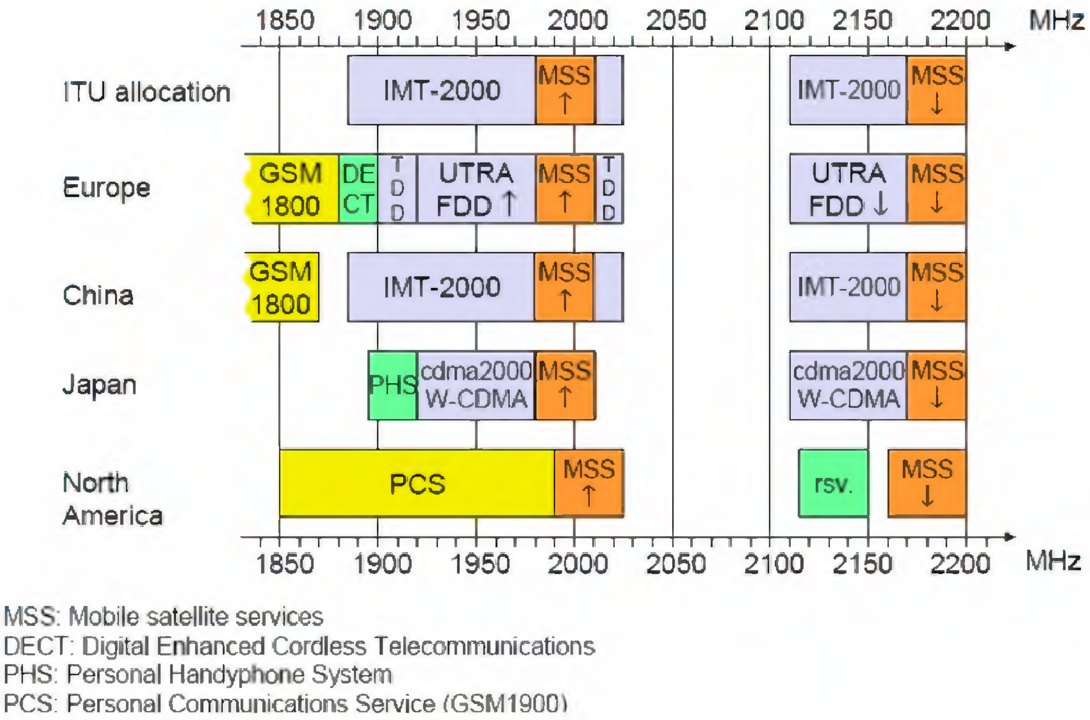
Chapter II

Frequency allocation

II.1 Spectrum and spectrum allocation, regulations (national and international)



MSS: Mobile satellite services
DECT: Digital Enhanced Cordless Telecommunications
PHS: Personal Handyphone System
PCS: Personal Communications Service (GSM1900)

