GSM
TDMA engineering

Cours RE56 Printemps 2004

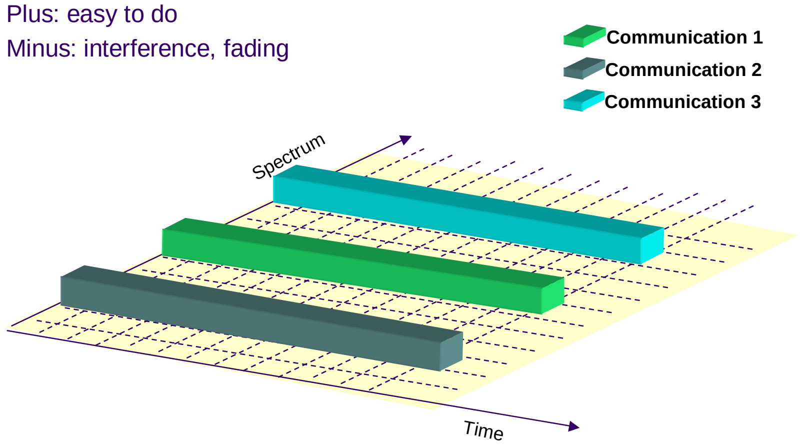
Alexandre CAMINADA
UTBM
Département Informatique
90010 SEVENANS Cedex

Contents

1. Spectrum use
2. Frequency assignment
3. Data and performance
4. Computing aspects
5. Frequency hopping

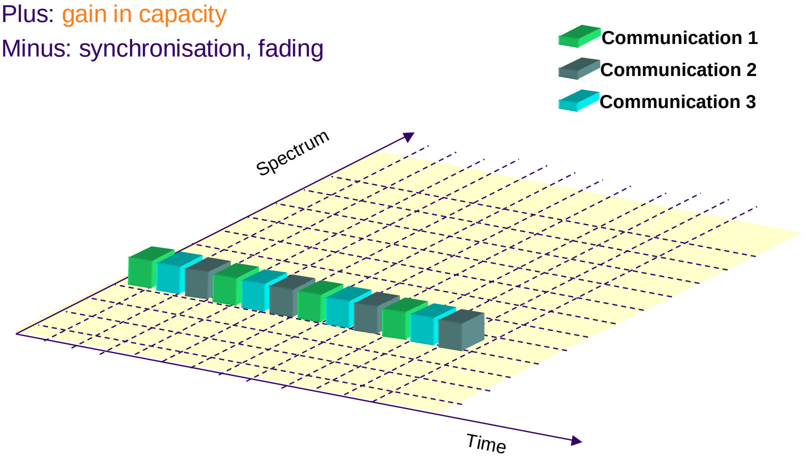
Spectrum use – FDMA

- 1G analogue systems
- Plus: easy to do
- Minus: interference, fading



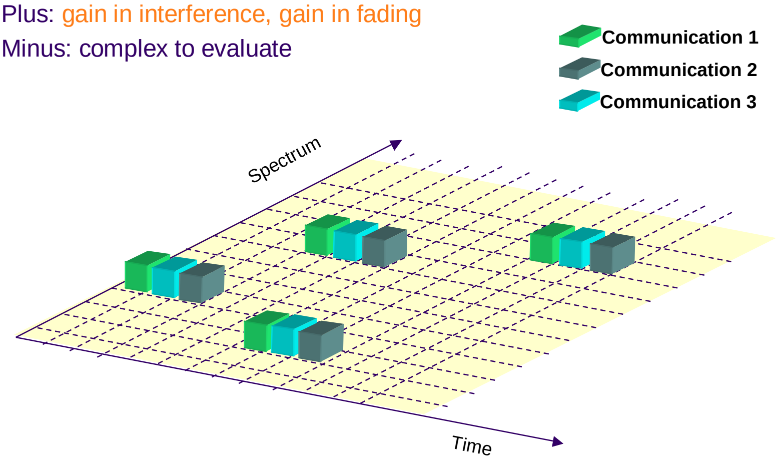
Spectrum use – F-TDMA (TDMA)

- 2G numeric systems: GSM, DECT, IS54…
- Plus: gain in capacity
- Minus: synchronisation, fading

