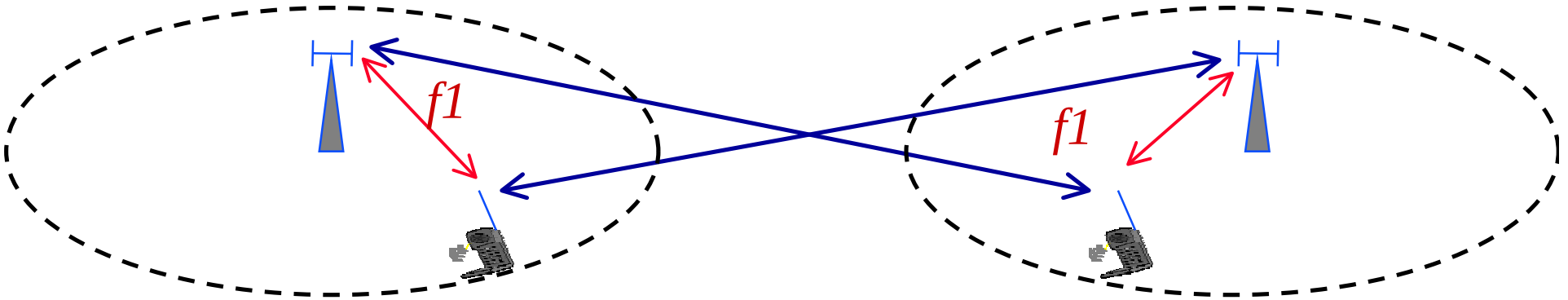
Mobile Radio Communications

Course 2: The cellular concept

Scarce radio spectrum

AMPS: 832 paired frequencies; 832 paired channels
GSM: 124 paired frequencies; 992 paired channels

FREQUENCY REUSE



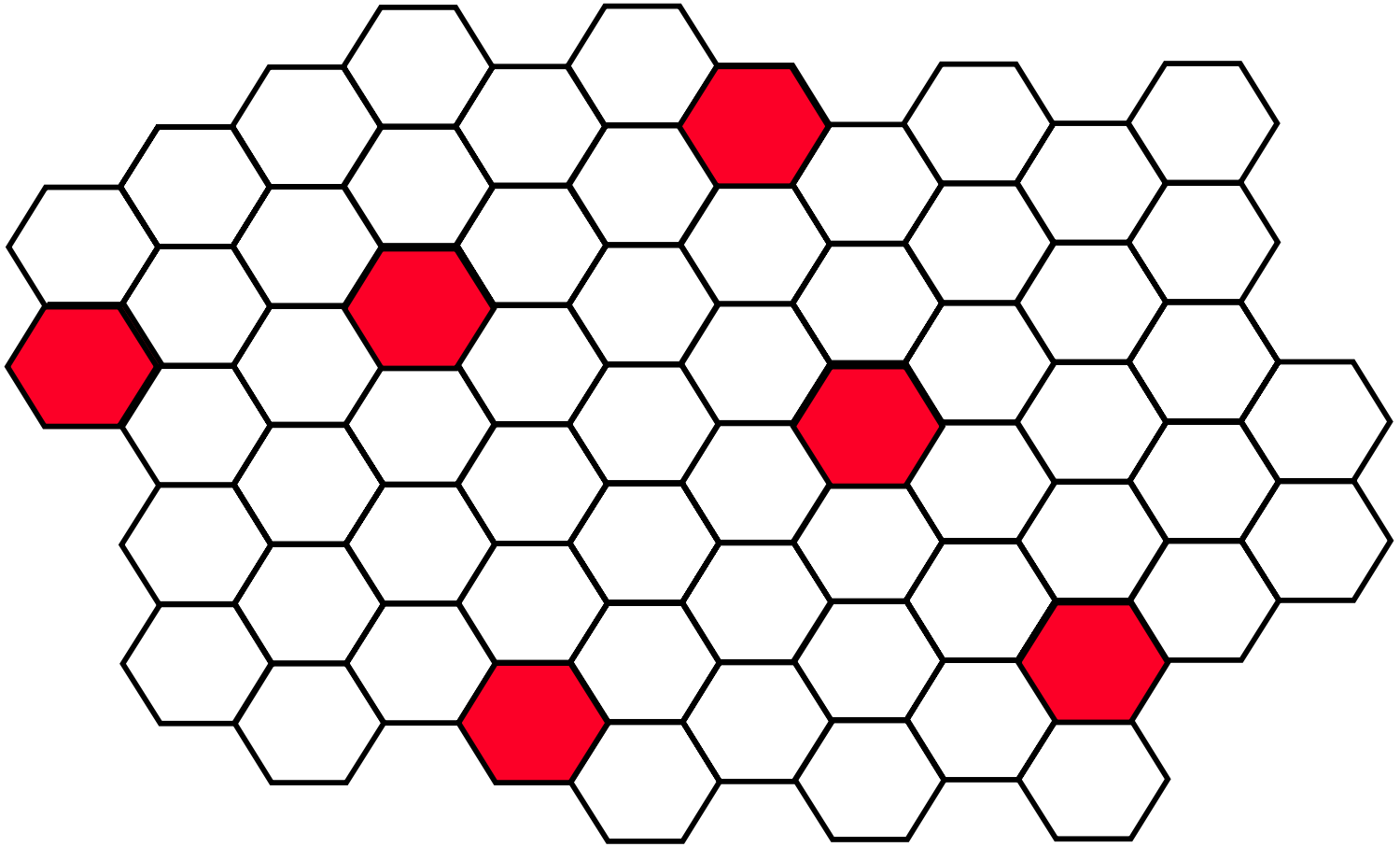
Signal-to-interference ratio

S: signal power from desired transmitter

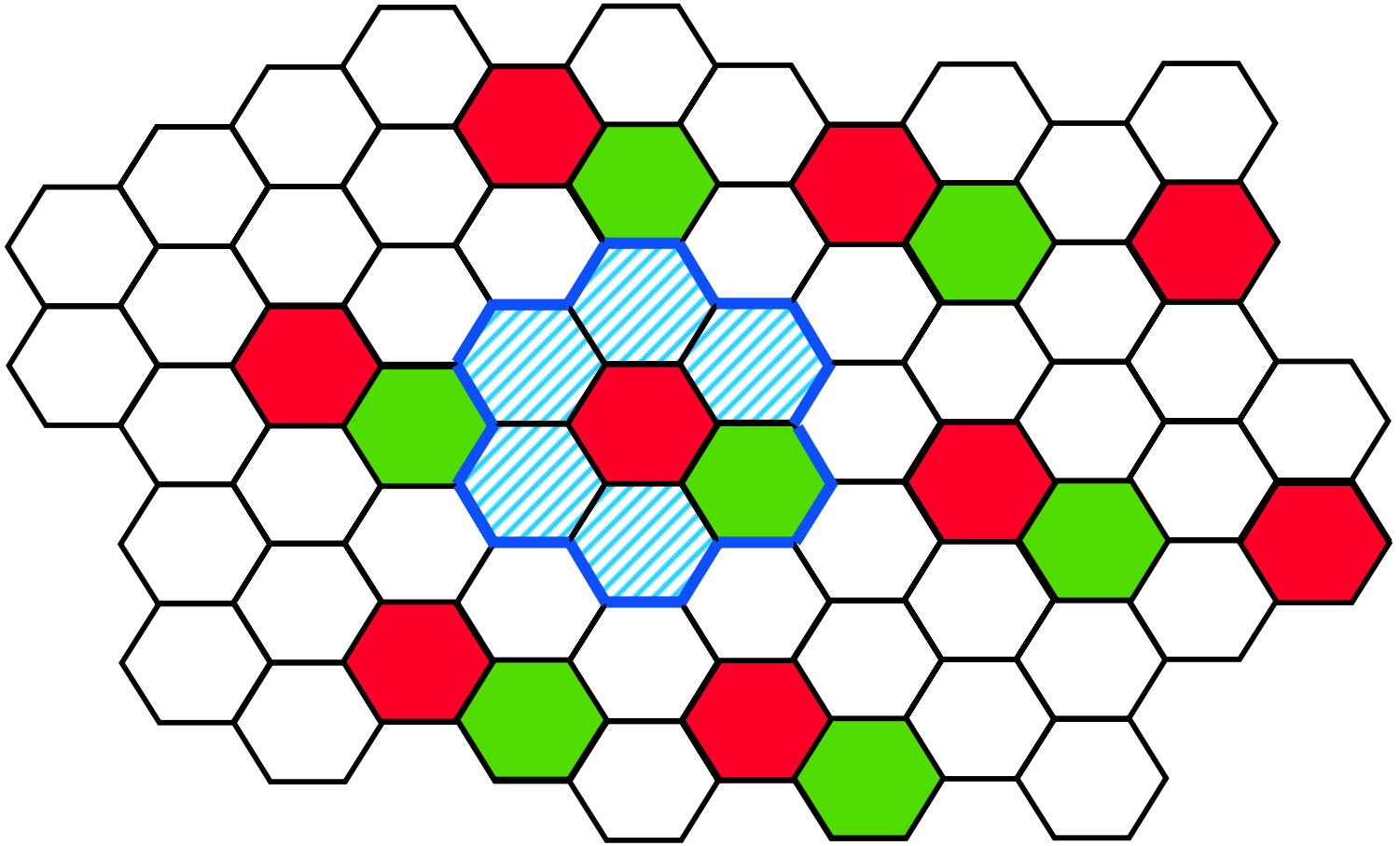
I: total signal power from undesired transmitters