Figure 2-1: *Spectrum reserved for IMT-2000s*

II.2 Frequencies used by mobiles

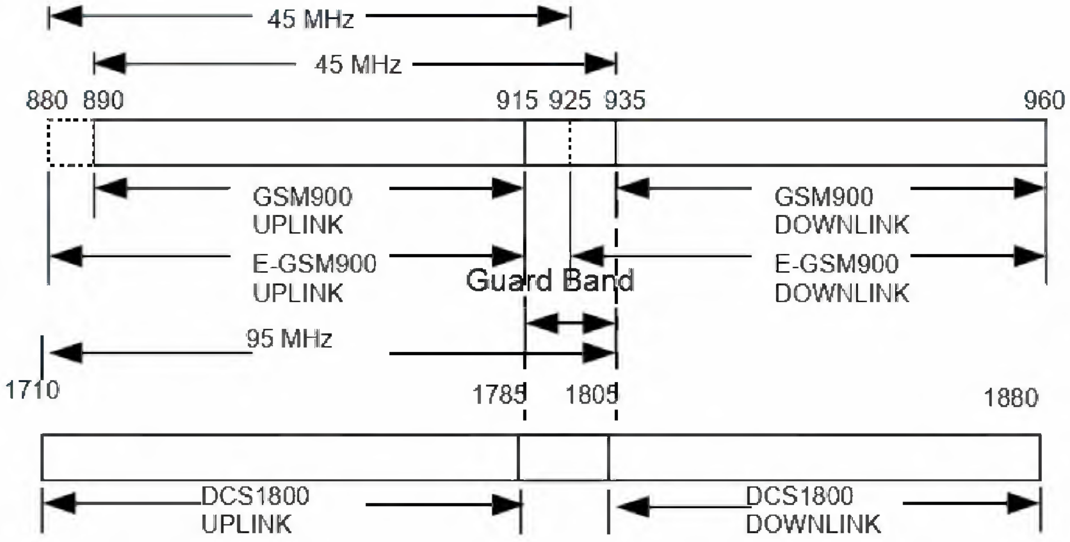


Figure 2-2: *Frequency allocation*

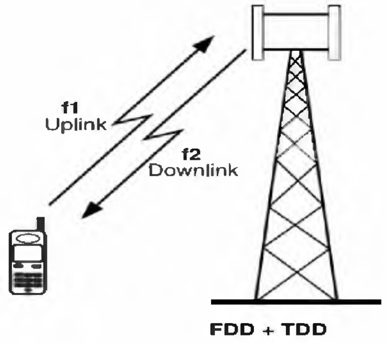


Figure 2-3: *Duplex in a GSM network*

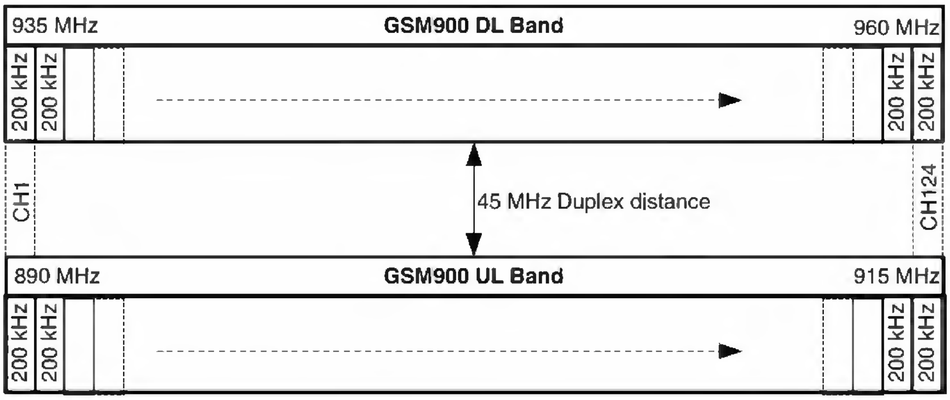


Figure 2-4: *The spectrum cf a GSM 900 (UL & DL)*

Note that the first GSM band (GSM 900) uses 124 channels of 200 KHz.

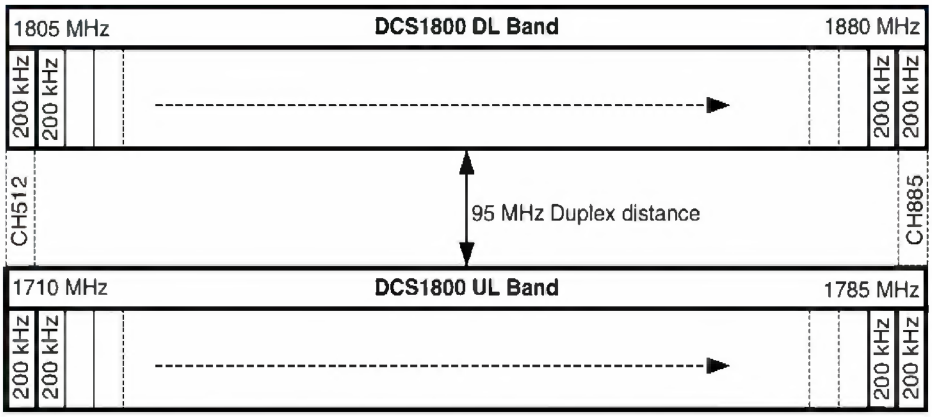


Figure 2-5: *The spectrum of a GSM1800 network (DCS 1800)*

Note that the second GSM band (DCS 1800) uses 374 channels of 200 KHz.

The following table illustrates the method of indexing frequency channels for different GSM network standards.