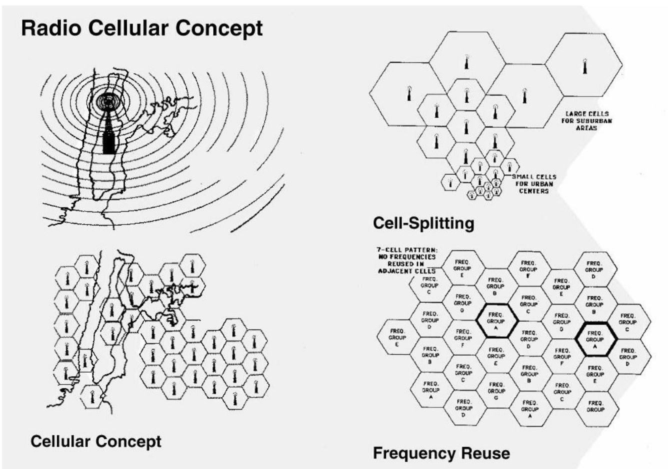


Spectrum use – SFH-TDMA (TDMA)

- GSM
- Plus: gain in interference, gain in fading
- Minus: complex to evaluate



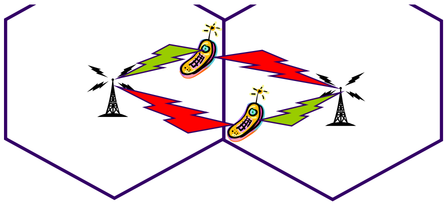
Spectrum use – Basis of spectrum use



Spectrum use – Interference

- Reuse is depending on system ability for interference management
- It is not possible to use the same frequency in adjacent cells: co-channel interference between 2 mobiles
- Interference is C/(I+N), where:
  - C, power of expected signal
  - I, set of interference, often limited to co-channel
  - N, white noise, where N << I

Co-channel interference
Signals are strong source of interference on the cell borders



utbm

Spectrum use – DL interference

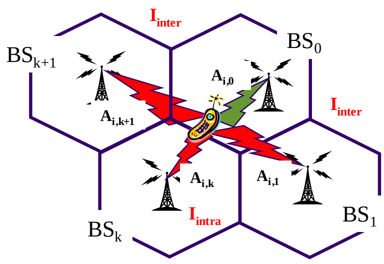
Let $Pe_{i,j}$ the emitted power from BS j to MS i, and $A_{i,j}$ the global loss from BS j to MS i

Then $C_{i,j} = Pe_{i,j} A_{i,j}$

$$I_{\text{intra}\,i} = \alpha \sum_{i' \neq i,\, i' \in C_0} Pe_{i',j} A_{i,j} \quad \text{et} \quad I_{\text{inter}\,i} = \sum_{j' \neq j,\, j' \in BS} Ptot_{i,j'} A_{i,j'},\ \alpha \text{ orthogonality factor}$$

$$C_{i,j} / Itot_i = \alpha \sum_{i' \neq i,\, i' \in C_0} \frac{Pe_{i,j} A_{i,j}}{Pe_{i',j} A_{i,j}} + \sum_{j' \neq j,\, j' \in BS} \frac{Pe_{i,j} A_{i,j}}{Ptot_{i,j'} A_{i,j'}}$$

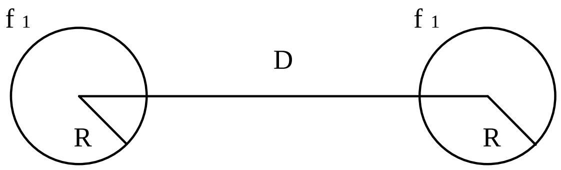
With TDMA, cell's circuits are rightly orthogonal (α=0) then there is no intra-cell interference



utbm

Spectrum use – Distance of reuse

- Lower required C/I means shorter reuse distance and higher capacity
  - Analogue system: C/I ≥ 18 dB
  - GSM: C/I ≥ 9dB
- *"Reuse separation distance ranges from 4 to 6 times the cell radius"* (W.C.Y. LEE)