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

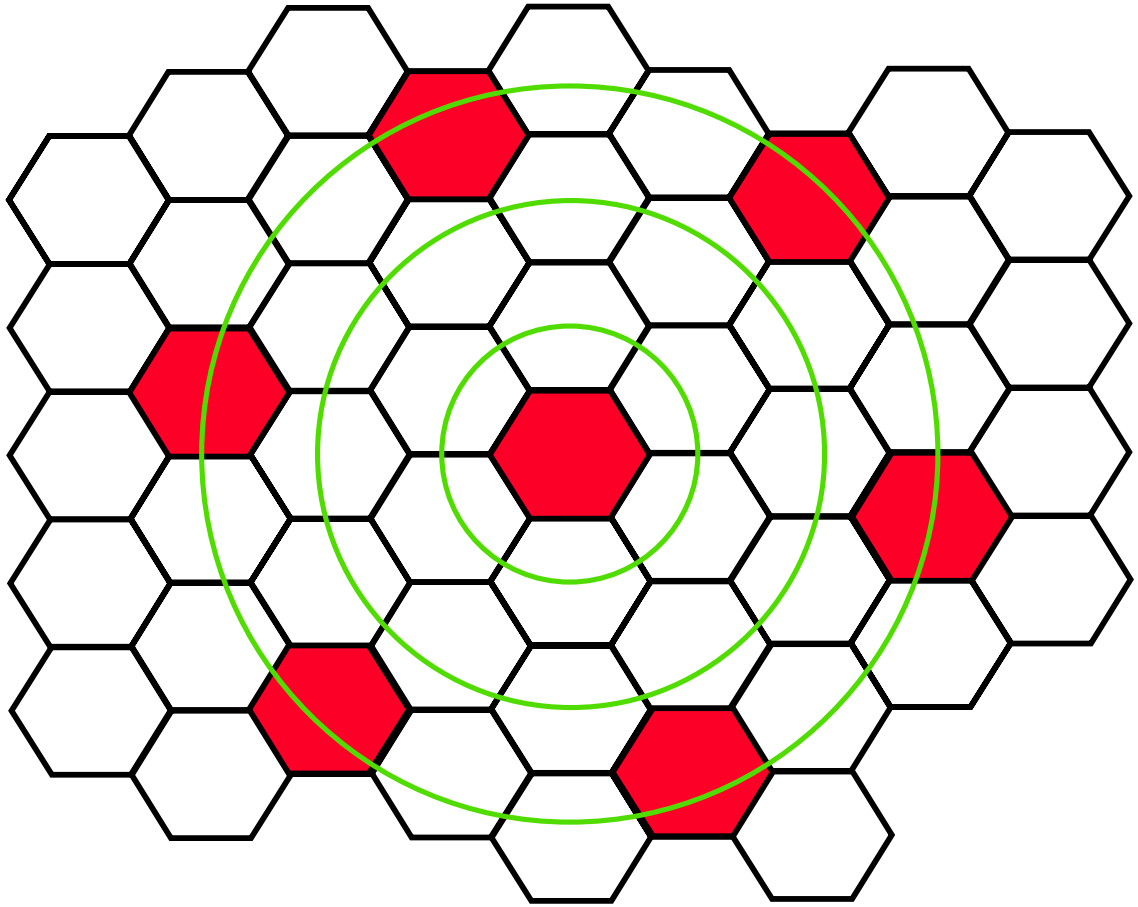
Cellular reuse



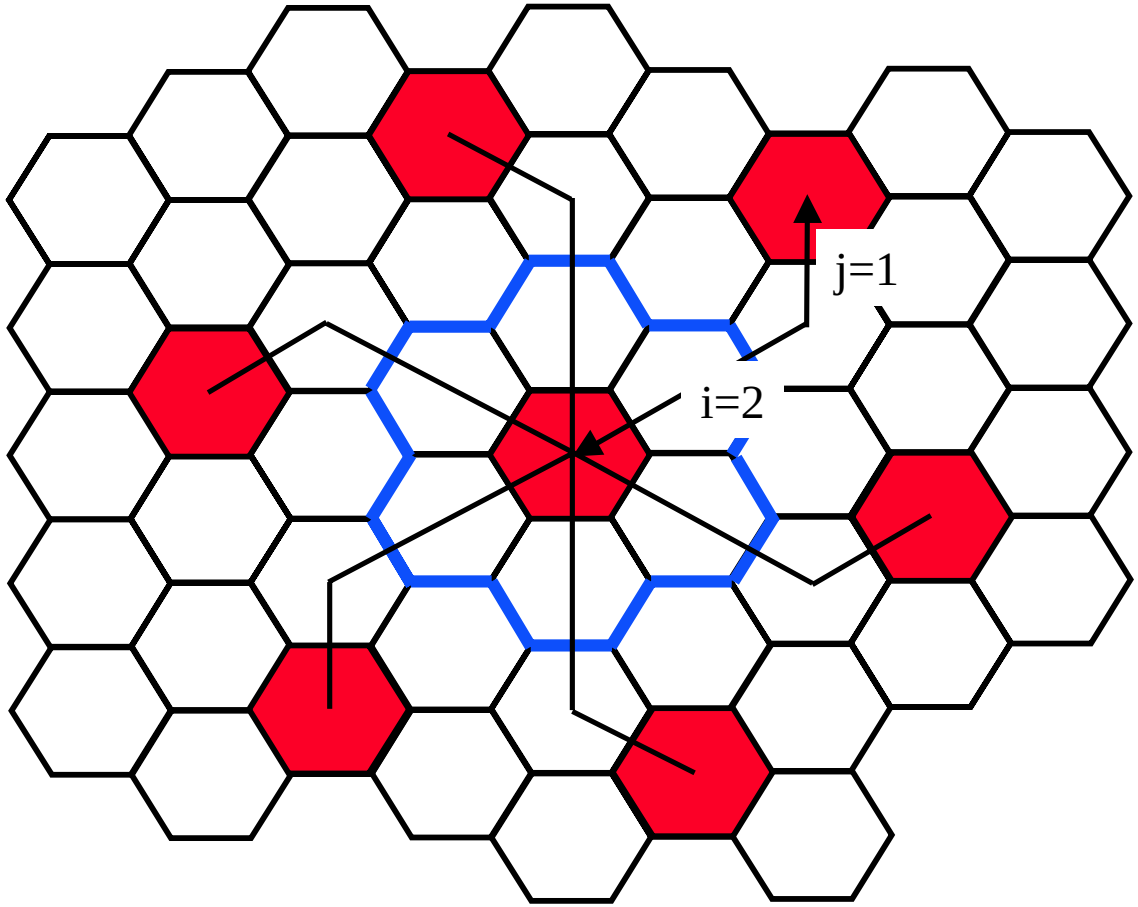
Reuse cluster



Cell tiers



Frequency reuse factor



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

i	j	N
0	1	1
1	1	3
0	2	4
1	2	7
0	3	9
2	2	12

Cell capacity

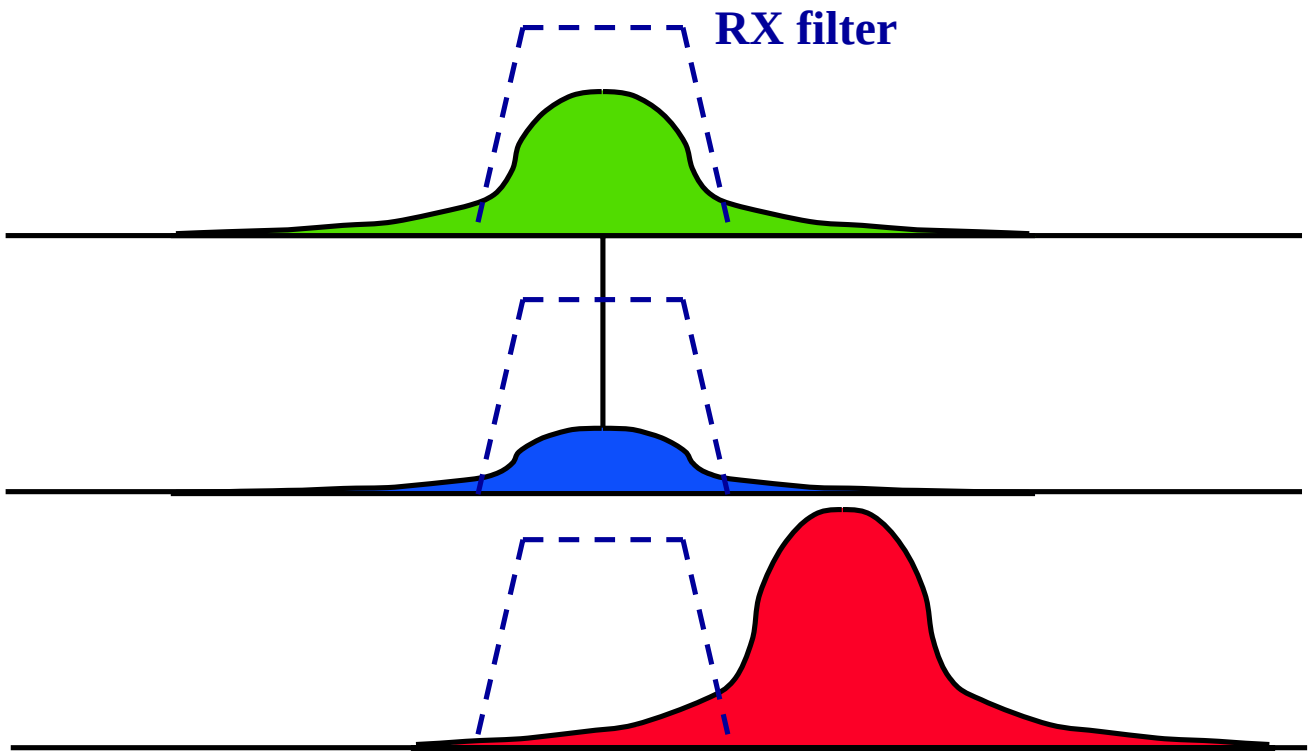
***N*:** **frequency reuse factor = cluster size**
***M*:** **total number of (paired) channels per system**
***k*:** **number of channels per cell**

$$k = \frac{M}{N}$$

Interference

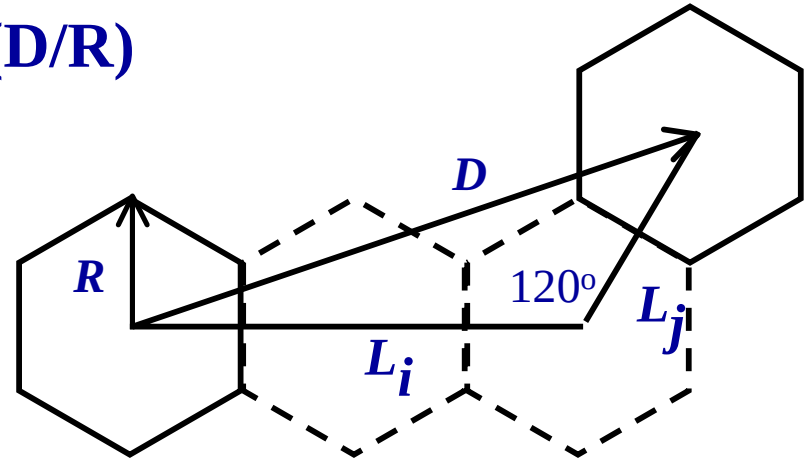
Co-channel: on same frequency

Adjacent channel: on neighboring frequencies



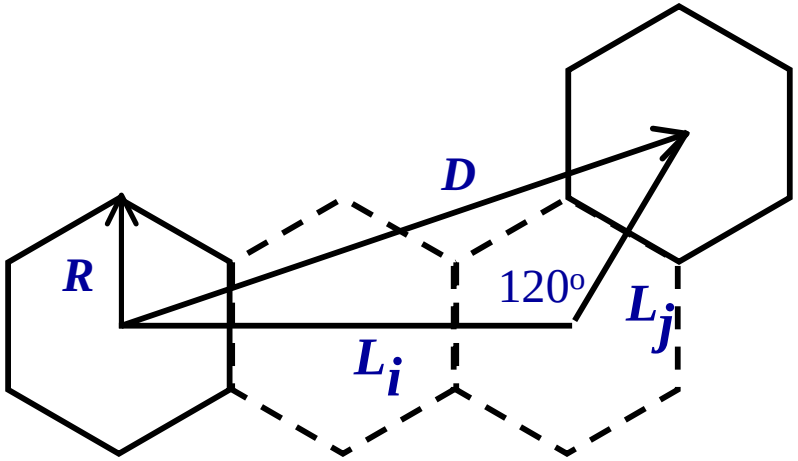
Reuse distance

R: cell radius
D: reuse distance
Q: reuse ratio (D/R)