Table 2-1: ARFCN for different standards of GSM networks

GSM Band	*Fl(n)*	*ARFCN*	*Fu(n)*
P-GSM 900	$890 + 0.2*n$	$1 \le n \le 124$	Fl(n) + 45
E-GSM 900	$890 + 0.2*n$	$0 \le n \le 124$	Fl(n) + 45
	$890 + 0.2*(n-1024)$	$975 \le n \le 1023$	
R-GSM 900	$890 + 0.2*n$	$0 \le n \le 124$	Fl(n) + 45
	$890 + 0.2*(n-1024)$	$955 \le n \le 1023$	
DCS 1800	$1710.2 + 0.2*(n-512)$	$512 \le n \le 885$	Fl(n) + 95
PCS 1900	$1850.2 + 0.2*(n-512)$	$512 \le n \le 810$	Fl(n) + 80
GSM 450	$450.6 + 0.2*(n-259)$	$259 \le n \le 293$	Fl(n) + 10
GSM 480	$479 + 0.2*(n-306)$	$306 \le n \le 340$	Fl(n) + 10
GSM 850	$824.2 + 0.2*(n-128)$	$128 \le n \le 251$	Fl(n) + 45

II.3 Frequency reuse

Frequency reuse is generally used to maximize the capacity of the mobile network as well as minimizing interference, which improves the quality of service (QOS) in terms of RxLev and RxQual.

The reuse of the same radio frequency within a limited geographical area poses several problems. Indeed, the mobile will receive not only a useful signal coming from the base station to which it is attached, but also other interfering signals coming from the base stations using the same frequency in the neighboring zones.

It is therefore essential to “skip” several cells before being able to reuse the same frequencies, hence the notion of co-cells (cells using the same frequency).

The frequency reuse technique operates as follows: the frequency band allocated to the system is subdivided into sub-bands, each sub-band is then allocated to a base station of a given cell, to then be reused in its co-cells.

II.3.1 Cluster

In GSM, a cluster is a collection of smallest group cells containing only one radio channel at a time. This cluster is repeated over the entire surface to be covered. The larger the cluster, the greater the reuse distance. In GSM900 network, the frequency band is limited to 25 MHz (for example on the uplink) distributed over 124 carriers, i.e., a maximum of (7x124=868) simultaneous communications. The frequency reuse is therefore a major constraint, mainly in areas with high traffic (urban areas). This critical point explains the emergence of DCS in urban areas, which has a large frequency range in the 1800 MHz band up to 150 MHz in full-duplex.

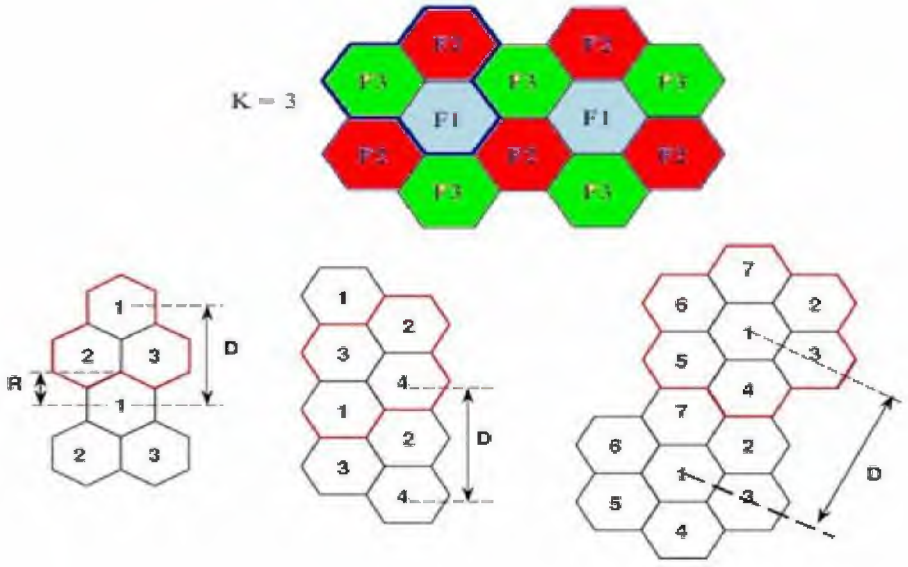


Figure 2-6: *A frequency reuse pattern with 3-cell clusters. (K=3)*

II.3.2 Regular pattern (cluster)

A pattern having a number of given frequencies is considered optimal if it is regular, In the sectorized case, each omnidirectional cell is split into typically either three sectors of 120°. In this case, the cluster size *N* can verify the following relationship

$$\boldsymbol{N = I^2 + I.J + J^2}$$

with I and J, natural integers or zero.

