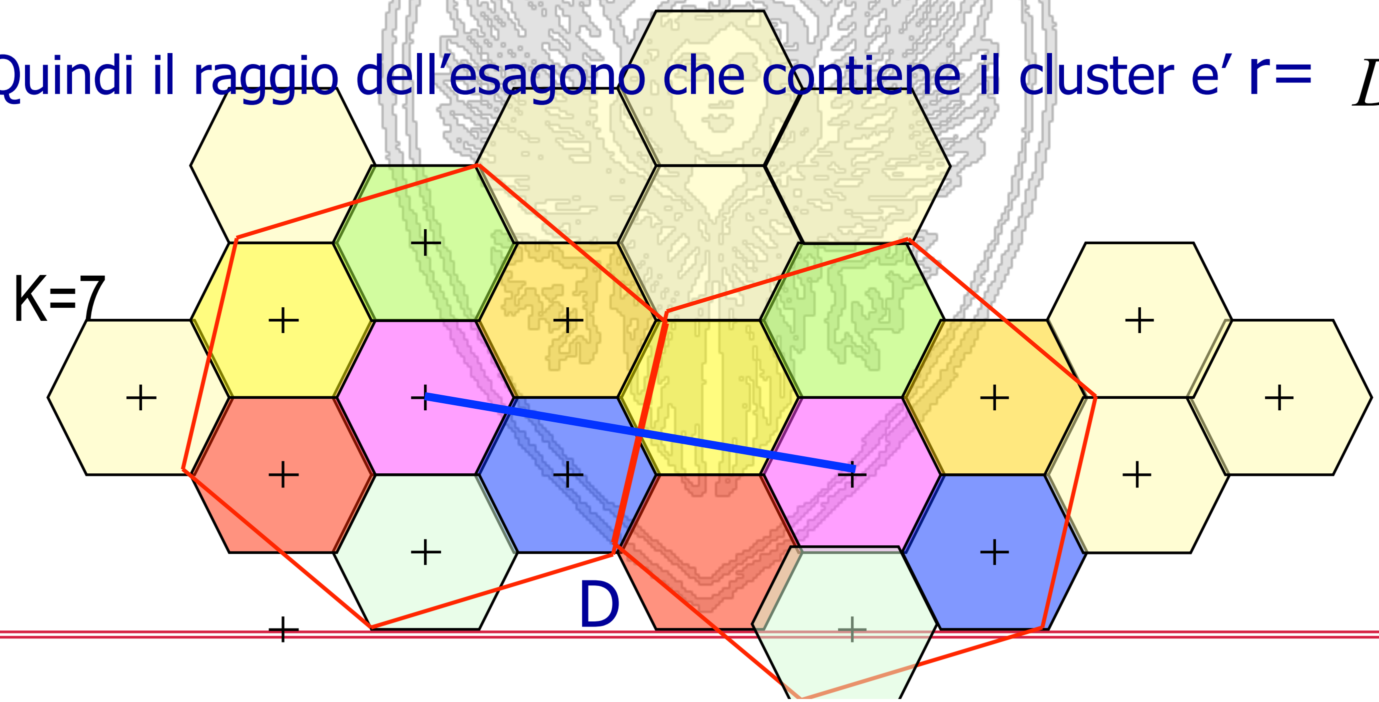
Proof

- Posso approssimare l'area di ciascun cluster con l'area di un esagono il cui raggio e' dato da $D/\sqrt{3}$

Se il raggio di una cella esagonale e' r la distanza tra i centri di due esagoni adiacenti e' $d = \sqrt{3}r$

Nel caso di cluster adiacenti la distanza tra i loro centri e 'D

Quindi il raggio dell'esagono che contiene il cluster e' r= $D/\sqrt{3}$



- L'area occupata da un cluster $A_{cluster}$ e' quindi data da: $$\frac{3}{2}\left(\frac{D}{\sqrt{3}}\right)^2\sqrt{3}$$

- Quanti esagoni di area $\frac{3}{2}(R)^2\sqrt{3}$ possono stare

in un'area pari a $\frac{3}{2}\left(\frac{D}{\sqrt{3}}\right)^2\sqrt{3}$?

- Risposta:

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

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

Proof

- L'area occupata da un cluster $A_{cluster}$ e' quindi data da:

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

- Quanti esagoni di area $\frac{3}{2}(R)^2\sqrt{3}$ possono stare in un'area pari a $\frac{3}{2}\left(\frac{D}{\sqrt{3}}\right)^2\sqrt{3}$?

dato che:

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

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

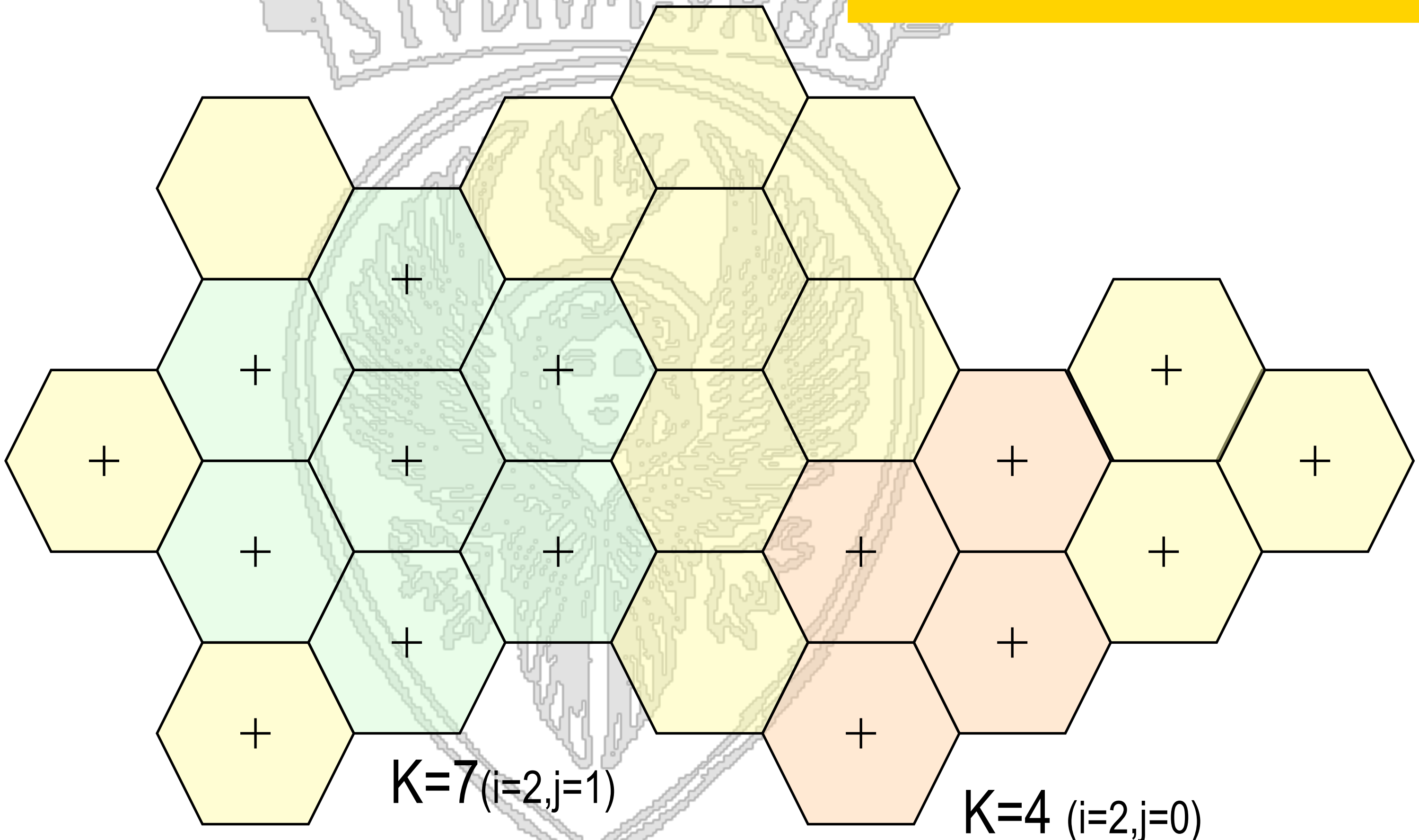
- Risposta:

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

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

Clusters

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

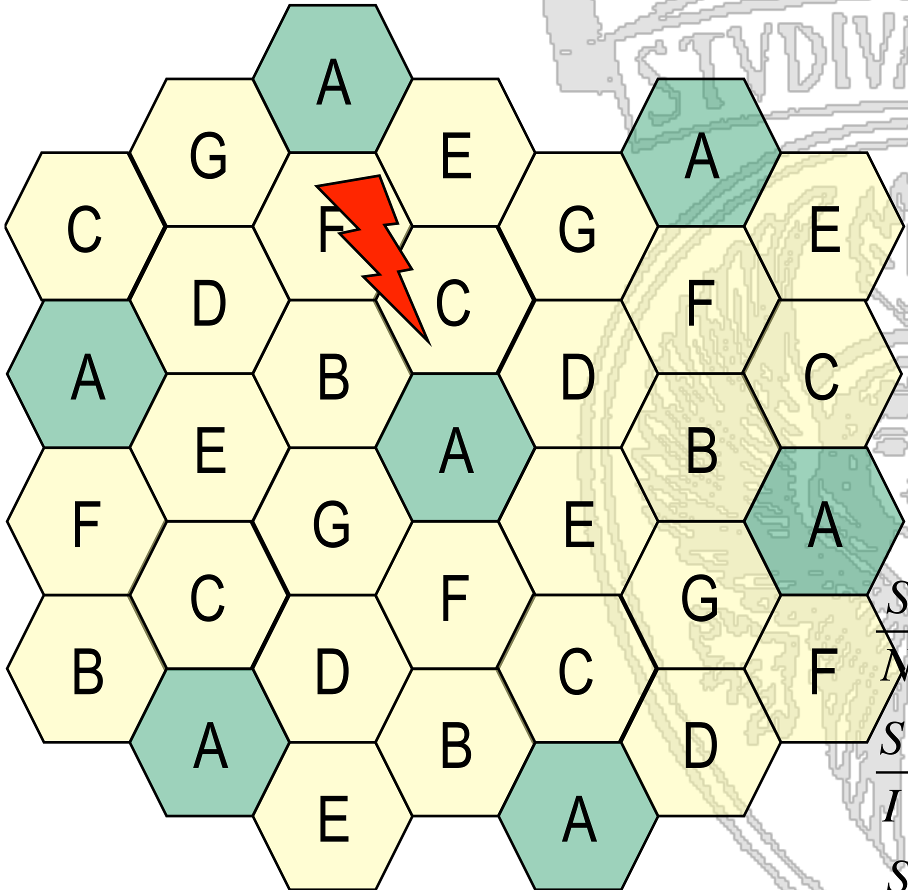


Possible clusters
all integer i,j values

i	j	K=ii+jj+ij	q=D/R
1	0	1	1,73
1	1	3	3,00
2	0	4	3,46
2	1	7	4,58
2	2	12	6,00
3	0	9	5,20
3	1	13	6,24
3	2	19	7,55
3	3	27	9,00
4	0	16	6,93
4	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

Dim.ammissibili dei cluster 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

$$\frac{S}{N} = \frac{\text{signal power (S)}}{\text{noise power } (\mathrm{N_S}) + \text{interfering signal power (I)}}$$

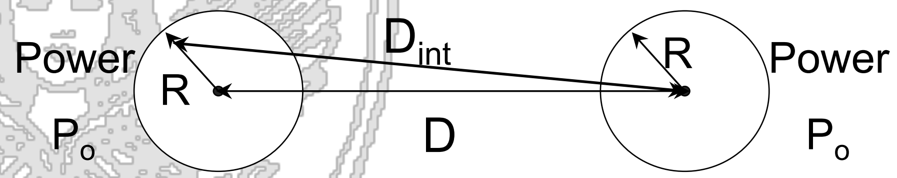
$$\frac{S}{I} = \frac{\text{signal power (S)}}{\text{interfering signal power (I)}}$$

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

CCI Computation – assumptions

- Assumptions
  - N_I=6 interfering cells
    - ✓ N_I=6: first ring interferers only
    - ✓ we neglect second-ring interferers
  - Negligible Noise N_S
    - ✓ S/N ~ S/I
  - $d^{-\eta}$ propagation law
    - ✓ η=4 (in general)
  - Same parameters for all BSs
    - ✓ Same P_{tx}, antenna gains, etc

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



$$D_{int} \sim D$$

CCI computation

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

$$= \frac{1}{N_I}\left(\frac{R}{D}\right)^{-\eta} = \frac{1}{N_I}\left(\frac{D}{R}\right)^{\eta} = \frac{1}{N_I} q^{\eta}$$

By using the assumptions of same cost and same D:

Results depend

on ratio q=D/R

(q=frequency reuse factor)

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

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

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

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

Examples

- target conditions:
  - S/I=9 dB
  - η=4
- Solution:

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

$$\left.\frac{S}{I} = \frac{(3K)^{\eta/2}}{6}\right|_{\eta=4} \Rightarrow K = \sqrt{\frac{2}{3}\cdot\frac{S}{I}}$$

$$K \geq 2.3 \quad \Rightarrow \quad K = 3$$

- target conditions:
  - S/I= 18dB
  - η=4.2
- Solution:

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

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

$$K \geq \frac{10^{1.23}}{3} = 5.63 \quad \Rightarrow \quad K = 7$$

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

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
13	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