$$L_i = i\sqrt{3}R; \quad L_j = j\sqrt{3}R;$$

Reuse ratio

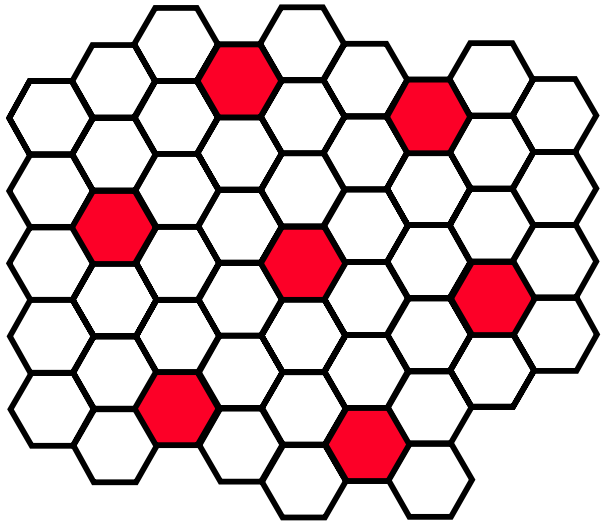


$$D^2 = \left(L_i + \tfrac{1}{2}L_j\right)^2 + \left(\tfrac{1}{2}\sqrt{3}L_j\right)^2 =$$

$$= L_i^2 + L_i L_j + L_j^2$$

$$= 3\cdot\left(i^2 + ij + j^2\right)\cdot R^2 = 3N\cdot R^2$$

Reuse and S/I



$$S = \frac{\alpha}{R^n}; \quad I_j = \frac{\alpha}{D^n}$$

$$\frac{S}{I} = \frac{D^n}{6 \cdot R^n} = \frac{1}{6}\left(\frac{D}{R}\right)^n = \frac{1}{6}(3N)^{n/2}$$

$$N = \frac{1}{3}\left(6 \cdot \frac{S}{I}\right)^{\frac{2}{n}}$$

Capacity

$$k = \frac{M}{N}$$

$$M = \frac{B_T}{B_C}$$

$$N = \frac{1}{3}\left(6 \cdot \frac{S}{I}\right)^{\frac{2}{n}}$$

$$\Rightarrow \quad k = 3\frac{B_T}{B_C\left(6 \cdot \frac{S}{I}\right)^{\frac{2}{n}}}$$

***k*:** **capacity in channels/cell**

Intrinsic capacity

$$C = k \cdot \frac{R_b}{B_T} = \frac{B_T}{B_C} \cdot \frac{1}{N} \cdot \frac{R_b}{B_T} =$$

$$= \frac{R_b}{B_C} \cdot \frac{1}{N}$$

C: capacity in bits/s/Hz/cell

N: reuse factor

R_b: data rate in b/s

B_c: channel bandwidth in Hz

Intrinsic capacity

Spectral efficiency: $\eta_B = \frac{R_b}{B_C} \Rightarrow$

$$C = \frac{\eta_B}{N}$$

C: **capacity in bits/s/Hz/cell**

N: **reuse factor**

η_B: **spectral efficiency b/s/Hz**

Intrinsic capacity

GSM: $\eta_B = 1.35$ b/s/Hz; $N = 3$ $C = 0.45$ b/s/Hz/site

IS-54: $\eta_B = 1.62$ b/s/Hz; $N = 7$ $C = 0.23$ b/s/Hz/site

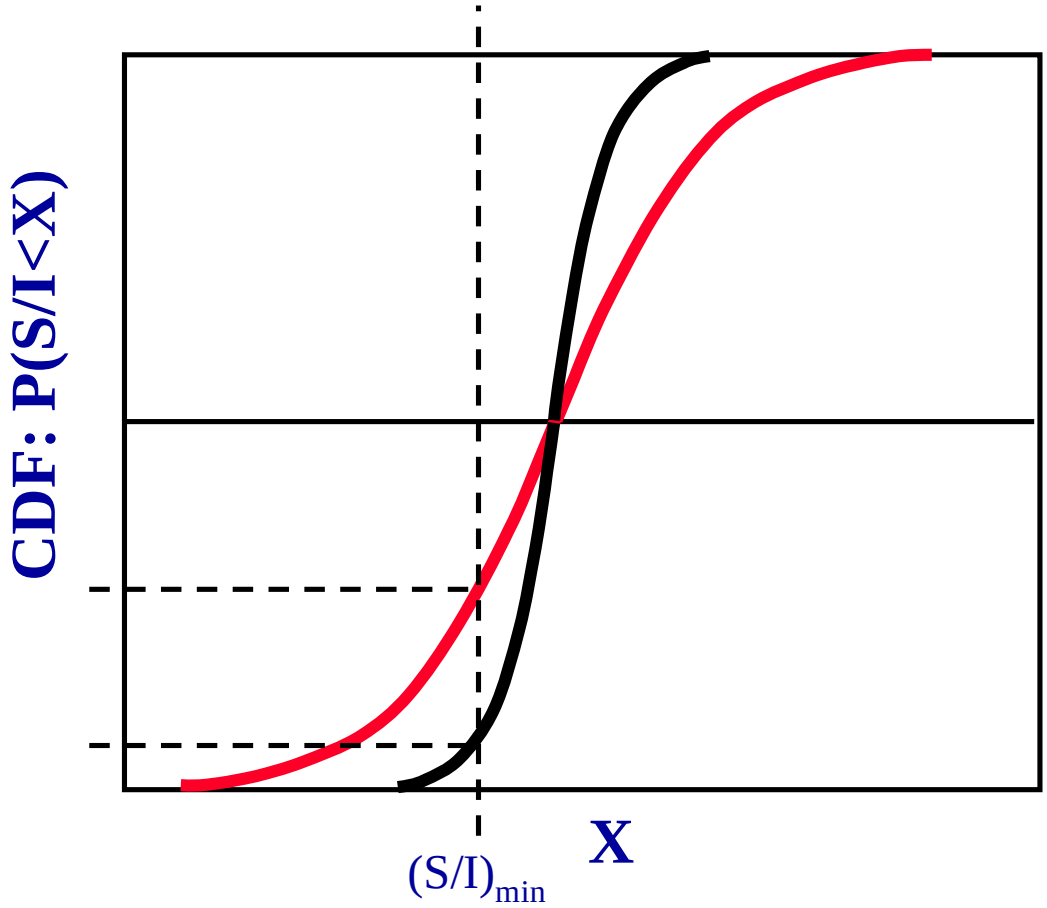
PDC: $\eta_B = 1.68$ b/s/Hz; $N = 7$ $C = 0.24$ b/s/Hz/site

DECT: $\eta_B = 0.67$ b/s/Hz; $N = 10$ $C = 0.07$ b/s/Hz/site

Improving system capacity

- Power control
- Dynamic channel assignment
- Channel hopping
- Improved coding and modulation
- Cell splitting
- Sectoring