Generally, the most common regular patterns include 3, 4, 7, 9, 12,13,19, 21, or 27 cells, etc. It is possible to use non-regular patterns but the reuse distance cannot be greater than that of the regular pattern of size immediately below. The use of the same frequency by transmitters in different cells leads to the appearance of jamming, one then speaks of co-channel interference. The C/I ratio is defined as being the ratio between the signal power arriving at the receiver from the transmitter located in its cell (called the wanted signal), and the power received from other transmitters using the same frequency.

By increasing the ratio D/R, the spatial separation between co-channel cells relative to the coverage distance of a cell is increased. Thus, interference is reduced from improved isolation of RF energy from the co-channel cell. The parameter Q, called the co-channel reuse ratio, is related to the cluster size. For a hexagonal geometry

$$Q = \frac{D}{R} = \sqrt{3N}$$

A small value of Q provides larger capacity since the cluster size N is small, whereas a larger value of Q improves the transmission quality, due to a smaller level of co-channel interference. A trade-off must be made between these two objectives in actual cellular design.

Decreasing cell size increases capacity, but increases interference and degrades received signal quality. The capacity and quality offered are therefore linked and conditioned by the C/I parameter.

Table 2-2: Co-channel reuse ratio for some values of cluster size (N)

	Cluster Size (N)	**Co-channel Reuse Ratio (Q)**
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

Let i_o be the number of co-channel interfering cells. Then, the signal to interference ratio (*S*/*I* or *SIR*) for a mobile receiver which monitors a forward channel can be expressed as

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

where S is the desired signal power from the desired base station and I_i is the interference power caused by the i^{th} interfering co-channel cell base station. If the signal levels of co-channel cells are known, then the *S*/*I* ratio for the forward link can be found using the precedent equation.

The average received power P_r at a distance d from the transmitting antenna is approximated by

$$P_r(\text{dBm}) = P_0(\text{dBm}) - 10n \log [d/d_0]$$

where P_0 is the power received at a close-in reference point in the far field region of the antenna at a small distance d_0 from the transmitting antenna and n is the path loss exponent. Now consider the forward link where the desired signal is the serving base station and where the interference is due to co-channel base stations. If D_i is the distance of the i^{th} interferer from the mobile, the received power at a given mobile due to the i^{th} interfering cell will be proportional to $(D_i)^{-n}$. The path loss exponent typically ranges between two and four in urban cellular systems.

When the transmit power of each base station is equal and the path loss exponent is the same throughout the coverage area, *S*/*I* for a mobile can be approximated as

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_o} (D_i)^{-n}}$$

If all the interfering base stations are equidistant from the desired base station and if this distance is equal to the distance *D* between cell centers, then the precedent equation can be simplified to

$$\frac{S}{I} = \frac{(D/R)^n}{i_o} = \frac{\left(\sqrt{3N}\right)^n}{i_o}$$

II.3.3 Reuse distance

The reuse distance between all cells using the same channel set is then

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

where, *R* is the radius of the cell and *D* is the distance between centers of the nearest co-channel cells.