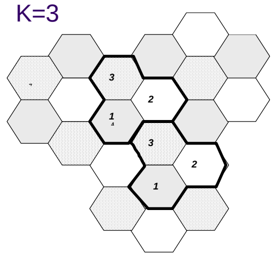
R: cell radius
D: frequency reuse distance

$$D/R \geq Seuil$$

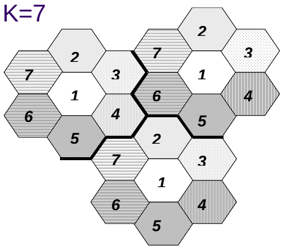
Spectrum use – Frequency reuse pattern

- Frequency reuse pattern (k=3, 7, 12)
- Hypothesis:
  - Regular network (grid)
  - Regular traffic demand
  - Regular propagation
- Graph-coloring problem
- Advantages:
  - Easy to do
  - No propagation model
- Inherent problem:
  - **High traffic demand requires small patterns**
  - **Small patterns produce interference**

K=3

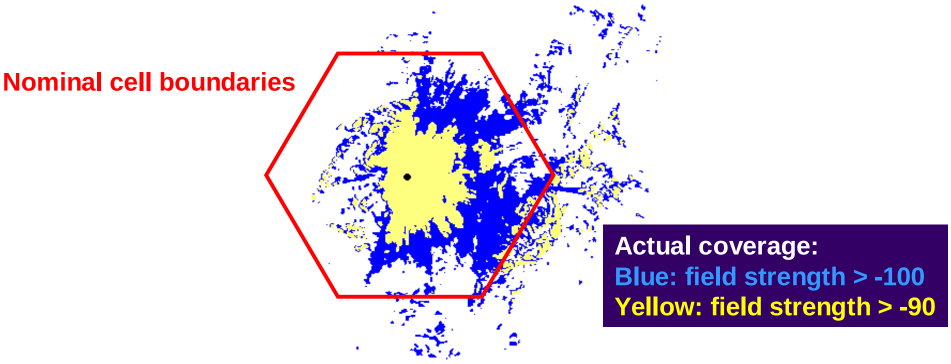


K=7

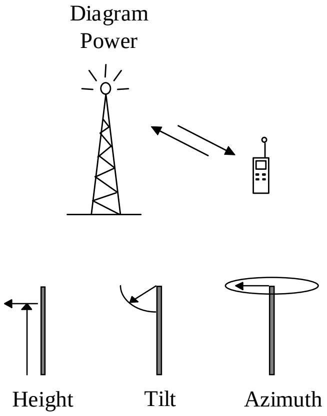


Spectrum use – The major problem

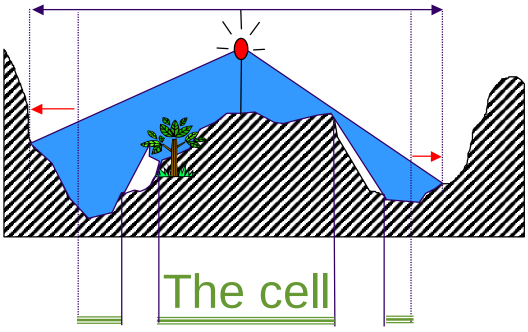
Ideal versus Real cell coverage



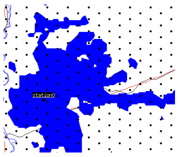
Spectrum use – Cell discontinuity



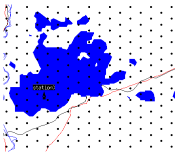
Area covered by the BS = cell
Field strength > threshold



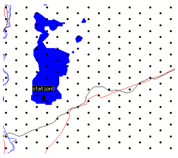
Spectrum use – Cells are randomized potatoes