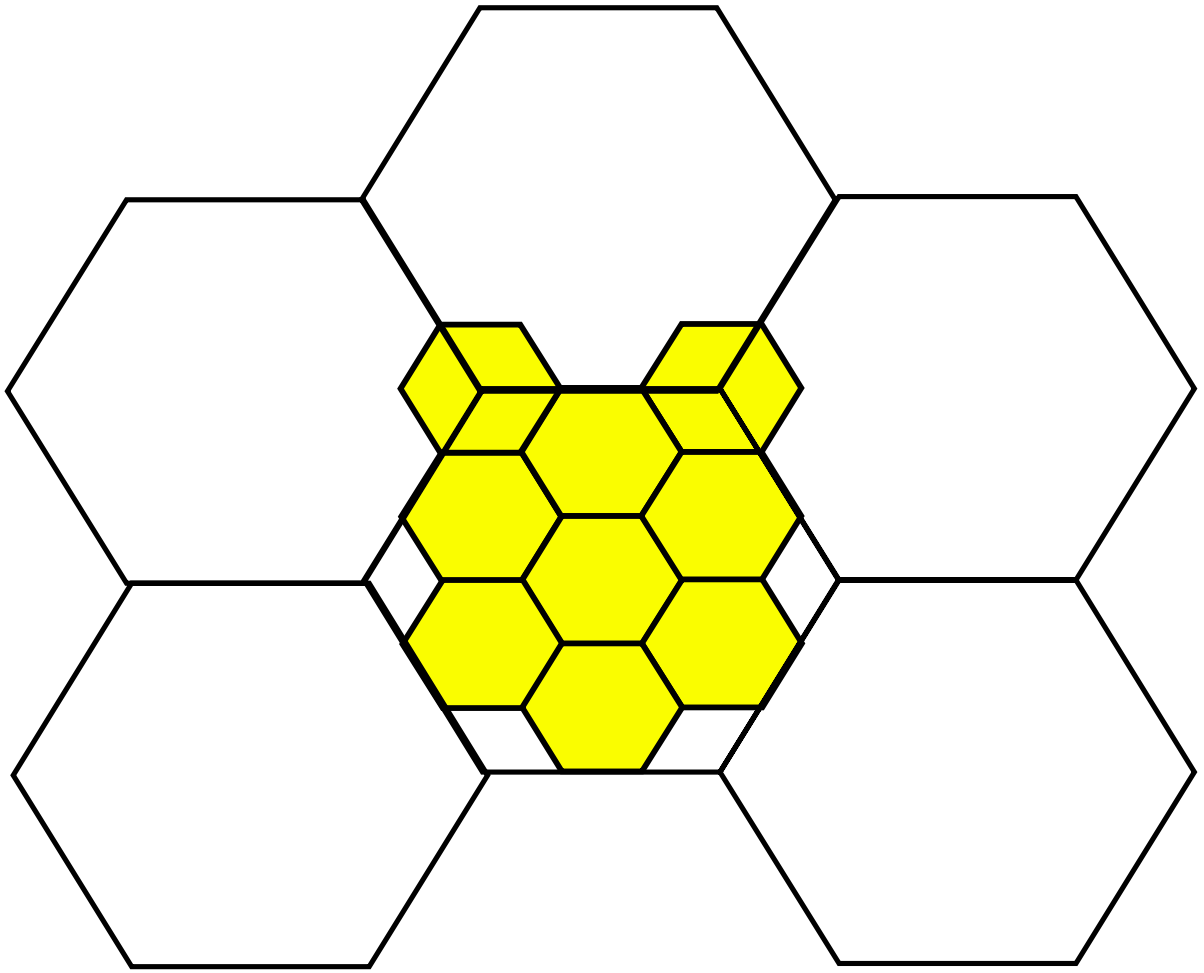
Power control



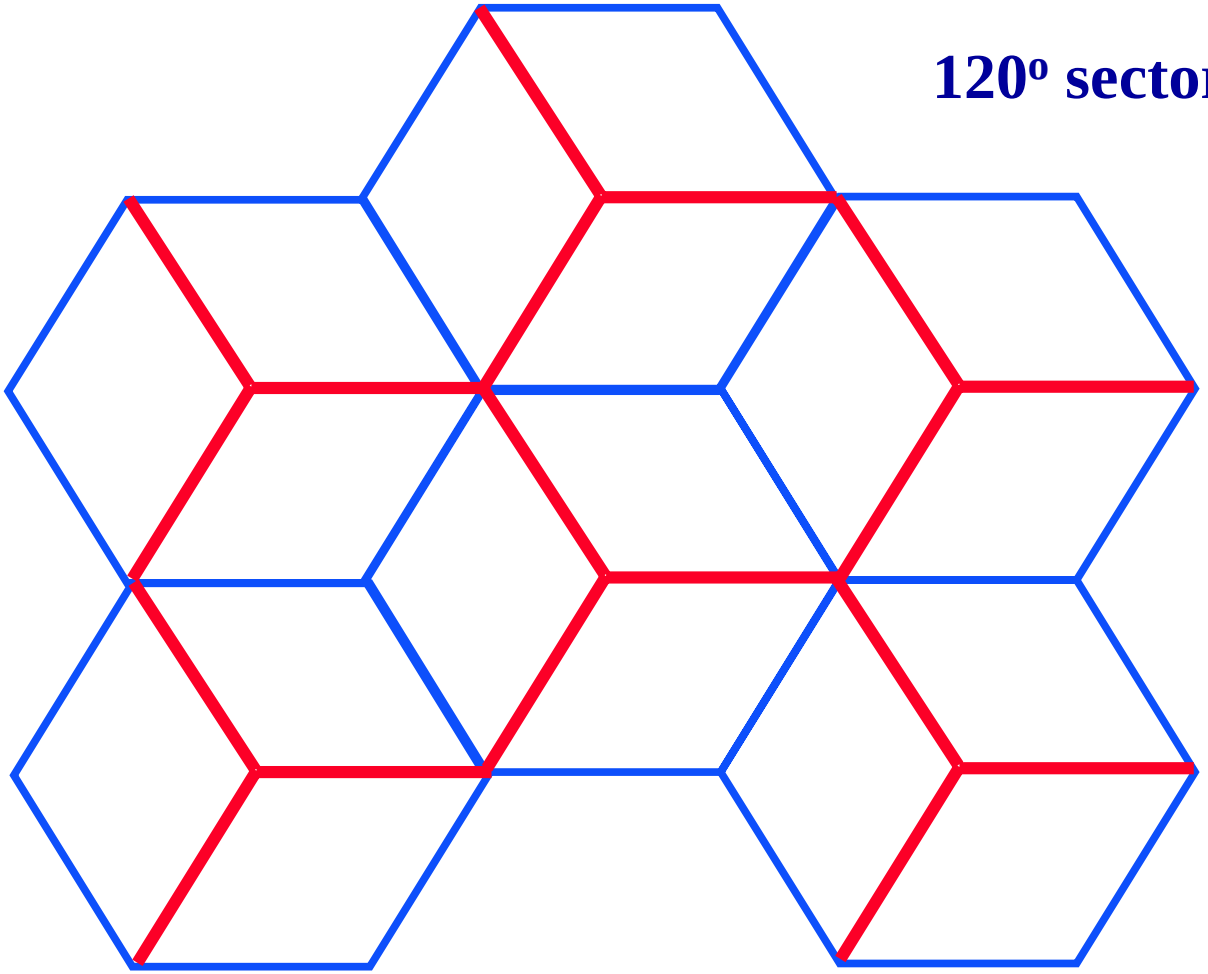
Outage:
percentage of users with

$$S/I < (S/I)_{min}$$

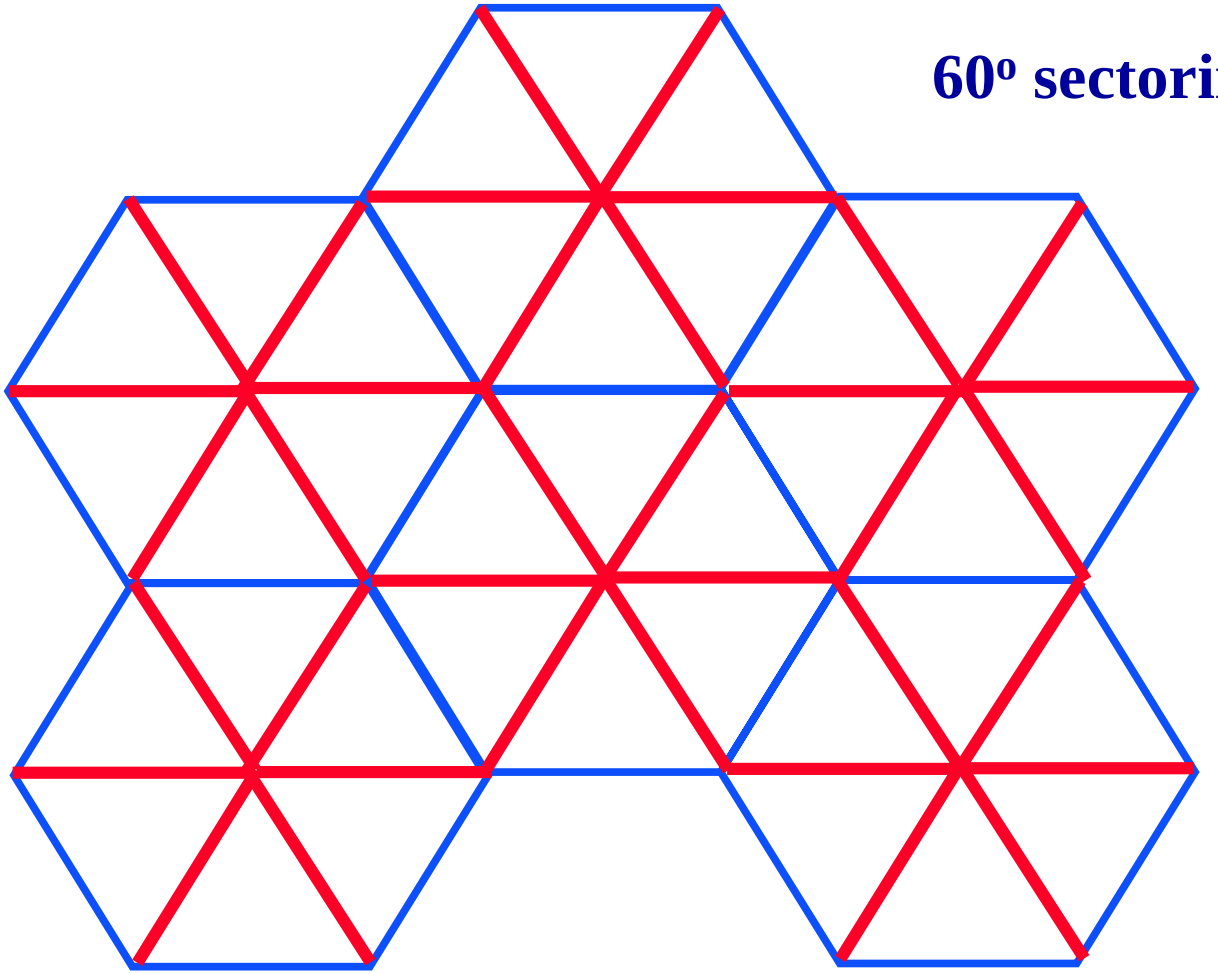
Cell splitting



Sectoring



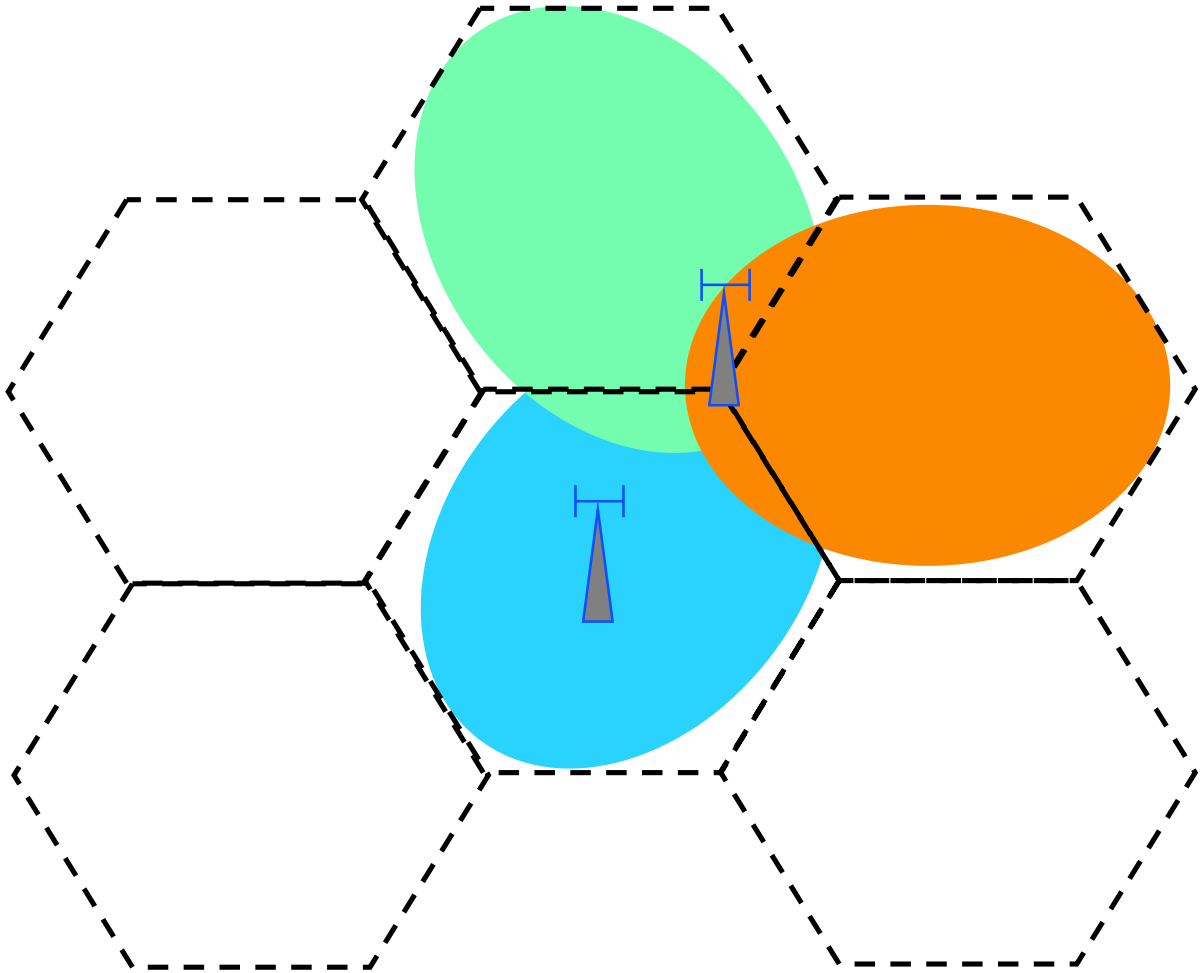
Sectoring



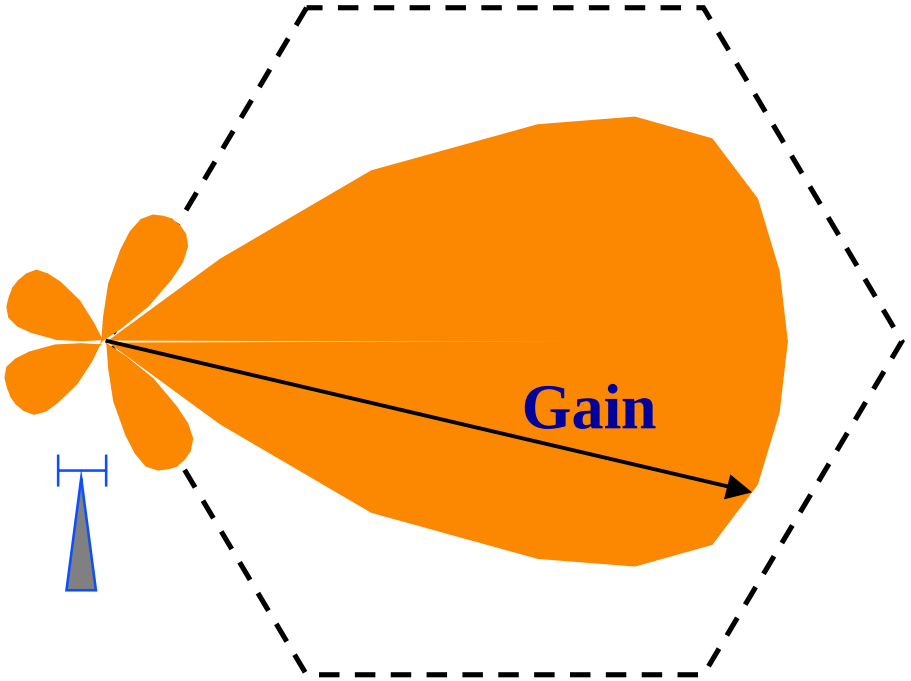
Sectoring

- Less number of dominant interferers
  - 120^o: 2 dominant
  - 60^o: 1 dominant
- Directional antennas
- n/m reuse: n-site/m-sector reuse
- Less channels per antenna