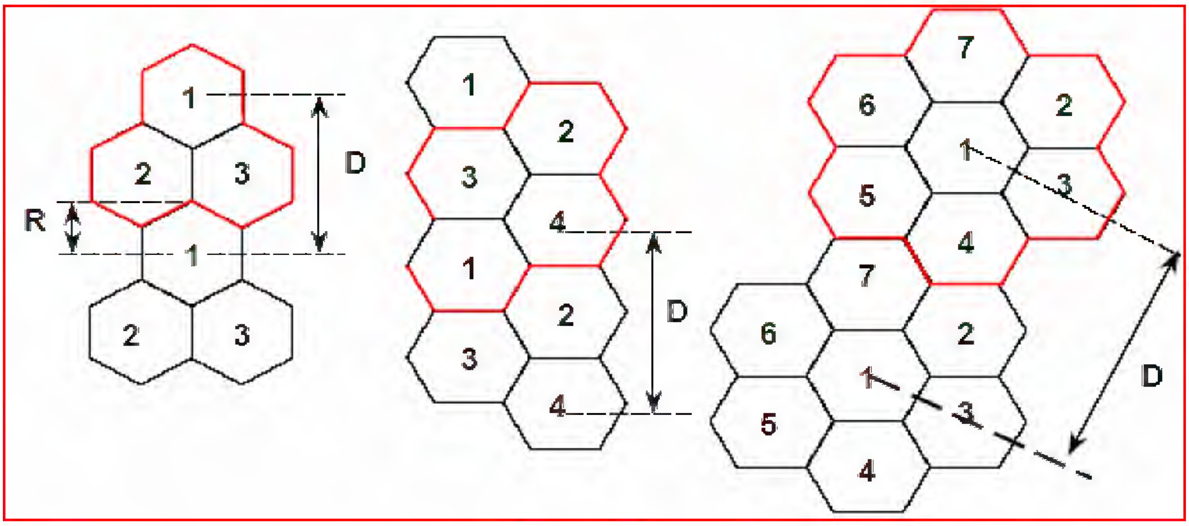


Figure 2-7: *Reuse distance. (K=3)*

Frequency reuse can be divided into two types

- The normal pattern (normal frequency reuse) is the 4x3 pattern.
- The strict model (tight frequency reuse) is the pattern of 1x3 and 1x1.

II.3.4 Interference and noise

A mobile station in a given cell receives a useful signal of power C (carrier signal power) coming from the attached base station and other interferer signals of two types: noise and interference. The quality of the received signal can be expressed by the ratio *C*/(*I*+*N*).

where I represent the total interference power, *N* denote the noise power, which is mainly corresponded to the background noise of the receiver.

II.3.4.1 Co-channel interference

This kind of interferences is caused by some equipment, which are operates at the same frequency of the attached cell. When the signals emitted on a frequency f_1 are scrambled by other signals emitted on the same frequency, there is co-channel interference. This phenomenon is frequently found due to frequency reuse in the cellular systems.

If a given operator wants to plan many frequency channels on each base station, frequency reuse must be used the most possible. In this case, the co-channel interference will dominate over all other interference ($N \ll I$).

To mitigate this kind of interference, a given frequency is only allocated by the MSC if it is not currently in use in the cell or in any other cell within the minimum distance for frequency reuse.

The ratio $C/(I+N)$ will take the following form

$$C/I = C/\sum I_k \qquad k \in Bi$$

where B_i is a group of base stations which are transmitting at the frequency used by the mobile station and I_k is the co-channel interference received from the kth cell of the first cluster.

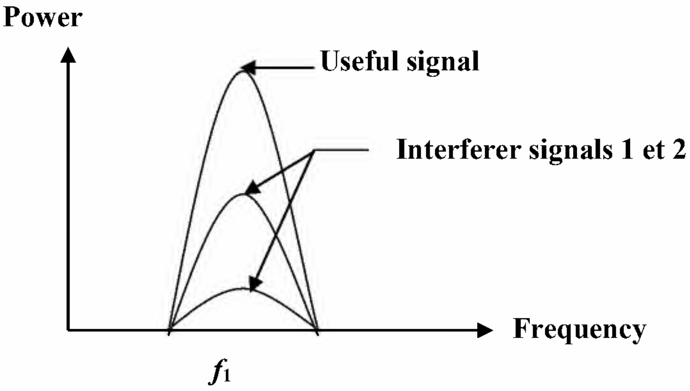


Figure 2-8: *Co-channel interference.*

II.3.4.2 Adjacent channel interference

Interference caused by adjacent channels occurs when receiver filters are not good, which allowing nearby frequencies to leak into the passband. This problem can be serious while mobile stations try to receive a base station on the desired channel, an adjacent channel BTS may transmit in close distance to the receiver (MS). Since each cell is given only a set of the available channels, a cell does not need to be assigned with adjacent frequencies.