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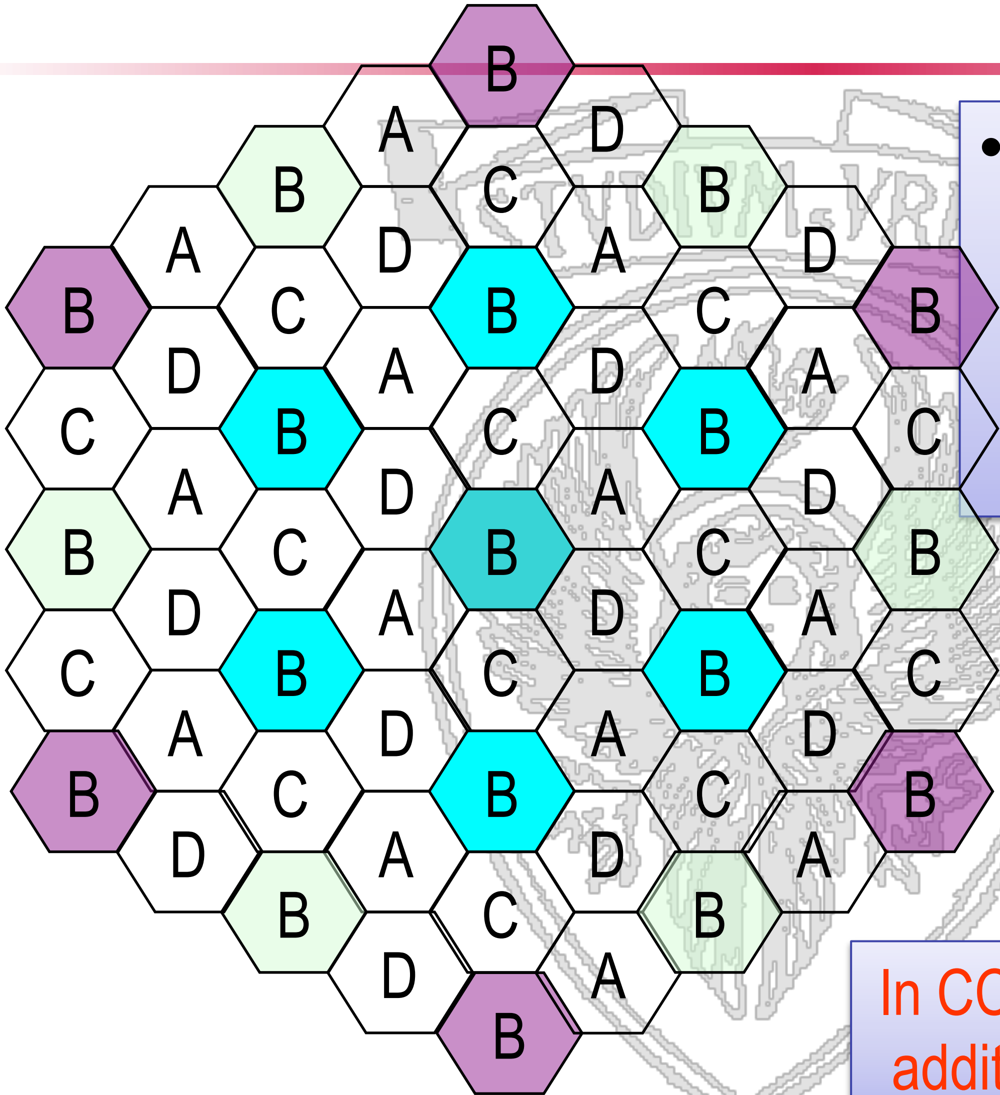
Additional interferers



- case K=4
  - note that for each cluster there are always N_I=6 first-ring interferers

In CCI computation, contribute of additional interferers is marginal

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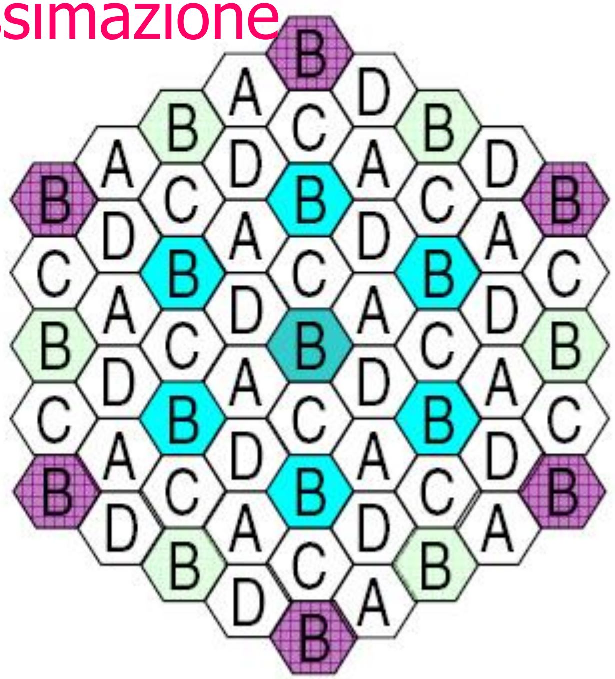
Multiple Tiers of Interferers

- Primo livello di interferenti a distanza D, secondo a distanza 2D, terzo a distanza 3D etc.

approssimazione



- Spesso gli interferenti oltre il primo livello hanno impatto non significativo
- Formula generale

$$SIR = \frac{R^{-\eta}}{N_{I1}(D)^{-\eta} + N_{I2}(2D)^{-\eta} + N_{I3}(3D)^{-\eta}}$$