Sectoring

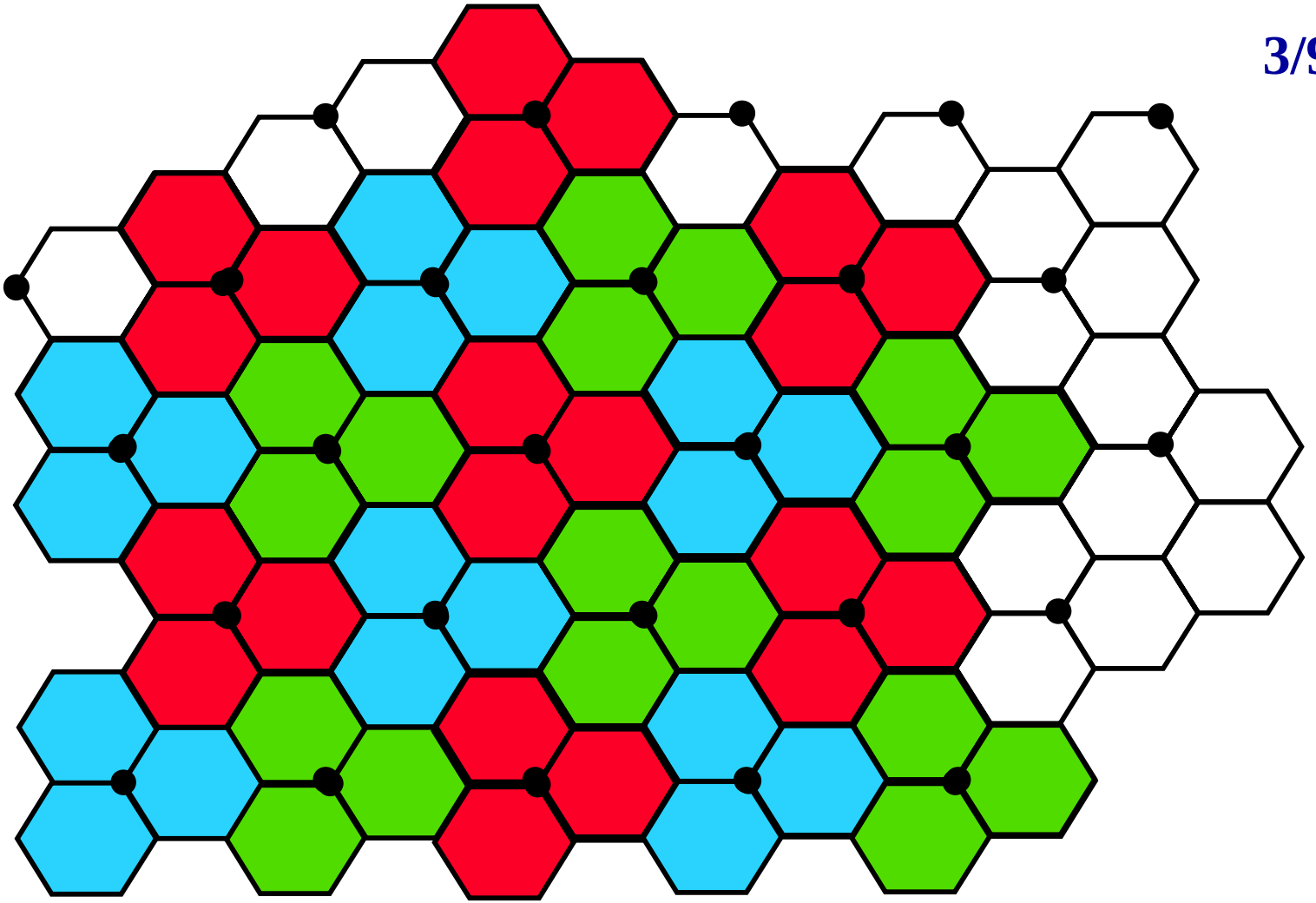


Directional antennas

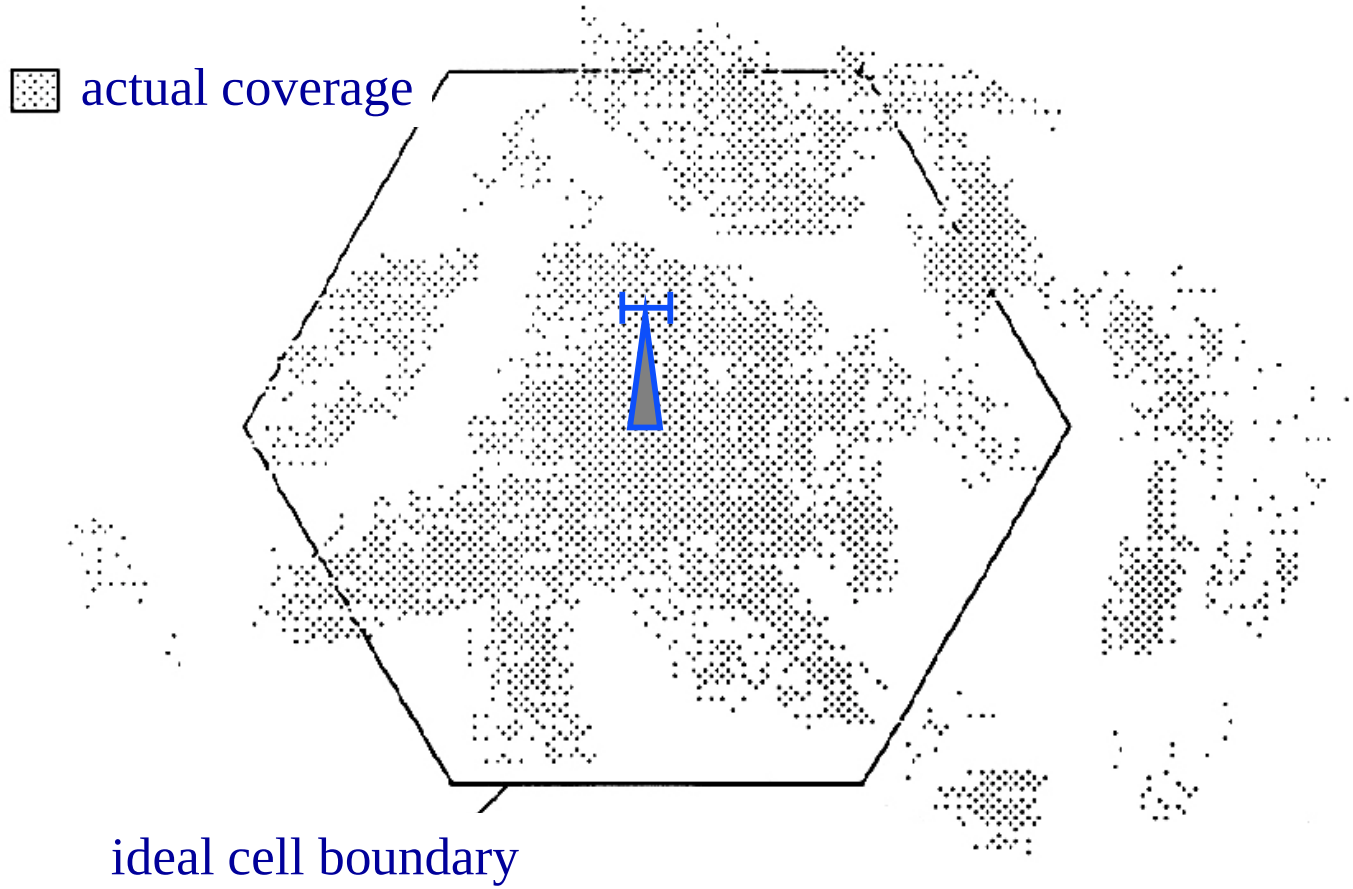


Sectored reuse cluster

3/9 reuse



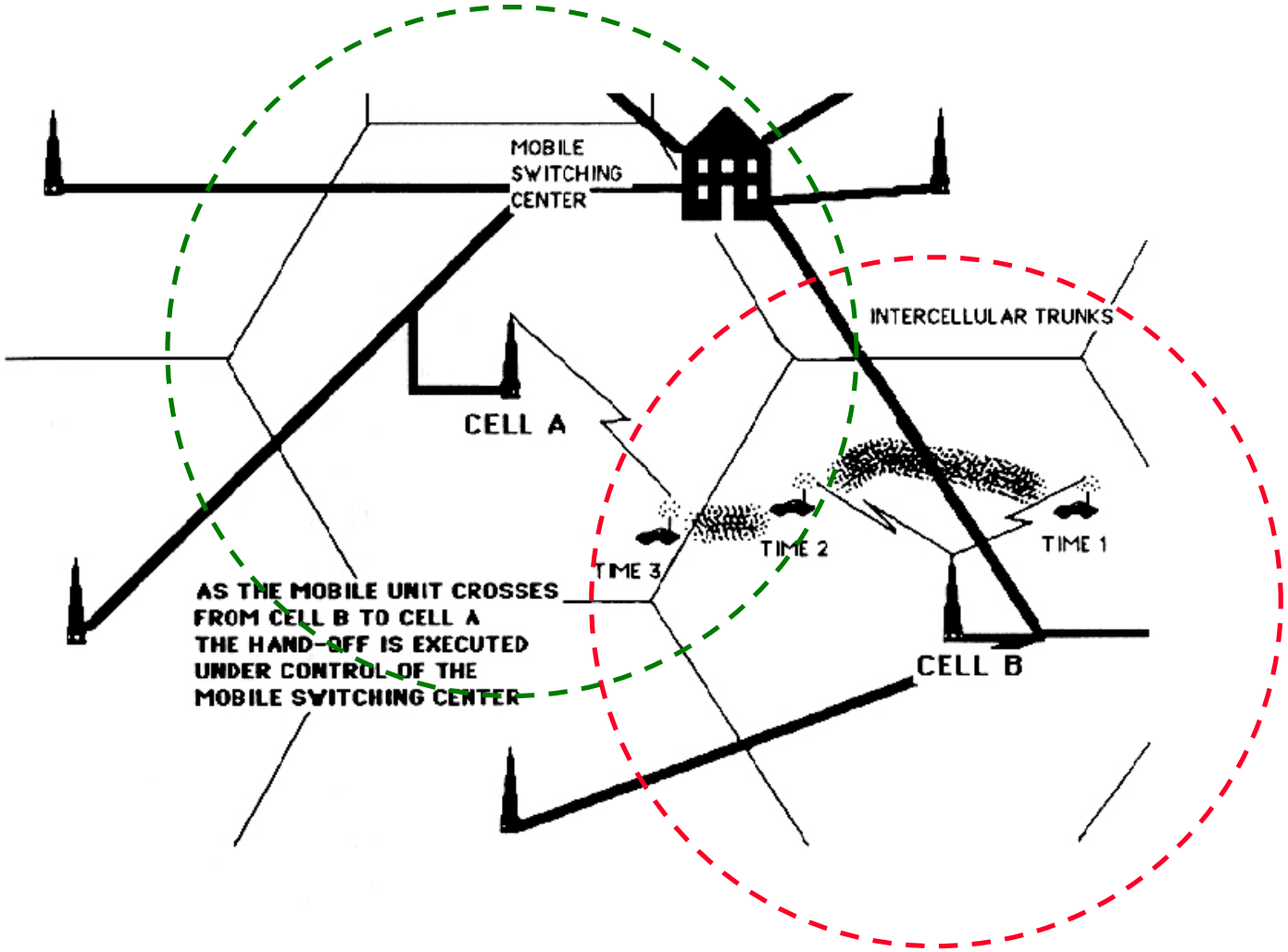
Cell planning



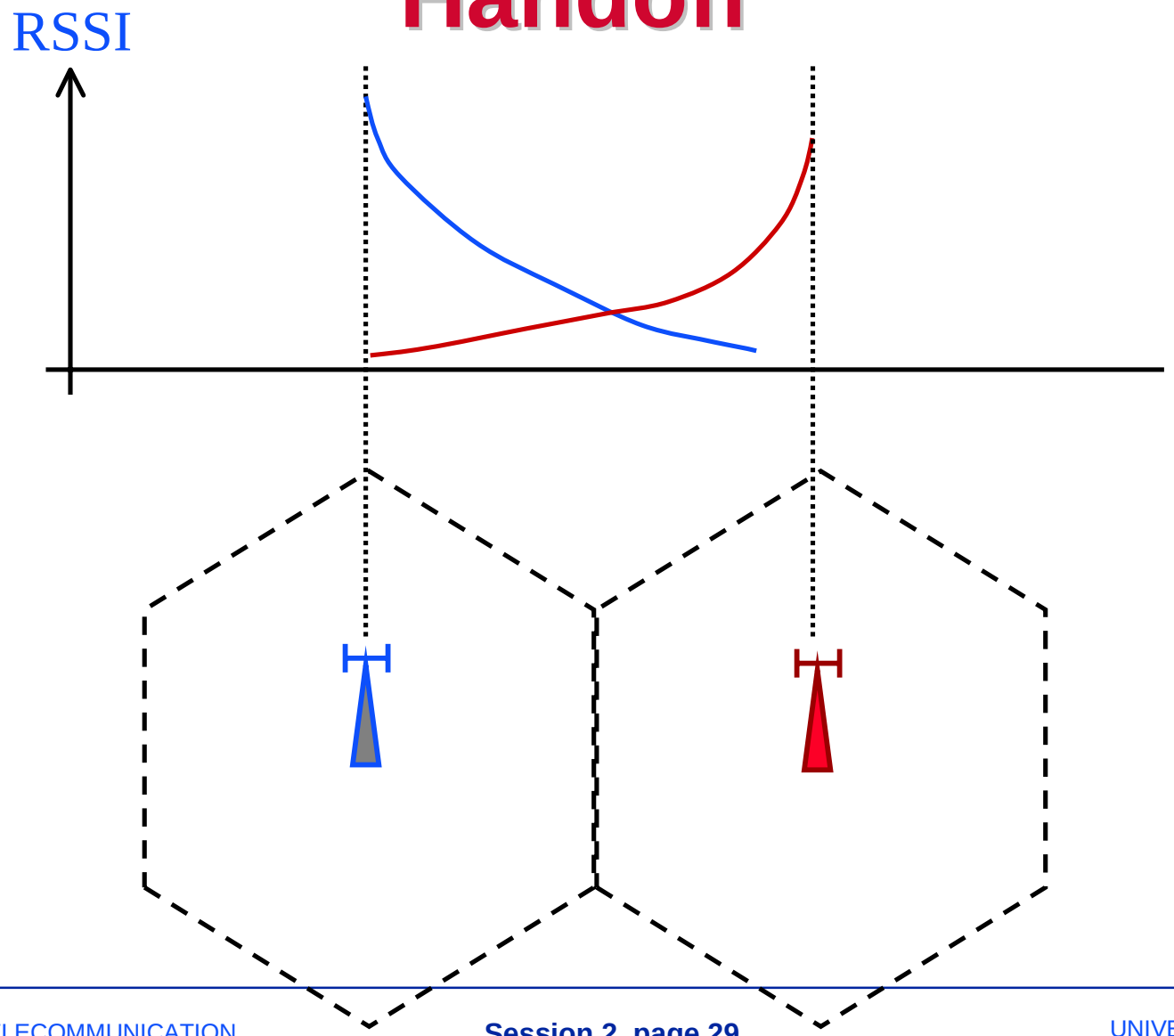
Cell planning

- Coverage
- Outage: percentage of coverage where $S/I<(S/I)_{min}$