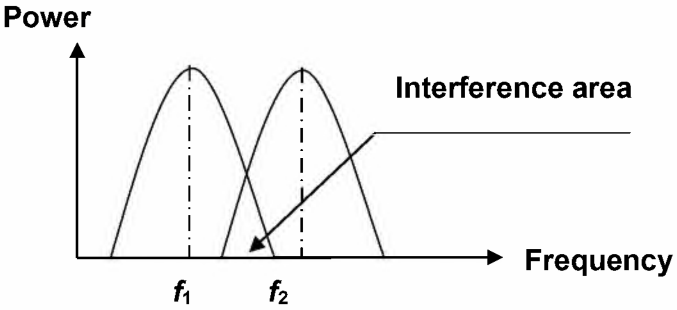
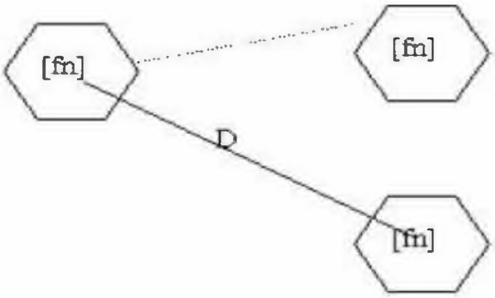


Figure 2-9: *Adjacent interference.*

In GSM network, Co-channel and adjacent channel interference can be measured at the base station or on the mobile device

II.3.5 C/I requirements

As the frequency resource in the cellular system is limited, the replicated use of the frequency can effectively promote frequency availability but can also increase interference in the cellular system (As frequency bands are closer, frequency availability increases, but interference increases too).



For a hexagonal geometry, the co-channel reuse ratio, is given by

$$Q = \frac{D}{R} = \sqrt{3N}$$

The ratio C/I is expressed as follow

$$\frac{C}{I} = \frac{C}{\sum I_k}$$

where I_k is the k^{th} interference signal with k=1, …, N the above expression can also be

$$\frac{C}{I} = \frac{1}{\sum (Q_k)^{-n}}$$

where n is the path fading offset, which is determined by the actual geographic environment (generally, n=4).

$$Q = \left(6.\ \frac{C}{I}\right)^{\frac{1}{n}}$$

The relation between C/I and Q become

$$\frac{C}{I} = \frac{(Q)^n}{6}$$

The ratio C/I should meet the following requirements

- For co-channel interferences, C/I>=9 dB with an allowance of 3 dB, which means C/I>=12 dB.
- For adjacent interferences, C/A>=-9 dB with an allowance of 3dB, which means C/A >=-6dB.

II.3.6 Concept of frequency reuse

Sharing frequencies between several users requires frequency reuse (transition from a macro cell to a microcell with a reduced coverage area). This transition increases the capacity of the system. For example, if we have 8 MHz for Mobilis, as frequency resources, that means 40 channels X 8 time slots = 320 users. If each frequency is reused *N* times, then the capacity becomes 320 x *N*.

The reuse distance depends on several parameters such as the C/I ratio and the signal intensity itself.

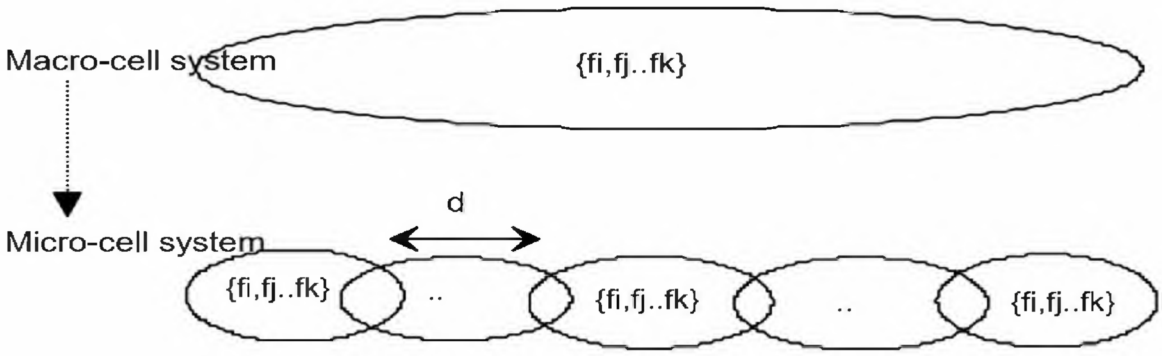


Figure 2-10: *concept of frequency reuse.*

The spectrum utilization ratio can be expressed by frequency reuse density (f_{reuse}), which reveals the tightness of the frequency reuse density and can be expressed by the following equation

$$f_{reuse} = \frac{N_{ARFCN}}{N_{TRX}}$$

where, N_{ARFCN} is the total number of available channel numbers

N_{TRX} is the number of configured TRX in a cell.