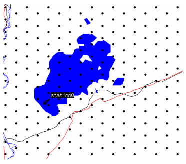
Omni directional
Power 60 dBm



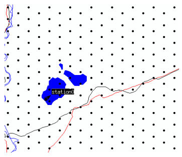
Large directional



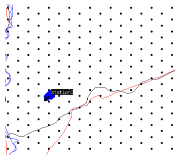
Narrow directional



Azimuth 50°



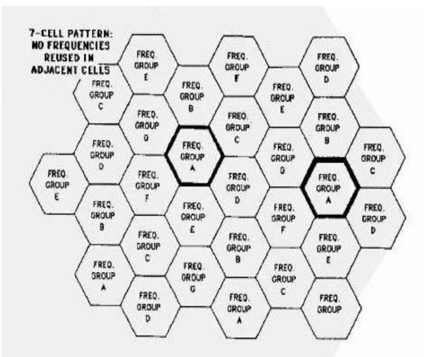
Power 50 dBm



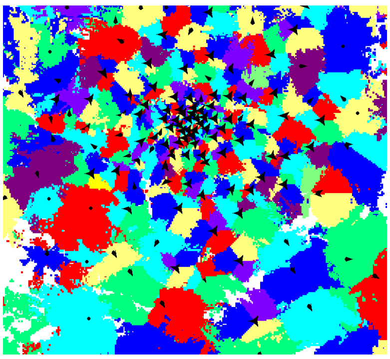
Tilt -15°

Spectrum use – Network level

Theory



Reality

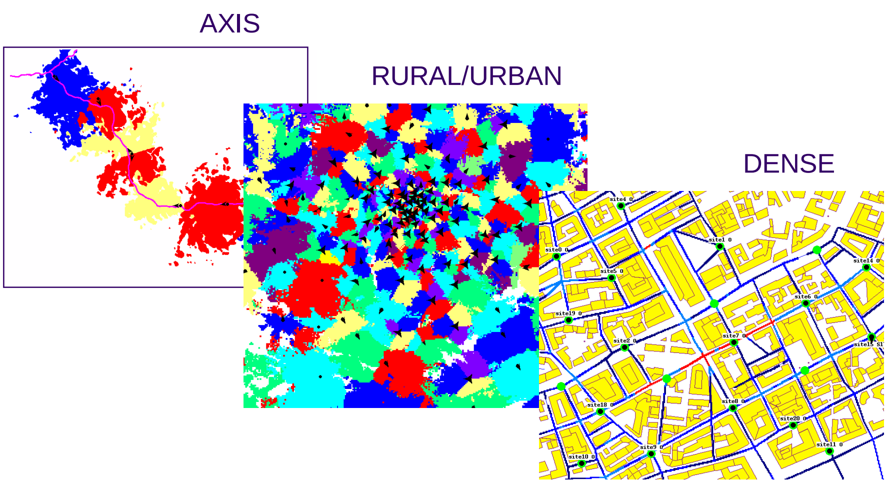


Spectrum use – The theory

– The model is built on ideal scenario

- Regular plane surface
- Uniform propagation (no obstacles)
- Uniform EM environment
- Each station located at a node on a regular grid
- No vacancy on node
- All stations parameters settings identical (omni directional diagram)
- One set of channel regularly used (regular traffic)
- Co-channel interference

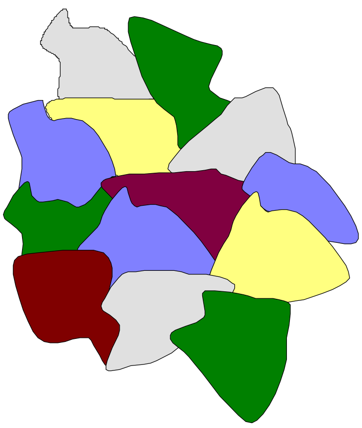
Spectrum use – The practices



Contents

Frequency assignment – The basis

- Definition: frequency reuse consists in using the same frequency channel on areas that are separated enough to avoid co-channel interference problems
- It is a graph colouring problem
- This concept is fundamental to get the gap between low bandwidth and high capacity one need to catch a lot of customers



Frequency assignment – Graph colouring problem

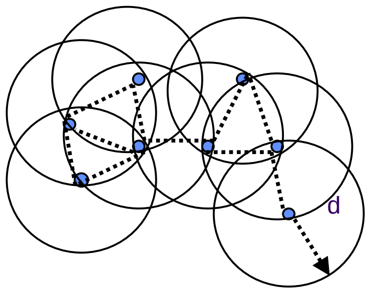
Set ***V*** of vertex in the plane ; ***d* > *0*** ;

Then ***u*** and ***v*** are adjacent in ***G(V,d)*** if the Euclidian distance ***D(u,v)<d***

Transmitter > vertices

D(u,v)<d > too close, edge between ***u*** and ***v***

t.i. needed different colours



T-Graph colouring:

Let put an integer label on edges ;

Then a graph colouring in a constraint graph ***G*** with vertex set ***V*** is a mapping ***gc: V -> C***, where ***C*** is a set of consecutive integers ***0,1,…,n***