- Trunking (Grade of service)
- Fixed channel allocation
- Dynamic channels allocation
- Planning tools

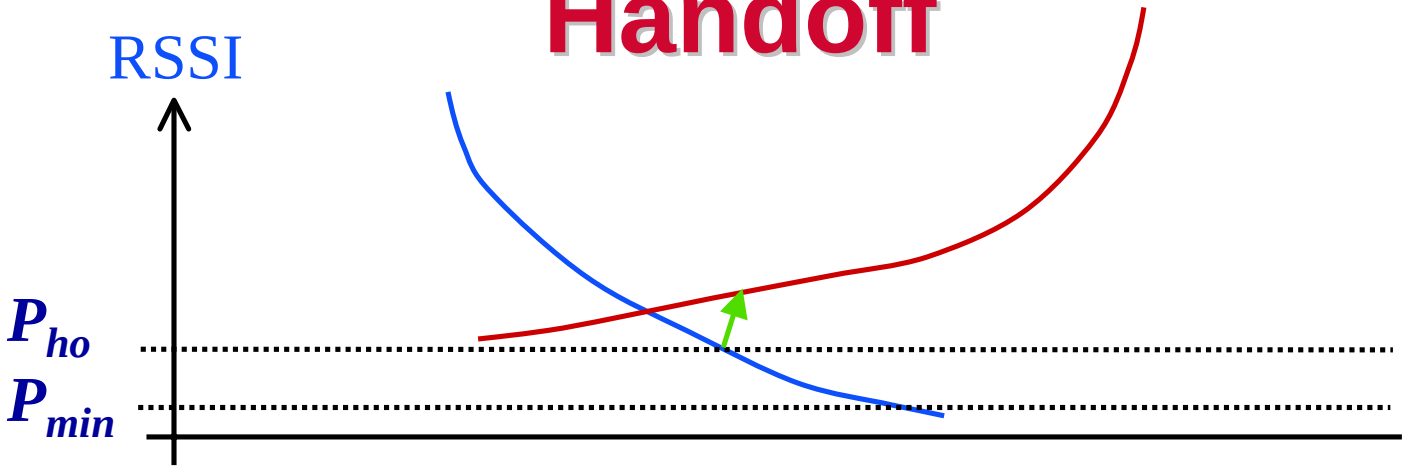
Handoff


MOBILE
SWITCHING
CENTER
INTERCELLULAR TRUNKS
CELL A
TIME 3
TIME 2
TIME 1
AS THE MOBILE UNIT CROSSES
FROM CELL B TO CELL A
THE HAND-OFF IS EXECUTED
UNDER CONTROL OF THE
MOBILE SWITCHING CENTER
CELL B