Example:

For a 12 MHz frequency band, if the frequency reuse density is 4x3. How many TRX in each cell of the cluster?

Solution:

N_{ARFCN}=nxm=12 => N_{TRX}= N_{ARFCN}/12

B=12 MHz=12x5=60 channels (60 ARFCN frequencies)

So, N_{TRX}= N_{ARFCN}/12= *60*/12=5 TRX for each cell

In the cluster, the configuration of a BTS is S5/5/5

II.4 Reuse density

Reuse density is the number of cells in a basic reuse cluster,

For the nxm frequency reuse pattern,

$$f_{reuse} = nxm,$$

where n is the number of BTSs in the reuse cluster and m is the number of cells under each BTS.

Example:

we take the model 4x3 frequency reuse. The available bandwidth is 10 MHz. The allocated frequencies are 45~94 with a BCCH frequencies 81~94 (14 channels, the frequencies 81~82 are reserved). The other channels are allocated for traffic (TCHs)

1. draw the assignment table of frequencies(affectation)
2. Configuration of the BTS
3. Calculate reuse density of frequencies

Solution:

1. The assignment table of frequencies

B=10 MHz => N_{ARFCN}=10x5=50 frequencies (45~94)

N=94-45 +1= 50 frequencies (ARFCN)

We have 4 BTS (A, B, C, and D)

Frequency group number	A1	B1	C1	D1	A2	B2	C2	D2	A3	B3	C3	D3	
Channel Number of Each Frequency Group	94	93	92	91	90	89	88	87	86	85	84	83	**TRX1**
	80	79	78	77	76	75	74	73	72	71	70	69	**TRX2**
	68	67	66	65	64	63	62	61	60	59	58	57	**TRX3**
	56	55	54	53	52	51	50	49	48	47	46	45	**TRX4**

2. The configuration of the BTS
   Following to the assignment table, the configuration of the BTS is S 4/4/4

   $$\frac{N_{ARFCN}}{N_{TRX}} = nxm = 12 \Rightarrow N_{TRX} = \frac{N_{ARFCN}}{nxm} = \frac{50}{12} = 4.16$$

   See that 4x12=48 (48=50 channels-2 of reserve)

3. Frequency reuse density

$$f_{reuse} = \frac{N_{ARFCN}}{N_{TRX}} = \frac{50}{4} = 12.5$$

So, the corresponding frequency reuse density is 12.5 (50/4 = 12.5)

II.4.1 Types of frequency reuse

Frequency reuse can be divided into two types

- The normal pattern (normal frequency reuse) is the 4x3 pattern.
- The strict model (tight frequency reuse) is the pattern of 1x3 and 1x1.

The 4 x 3 frequency reuse pattern is the most technology applied in frequency planning. Which is usually used to the BCCH in frequency aggressive reuse technologies.

To enhance the network capacity much more, some techniques can be taken such as

- Split a cell into smaller cells.
- Using new frequency resources. For example, an engineer can establish a DSC network (1800MHz).
- Under the GSM 900MHz network, tight frequency reuse technology can be used more to expand the network capacity.

For the tight frequency reuse technology, it can be considered as the most economical and convenient way to expand the network capacity, so it is also the most popular with carriers. The typical frequency reuse technology includes 3 x 3, 2 x 6, 2 x 3, 1 x 3, and 1 x 1.

II.5 Frequency h*opping*

Sometimes, the required capacity is greater than that can be provided by the macrocells. In this case, capacity enhancement techniques must be used such as frequency hopping. Using this last technique, frequency diversity and interference averaging can be achieved.