Such that, if the edge (v_i, v_j) as a label ***k*** then

$| gc(v_i) - gc(v_j) | \geq T_k$

Where T_k is a set of non negative integers

Frequency assignment – TS graph colouring

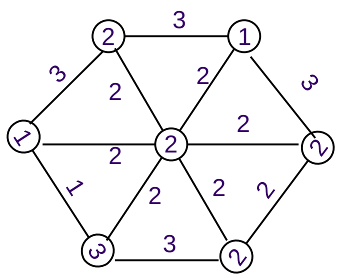
FAP

Frequency Assignment Problem

Channel demand for each cell

t

Interference constraint between cells



Frequency assignment – Major FAP problems

– Minimize Spectrum FAP
  - A number of frequencies is available for the network
  - Objective is to minimize the number of frequencies used while satisfying all constraints EMC and demand constraints

– Minimum Span FAP
  - Span of an assignment is the difference between the largest channel used and the smallest channel used
  - Objective is to minimize the span needed to satisfy all EMC and demand constraints

– Minimize Interference FAP
  - Finite, fixed number of frequencies available for the network
  - Objective is to satisfy all demands constraints and to minimize some measure of interference (e.g. EMC constraints violation) with the given frequencies

Frequency assignment – MI FAP specification

1. Radio spectrum is split in channels (GSM - 200 kHz per channel at 900 MHz)
2. Only N frequencies are available for GSM operators in France at 900 MHz
3. Channels must be assigned to base stations for Up Link (from MS to BS) and Down Link (from BS to MS) communications
4. FP gives geographical location of frequency in the network
5. Limited number of frequency → high rate of frequency reuse: frequency reuse gives capacity
6. But, frequency reuse gives radio interference: interference gives bad quality
7. **The problem is to satisfy the traffic demand (reuse rate) while maximizing the quality (minimizing radio interference)**
8. There are operational constraints: frequencies are pre-assigned and can't be moved, frequencies are forbidden for some cells and can't be assigned
9. Problem complexity is mainly due to irregular traffic distribution and propagation properties: sea, mountains, sites with irregular heights or positions…

Contents

Data and performance – Input data

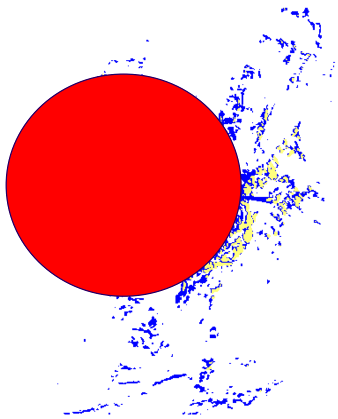
- Data from network:
  - Site, Base Station, TRX, frequency
  - Traffic and mobility reports (traffic level, calls dropped, hand over)
- Data from simulation:
  - Digital map database
  - Propagation model
  - **Pixel radio interference**
- Data from mobile:
  - **Field and neighbor measurement reports** => Bad Reuse List
  - Quality measurement reports
- Data from engineering:
  - Several quality thresholds: BCCH, TCH, hopping, voice, data...
  - Specific engineering rules: micro/macro, in building, train...

Data and performance – Cell cover

Radio link

Transmitter
↓
T-antenna
↓
Propagation & Environmental effects
↓
R-antenna
↓
Receiver

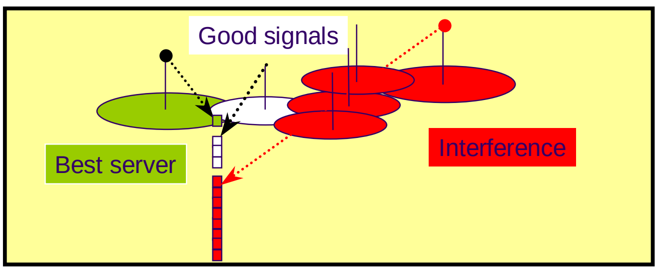
Frequency
Distance
Weather
Obstacle
…dependent