N_{Ii} = *numero di celle interferenti a livello i*

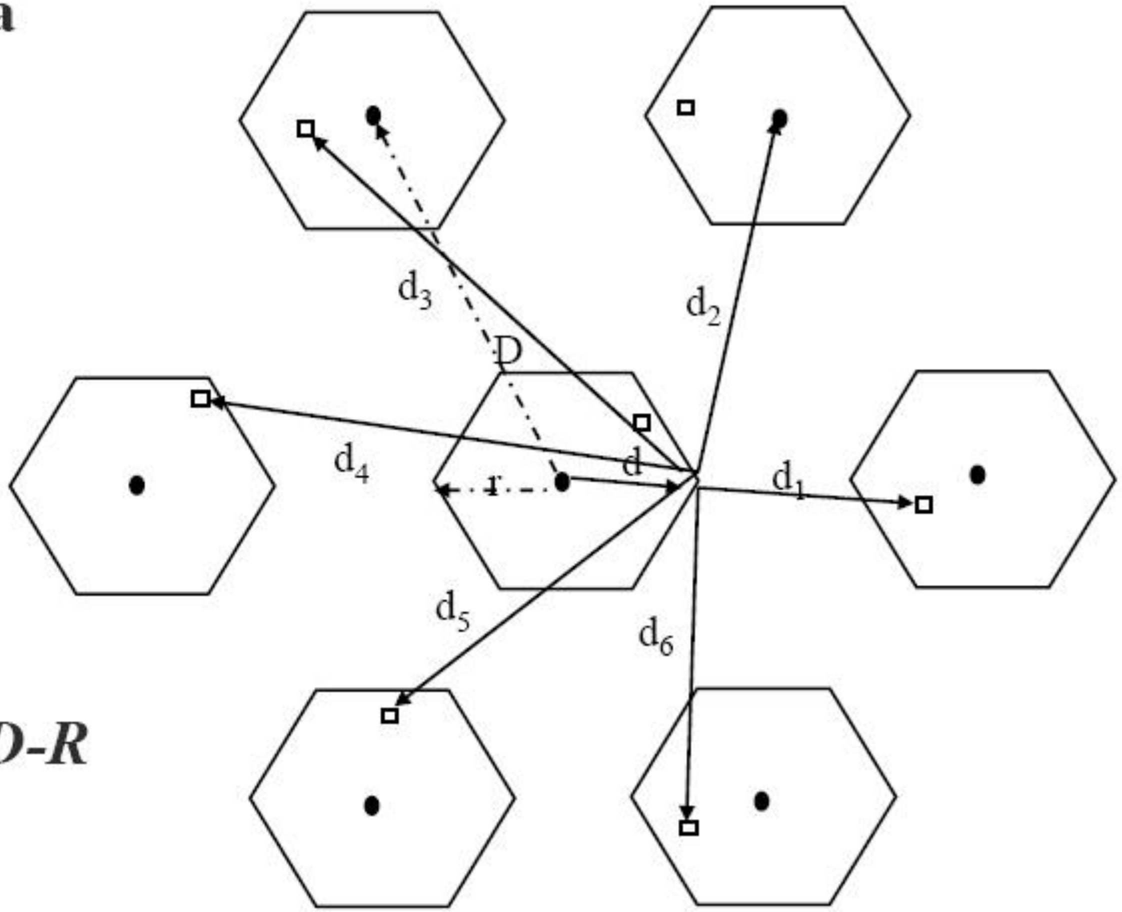
Special case of co-channel interference

- **stesse antenne e stessa potenza**

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

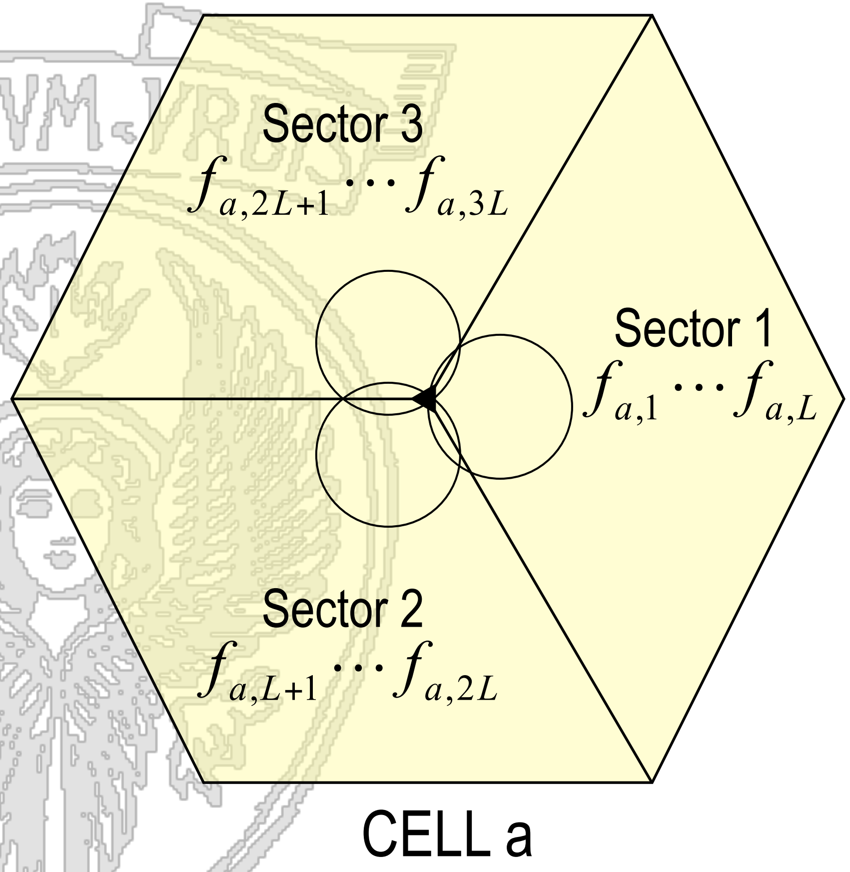
- **caso peggiore $d = r$**
- **approssimazione $d_i = D\text{-}R$**

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



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



CCI reduction via sectorization
three sectors case

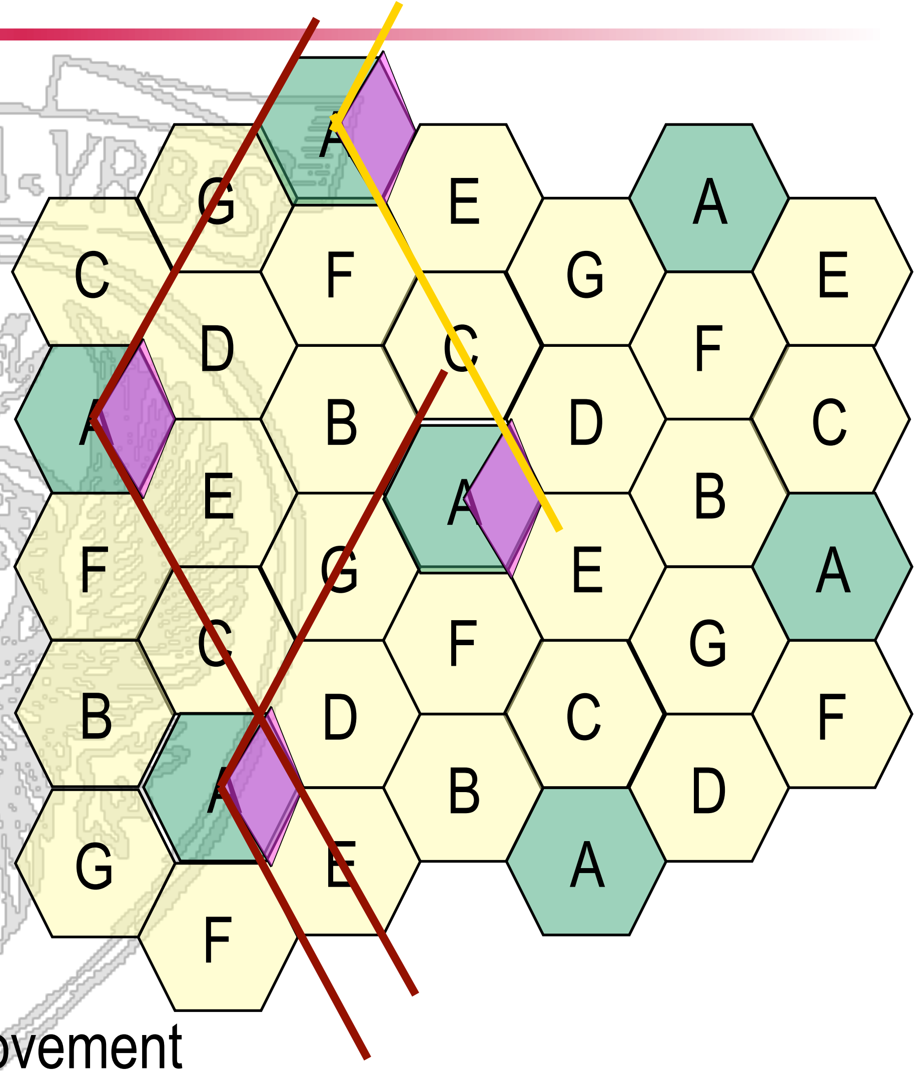
- Inferference from 2 cells, only
  - Instead of 6 cells