Handoff



Handoff



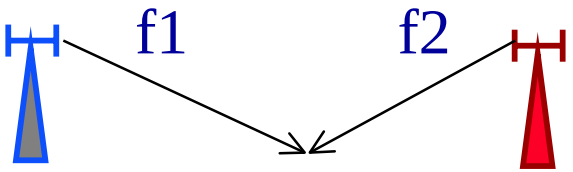
P_{ho}: handoff threshold

P_{min}: minimum usable

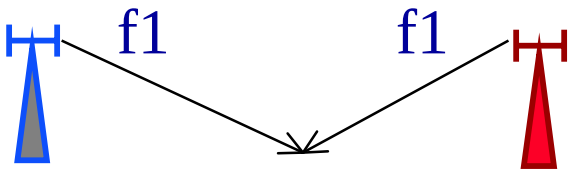
$$\Delta = P_{ho} - P_{min}$$

Handoff

- **Margin / hysteresis**
- **Handoff threshold**
- **Mobile Assisted Handoff (MAHO)**
- **Hard handoff versus Soft handoff**

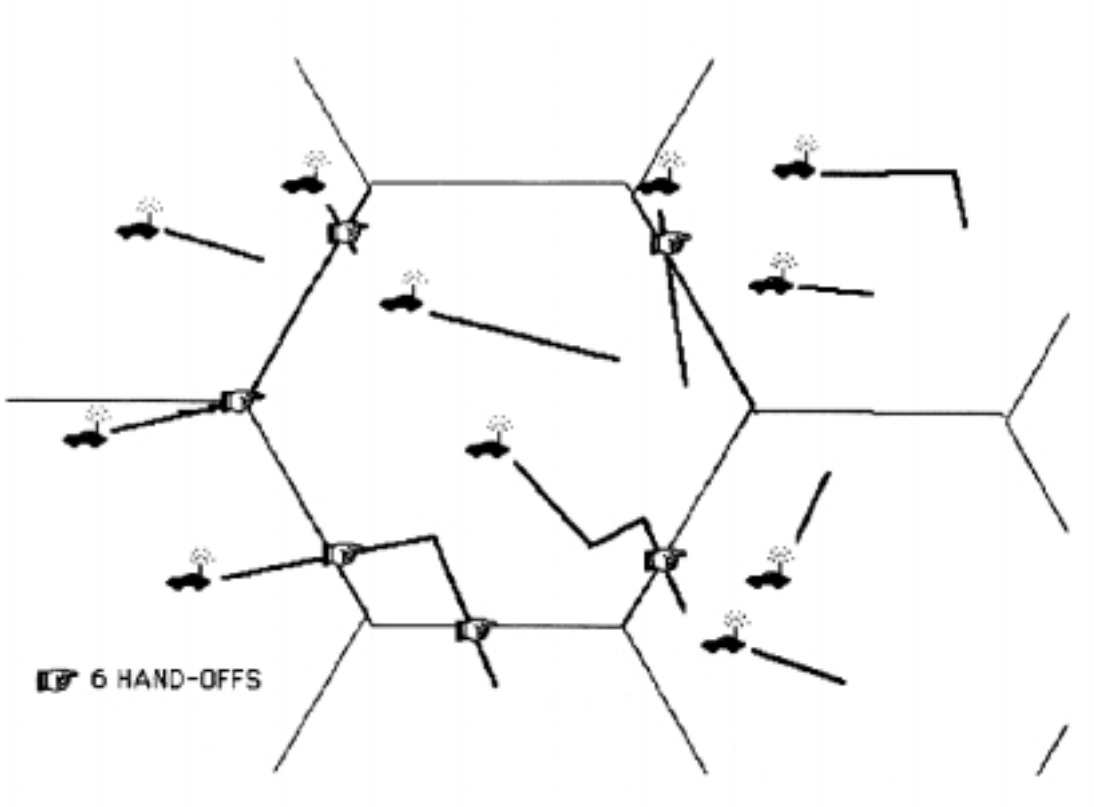


hard

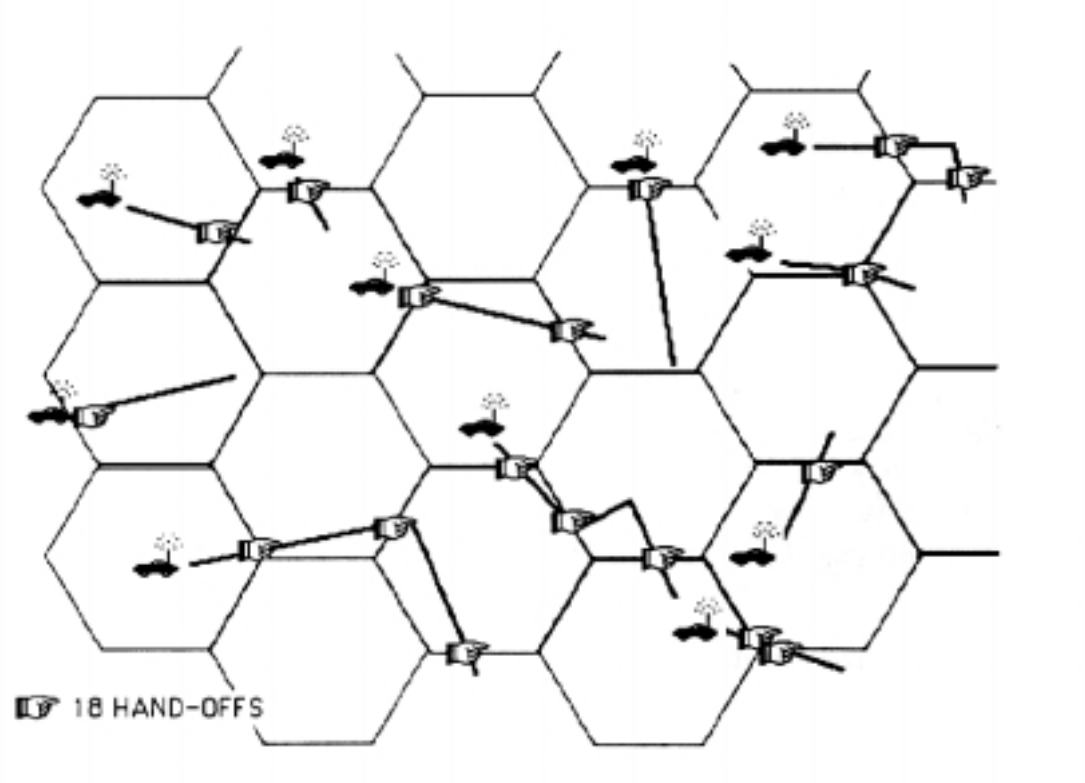


soft

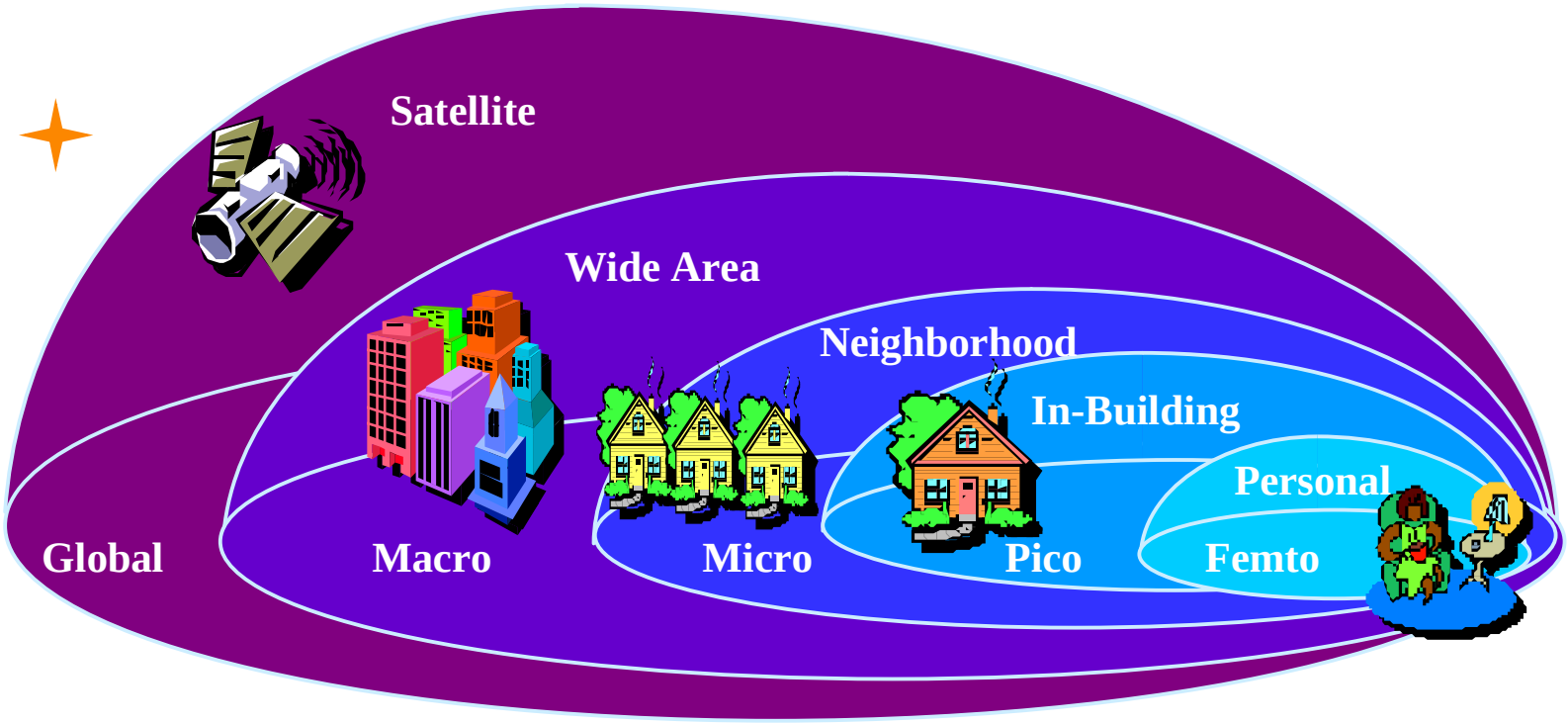
Handoff



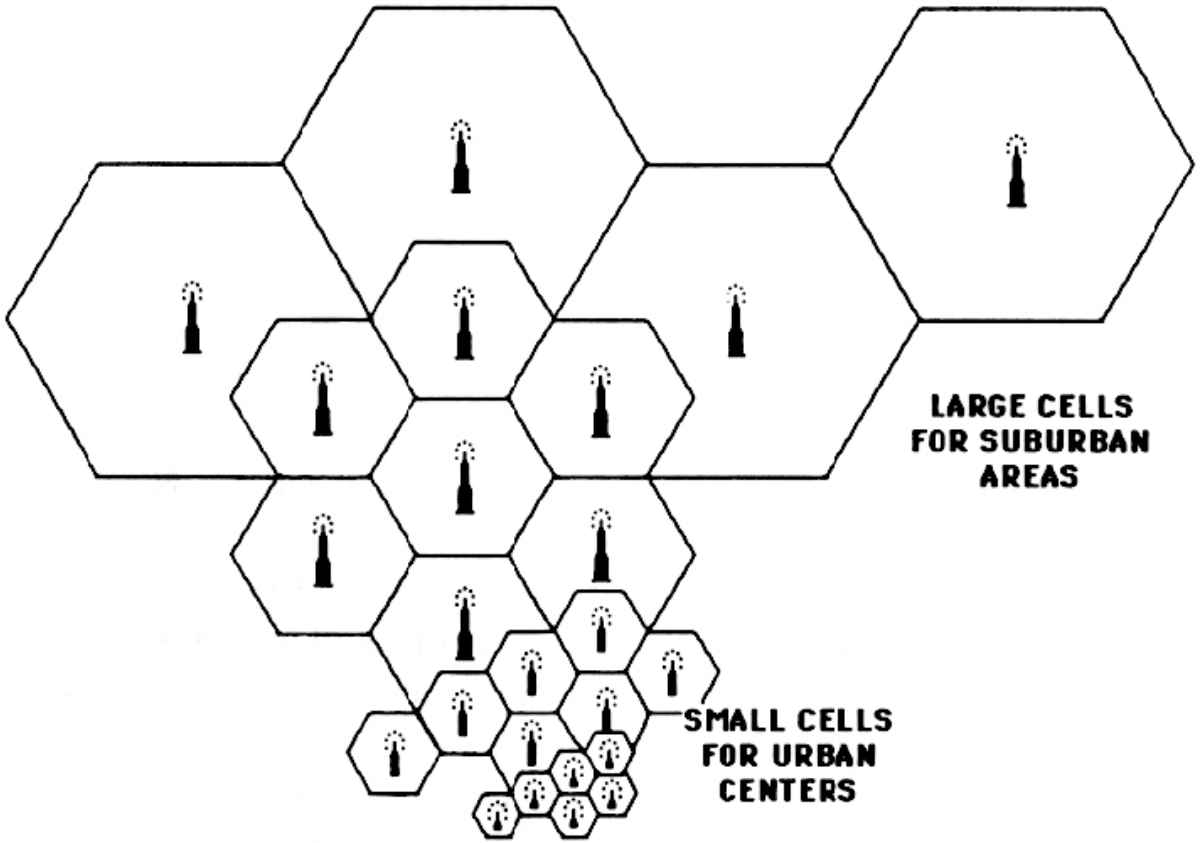
Handoff



Macro, micro and pico cells



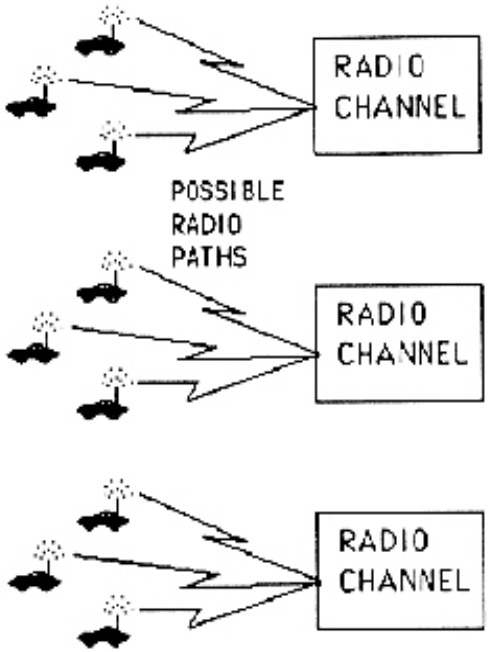
Macro, micro and pico cells



Trunking

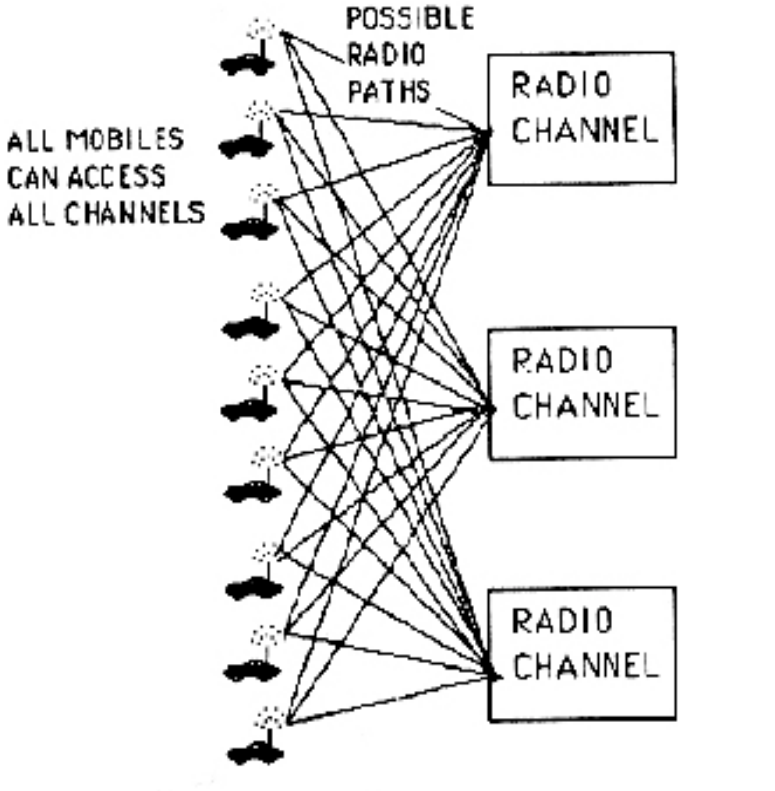
- Sharing channel among several users
- Statistical multiplexing (traffic behavior)
- Trunking gain

Trunking



EACH CHANNEL SUPPORTS A DISTINCT GROUP OF MOBILES

Trunking



TRUNKED RADIO SYSTEM

Traffic intensity

Erlangs: traffic load

$$A_{user} = \mu_{ave} \cdot H_{ave}$$

A_{user}: user load in Erlangs
μ_{ave} : average number of call requests per second
H_{ave} : average call duration in seconds

Traffic intensity

Example: 10 calls a day (12 hours); 20 minutes each

Arrival rate μ: **10 calls/12 hours = 2.3e-4**
Duration H: **20×60=1200s**

A_{user}: **276mErlangs**

Traffic intensity

Offered load by *U* users:

$$A_{offered} = U \cdot A_{user}$$

Maximally carried load by *k* channels:

$$A_{carried} = k$$

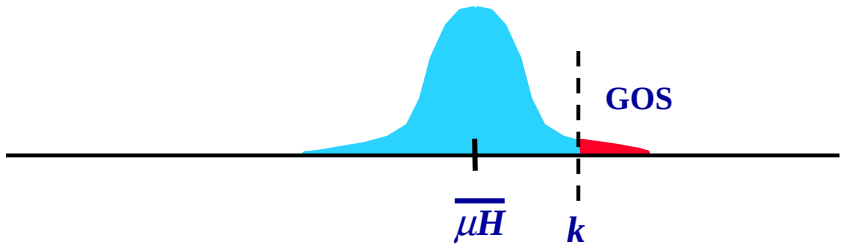
To prevent blocking:

$$A_{offered} < A_{carried}$$

Grade of service

GOS: percentage of blocked calls

μ: Poisson distributed
H: Exponentially distributed



ErlangB formula

$$GOS = \frac{\frac{A_{offered}^{k}}{k!}}{\sum_{i=0}^{k} \frac{A_{offered}^{i}}{i!}}$$

GOS: percentage of blocked calls

Grade of service

	Capacity (Erlangs)	
k	GOS=1%	0.1%
2	0.153	0.046
4	0.869	0.439
10	4.46	3.09
20	12.0	9.41
40	29.0	24.5
100	84.1	75.2

Trunking gain

Required GOS=1%

5 sites with 2 channels each:

$A_{offered}$/site = 0.153 Erlangs

$A_{offered}$ = 0.765 Erlangs

1 sites with 10 channels:

$A_{offered}$/site = 4.46 Erlangs

$A_{offered}$ = 4.46 Erlangs

Trunking gain = 4.46/0.765 = 5.8

Capacity

Capacity *U* in users per cell

***k* channels per cell:**

$$U = \frac{A_{offered}(k, GOS)}{A_{user}}$$

***k*=16 channels/cell, GOS=2%, A_{user}=100mErlangs**
$\Rightarrow A_{offered}$=10
$\Rightarrow U$=100

Effective reuse

$$N = \frac{M}{k}$$

$$N_{eff} = \frac{M}{A_{offered}} = \frac{k}{A_{offered}} N$$

k=16 channels/cell, GOS=2%, N=7 $\Rightarrow$ $A_{offered}$=10

$\Rightarrow$ N_{eff}=11.2

Trunking gain

- maximize k
- minimizing reuse factor N will improve k
- sectoring will reduce k
- dynamic channel allocation will improve k
- radio ports & costs

FOR NEXT WEEK

- **Read:**

  Chapter 3: §3.1, 3.2, 3.4, 3.6, 3.9, 3.10.3, 3.10.4

  Chapter 4: §4.1, 4.2 (not 4.2.1), 4.4 - 4.6

- **Solve problems:**

  Chapter 2: 2.5, 2.8, 2.18, 2.20

  Note, for 2.5: take # channels=395