Blue: FS > -100
Yellow: FS > -90

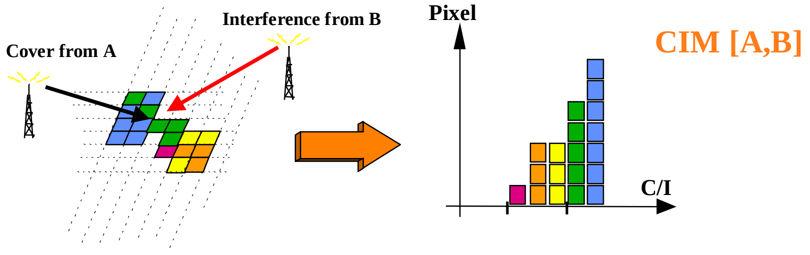
Data and performance – Cell overlap

- Cell overlap is measured from
  - Propagation simulation
  - Field and neighbor measurement reports
- On one pixel, currently are 40 to 70 significant signals
- 6 or 7 good signals are needed (HO)
- Others are multiple radio interference: I = I1+I2+…+In



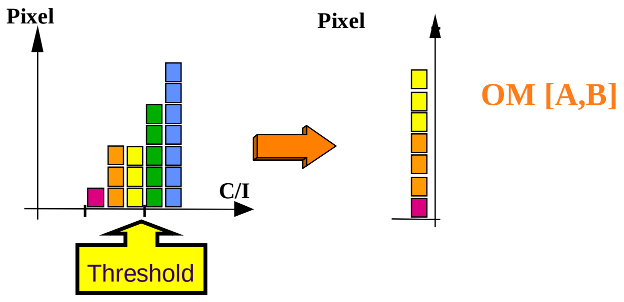
Data and performance – C/I matrix

- CIM [i,j] = surface with single radio interference between stations i (carrier) and j (interference) at all C/I level
- Computed from cell overlap
- Pixels restricted to single radio interference



Data and performance – Interference matrix

- OM [i,j] = surface with single radio interference between stations i (carrier) and j (interference) for a given C/I compatibility threshold for co-channel and adjacent channel
- Computed from C/I matrix
- Threshold per cell, per channel, per network layer….



Data and performance – Interference matrix

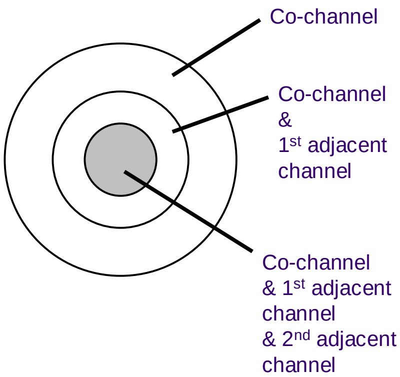
- Co-channel and adjacent channel interference rating for cell pairs are specified in terms of affected areas
- Specification are cell planned ; it supposes that TRX in a cell use the same technology and the same transmission power, and emit from the same antenna ; or several cells have to be defined

Stations	A	B	C	D
A		0,30 0,12		0,25 0,15
B	0,12 0			
C				0,34 0,08
D	0,18 0,12		0,15 0	

Data and performance – EMC constraints

- EMC constraints define a status in which the system operates properly without introducing intolerable disturbances to its environment

- Incompatibility constraints on frequency assignment inside a cell or on co-site conditions



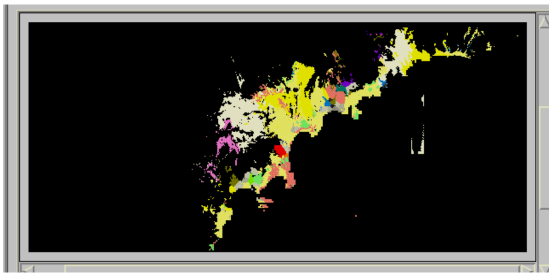
Data and performance – Separation matrix

- Additional separations required for engineering constraints:
  - Co-station separation: 3 channels (>= 3)
  - Co-site separation: 2 channels (>= 2) ; A and C are co-located
- SM [i,j] = channel separation requirement between frequency assigned to stations i and j to avoid any interference from j on i
- Computed from overlap matrix for (i,j) where i $\neq$ j

Stations	A	B	C	D	….
A	3	1	2	0	….
B	1	3	0	1	….
C	2	0	3	0	….
….					