With usual approxs

(specifically, $D_{int} \sim D$)

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

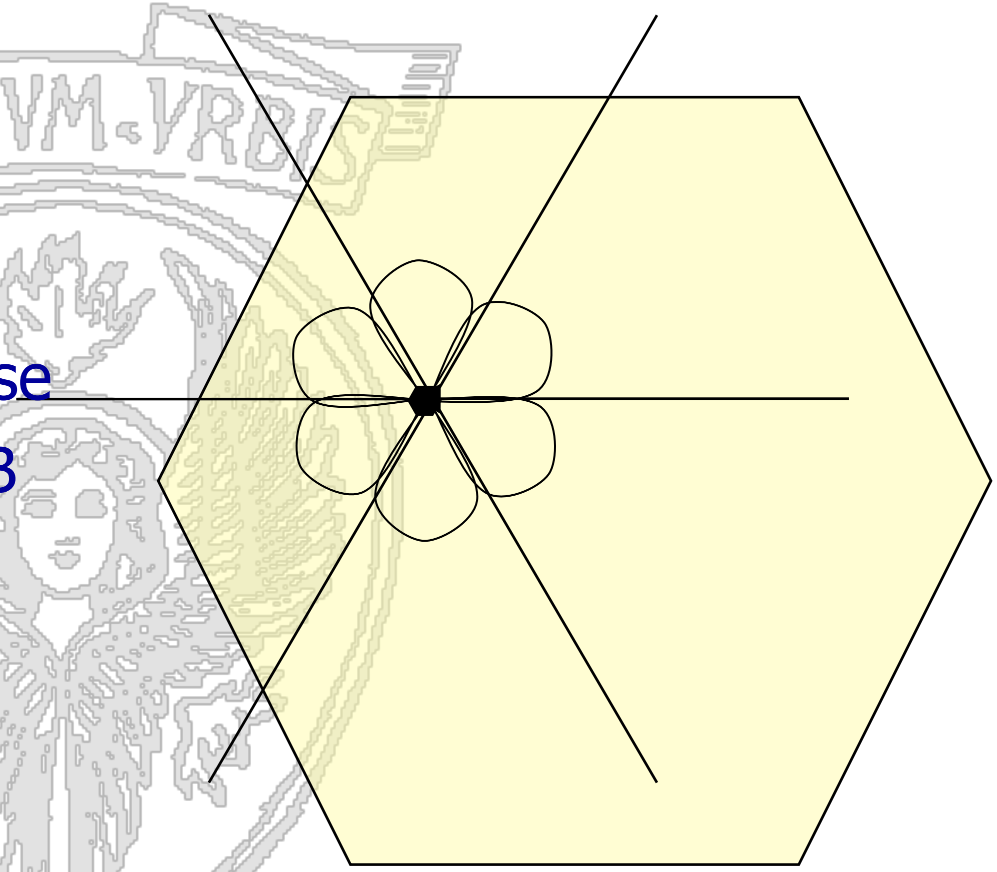
$$\left[\frac{S}{I}\right]_{120^o} dB = \left[\frac{S}{I}\right]_{omni} dB + 4.77$$