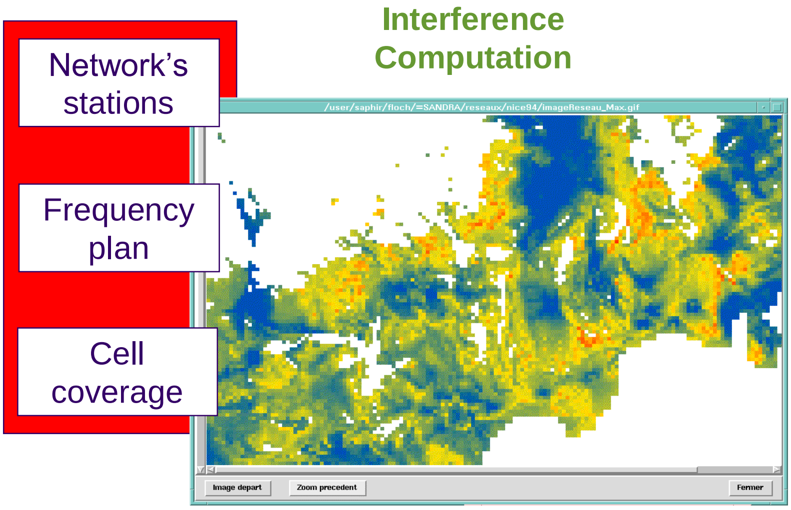
Data and performance – Traffic measurement reports

- Minimize interference where traffic is located at cell level
- Detection of problem from network measurements: Traffic level and Call dropped



- Traffic measurements may be added to interference data:
  - Use of Timing Advance data: distance BS / MS
  - Use of Digital Map Database: distinguish roads from fields, streets from indoors
  - Use of Mobile speed: distinguish cars from pedestrians
  - GPS for outdoor

Data and performance – FP evaluation

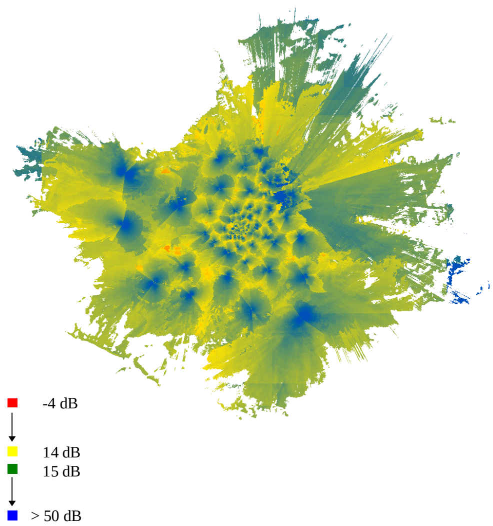


Data and performance – Radio interference

- Radio interference C/I+N ; N<<I (carrier/interference+noise)
- Surface-based or traffic-based criteria
- Co-channel, adjacent channel and multiple interference are considered:

$$C/I(i,j,k,p) = C_i \Big/ \sum_j I_j \rho_{k,p}$$

- Radio interference are analyzed continuously



Data and performance – Quality thresholds

– C/I thresholds depend on the engineering on frequency planning

– Most of the time radio interference are considered around:
  - 14 dB on non hopping network
  - 12 dB on base band hopping network
  - 8 dB on synthesized hopping network on theoretical conditions

– Several FP evaluation are available on one pixel:
  - C/I worst case on the pixel; non hopping
  - C/I mean value on the pixel; average of all frequencies; band base hopping
  - C/I worst case among the best frequency per cell; BCCH
  - FER evaluation with synthesized hopping

Data and performance – Quality thresholds

– Le niveau de C/I dépend de l'espacement des canaux affectés aux communications

Co-canal	C/I = 9 dB	2ème adjacent	C/I = - 41dB
1er adjacent	C/I = -9 dB	3ème adjacent	C/I = - 49 dB

– La mesure de qualité est très complexe en saut de fréquences
  - Intervention du facteur de charge, donc du trafic réel
  - Du C/I au FER (après code correcteur d'erreurs)
  - Nécessite des tables de qualité obtenues en simulation

– Le gain du SFH est fort en TU3, faible en TU50 car le canal apporte déjà une forte diversité (variations rapides)

Pour C/I = 9 dB	FER sans SFH	FER avec SFH
TU3	21%	3%
TU50	6%	3%