Conclusion: 3 sectors = 4.77 dB improvement

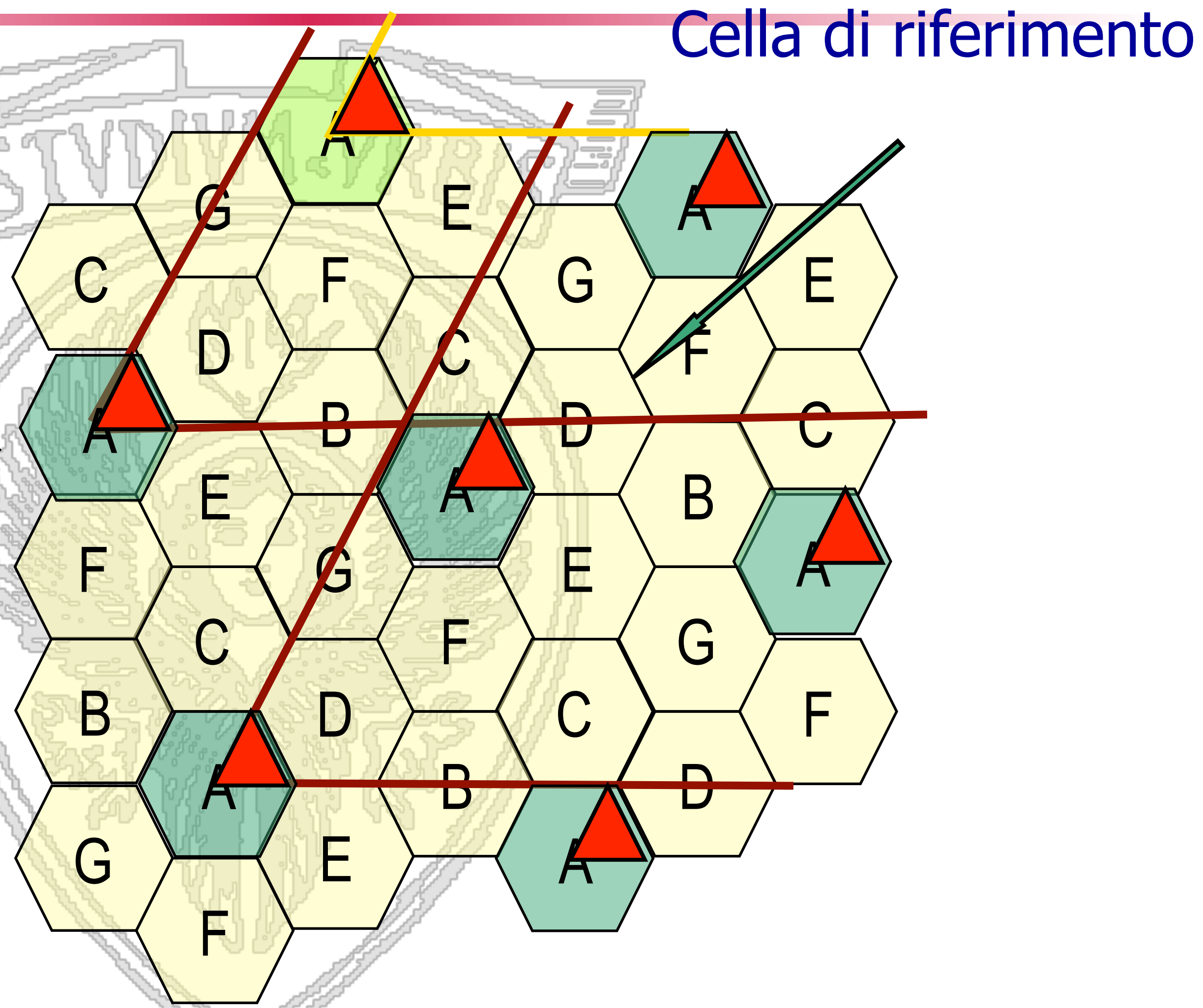
6 sectors

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



6 sectors

Unica BS che disturba le ricezioni/ trasmissioni verso/dalle MU nella cella di riferimento



Pianificazione di sistemi cellulari

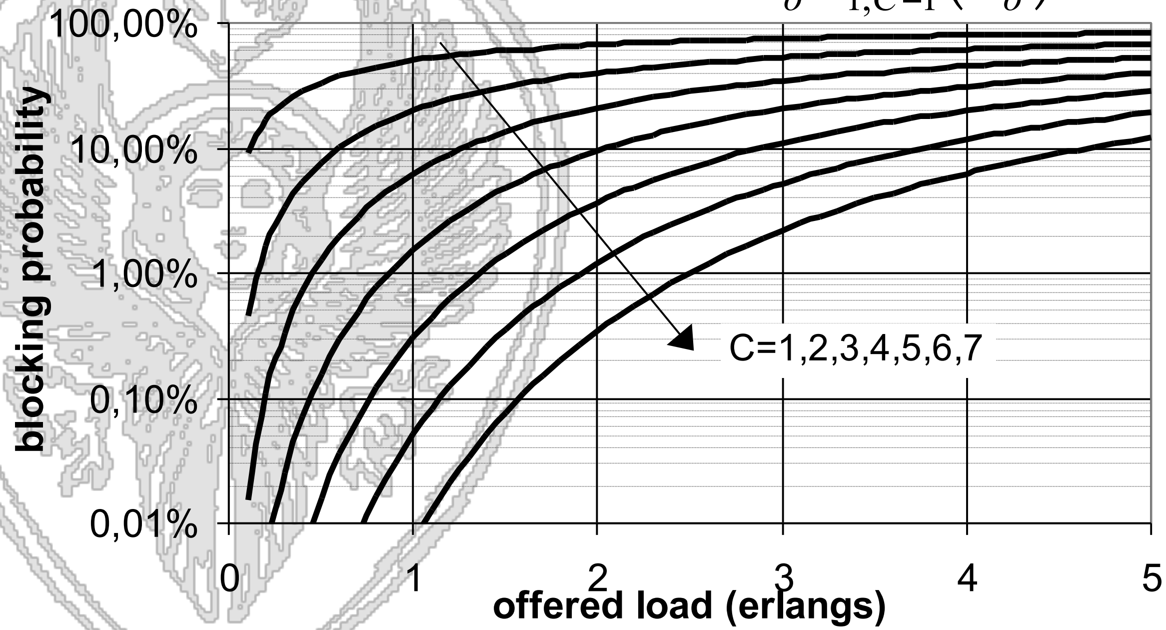
Blocking probability: Erlang-B

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

➔ Efficient recursive computation available

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

$$\Pi_{block} = \frac{\dfrac{A_o^C}{C!}}{\displaystyle\sum_{j=0}^{C} \frac{A_o^j}{j!}} = E_{1,C}(A_o)$$



- 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 A_o
    - ✓ Target GOS B_{target}
  - C (number of channels) is obtained from numerical inversion of

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

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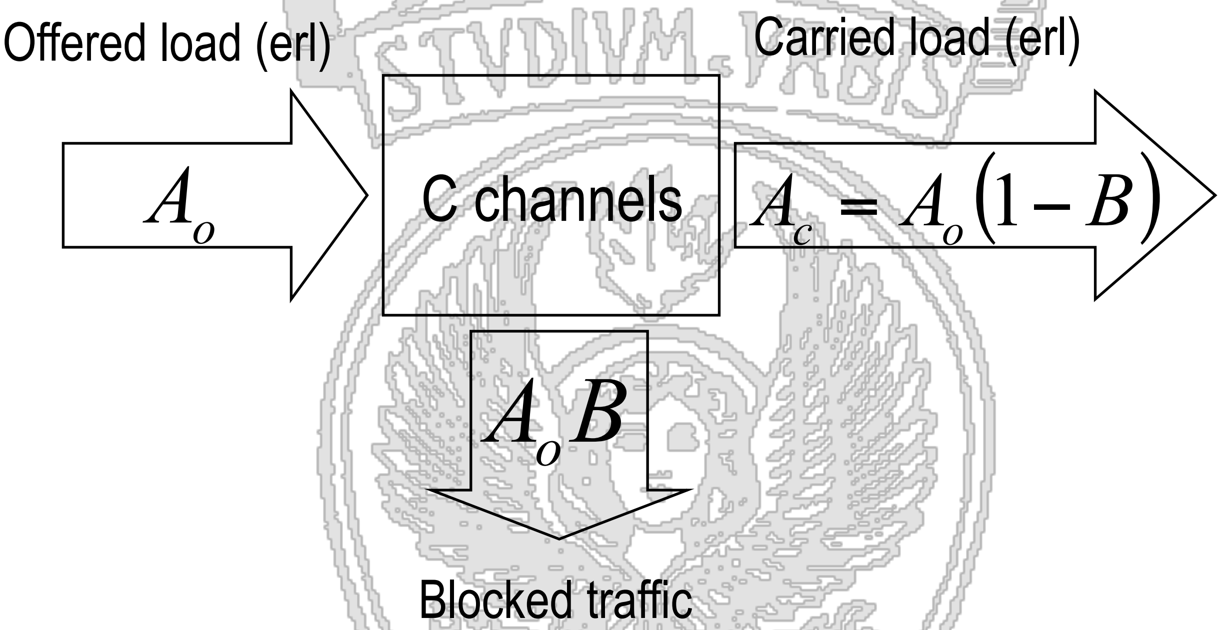
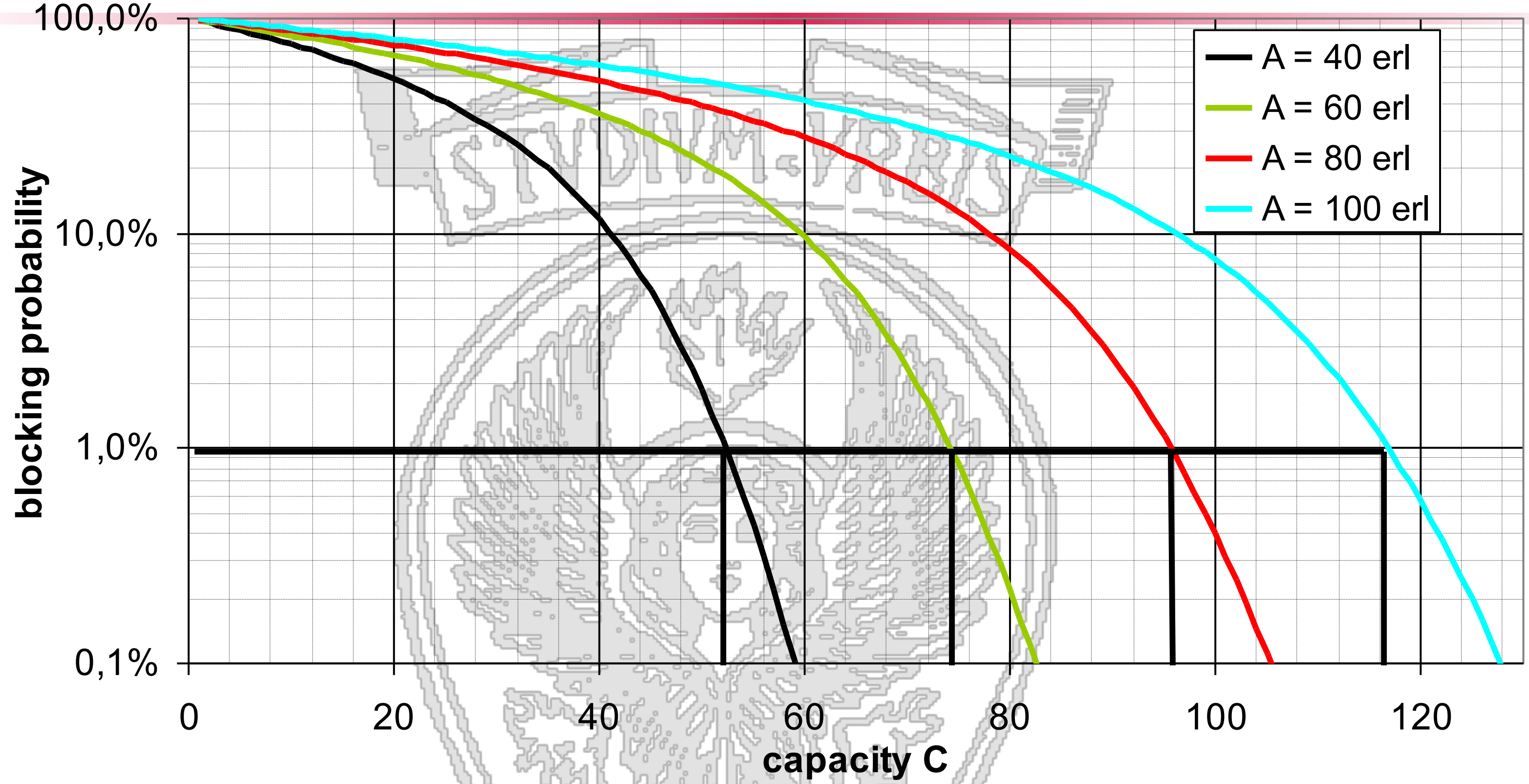
Channel usage efficiency



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

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

example



GOS = 1% maximum blocking.

Resulting system dimensioning and efficiency:

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

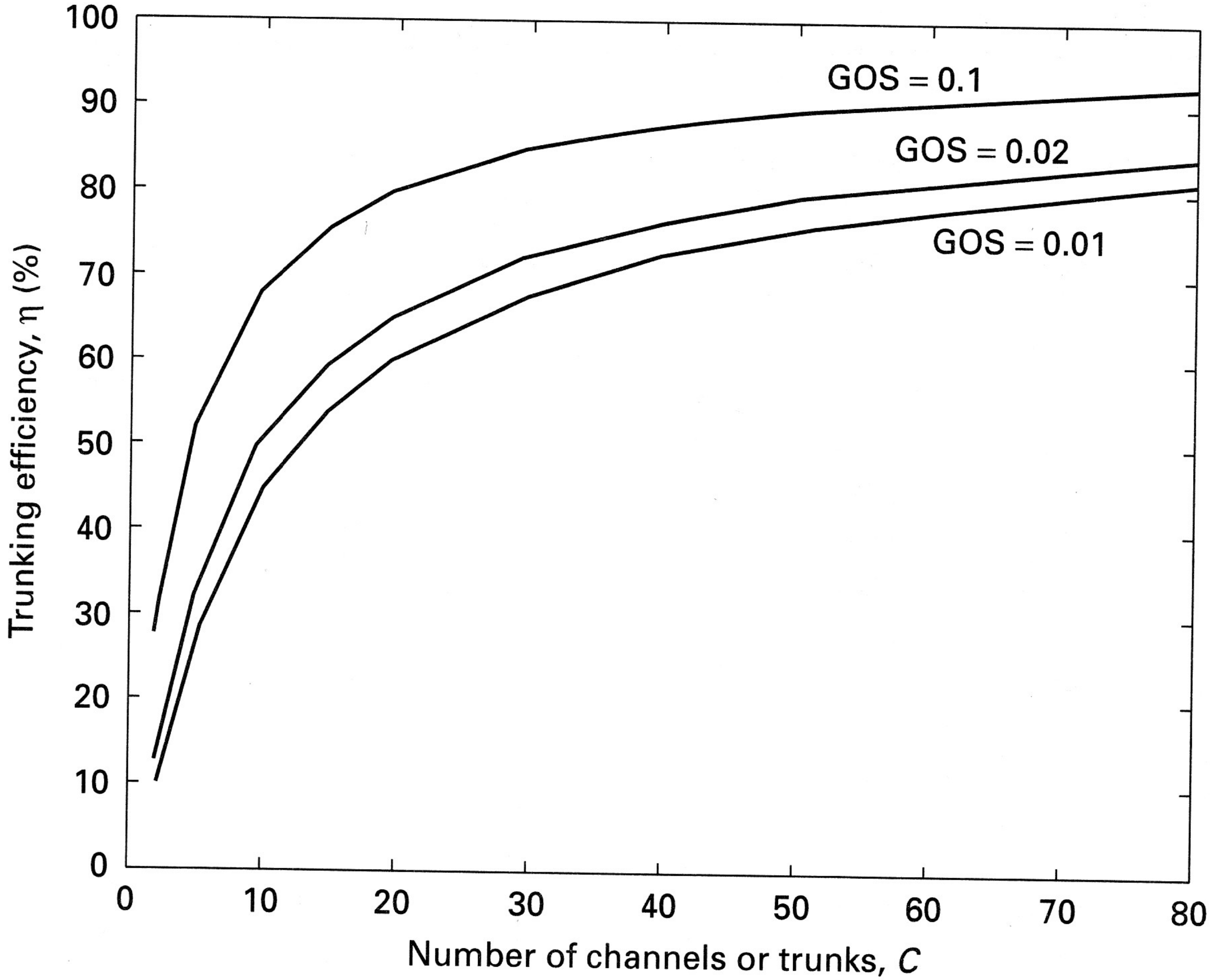


FIGURE 4.21 Trunking efficiency plots.

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 P(B)=	0.01	0.015	0.02	0.03
1	0.010	0.015	0.020	0.031
2	0.153	0.190	0.223	0.282
3	0.465	0.536	0.603	0.715
4	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
7	2.503	2.743	2.936	3.250
8	3.129	3.405	3.627	3.887
9	3.783	4.096	4.345	4.748
10	4.462	4.808	6.084	5.529

ErlangB Online calculator:

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

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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?

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

Meglio con area dell' esagono !

➔ **Third step:**
- ⇨ Given density of users
  - →δ=500 users/km²
- ⇨ Evaluate cell radius
- ⇨ R~438m

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

→ Provider B:
- ⇨ 30 channels/cell
- ⇨ at 2%: A_o=21.93 erl/cell
- ⇨ 657.9 erl-total (30 cells)
- ⇨ M=**4386** overall users

→ Provider C:
- ⇨ 20 channels/cell
- ⇨ 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)
  - Question: how many users can support each provide
- 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

il fatto di avere più celle con pochi canali (ad esempio perche' ho scelto un K diverso) non porta ad un vantaggio in termini di capacità del sistema

→ Provider A:
- ⇨ 40 channels/cell
- ⇨ at 2%: A_o=30.99 erl/cell
- ⇨ 619.8 erl-total (20 cells)
- ⇨ M=**4132** overall users

→ Provider B:
- ⇨ 30 channels/cell
- ⇨ at 2%: A_o=21.93 erl/cell
- ⇨ 657.9 erl-total (30 cells)
- ⇨ M=**4386** overall users

→ Pro
- ⇨
- ⇨
- ⇨
- ⇨

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

Sectorization and traffic

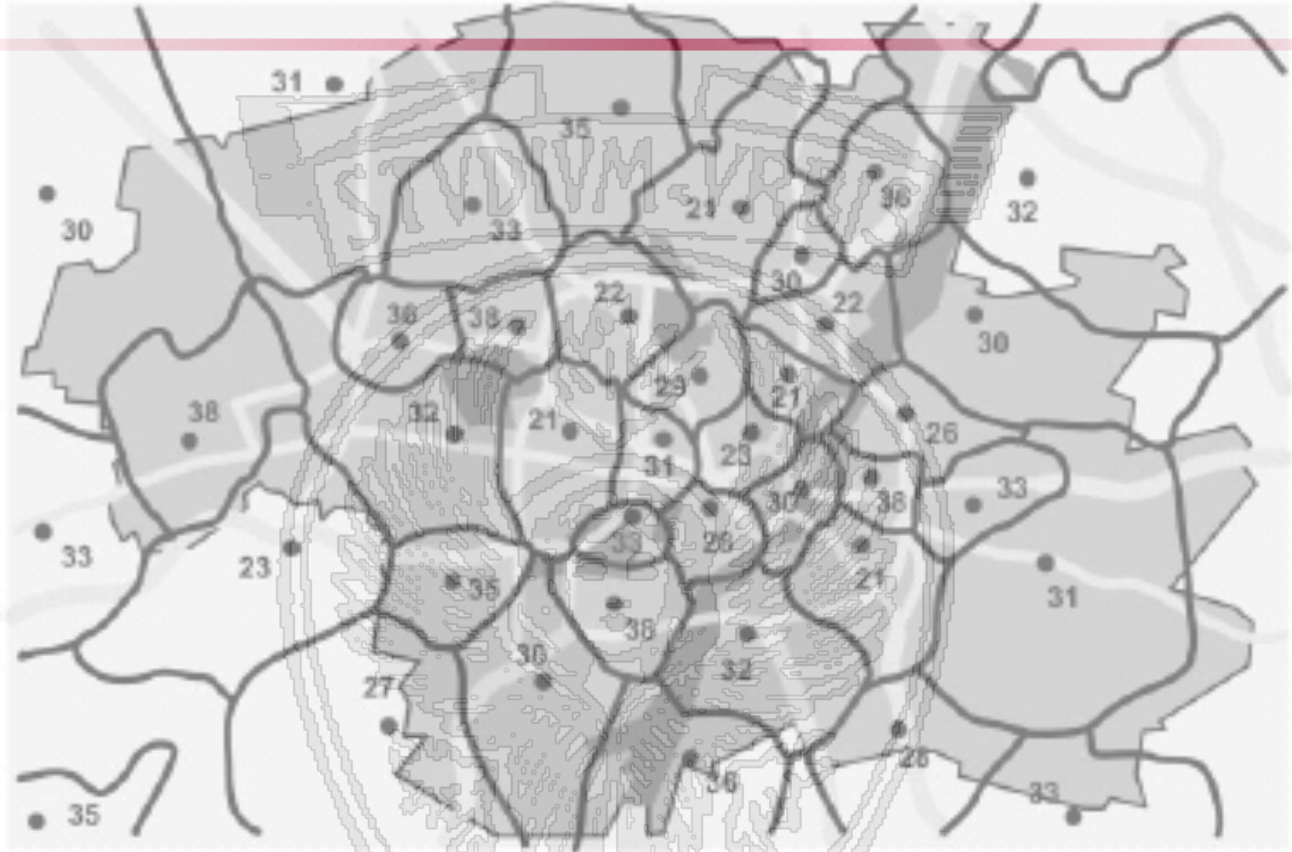
- Assume cluster K=7
- Omnidirectional antennas: S/I=18.7 dB
- 120° sectors: S/I=23.4 dB
- 60° sectors: S/I=26.4 dB

- 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 A_o=1x46.95= 46.95 erl
    ρ=77.46%
  - 120°: 60/3=20 channels A_o=3x12.03= 36.09erl
    ρ=59.54%
  - 60°: 60/6=10 channels A_o=6x4.46= 26.76erl
    ρ=44.15%

Erlang supportati per settore

Cells in real world



Shaped by terrain, shadowing, etc

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