As a feature of the GSM system, frequency hopping is used to reduce simultaneous usage of the same frequency, which reduce interference. Compared to the classical frequency reuse, which is static, frequency hopping allows the dynamic frequency(carrier) to change cyclically or randomly.

Frequency hopping can be activated or disactivated in each cell separately.

Since BCCH is a broadcast channel, it does not participate in frequency hopping while TCH and SDCCH channels can utilize frequency hopping.

II.5.1 Types of frequency hopping

According to the implementation mode, there are two types of frequency hopping that can be used by BTS: Base Band hopping (BB hopping) and radio frequency hopping (RF hopping).

Base Band hopping (BB hopping): In this type, the BCCH carrier can attend hopping but the TS0 must be away from the hopping.

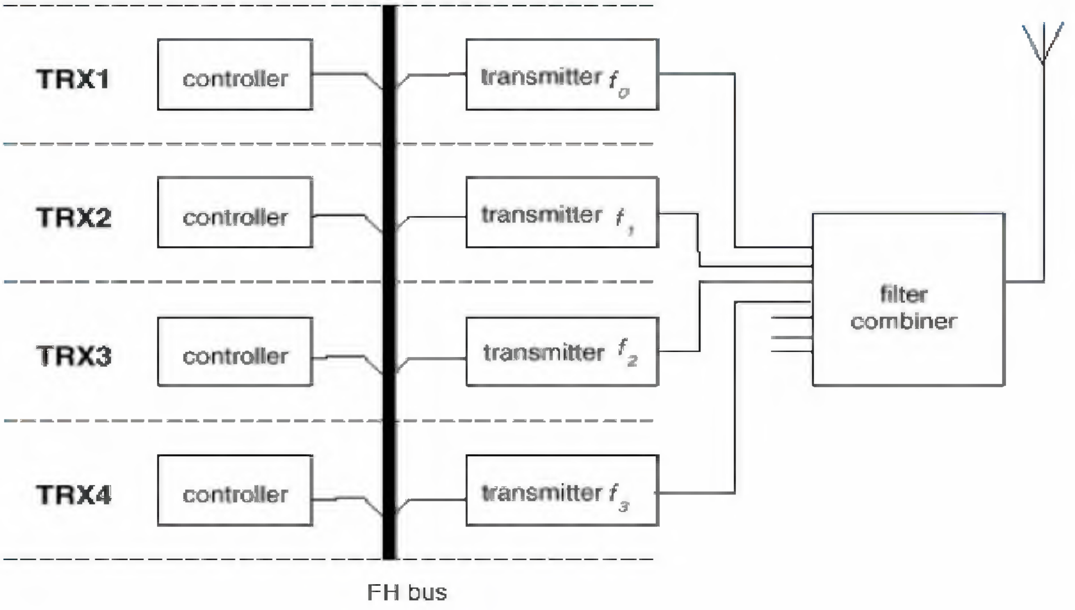
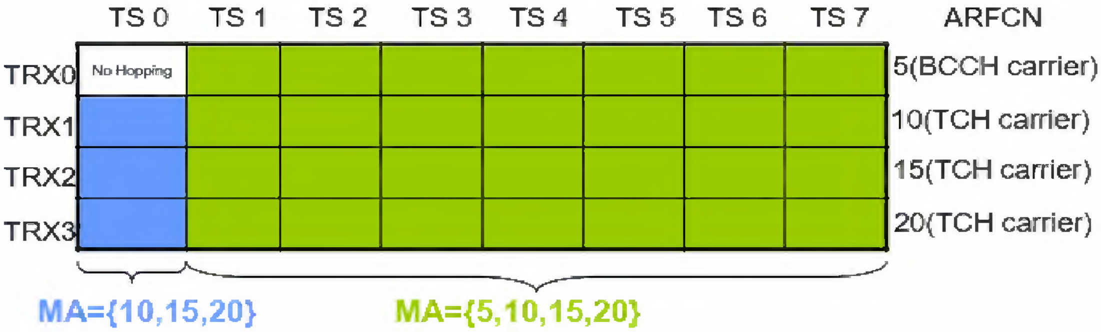


Figure: BB frequency hopping



Radio frequency hopping (RF hopping): In this type of hopping, frequency synthesizers will be used. The number of frequency hopping does not depend on the number of TRx. For that the BCCH does not attends on hopping.

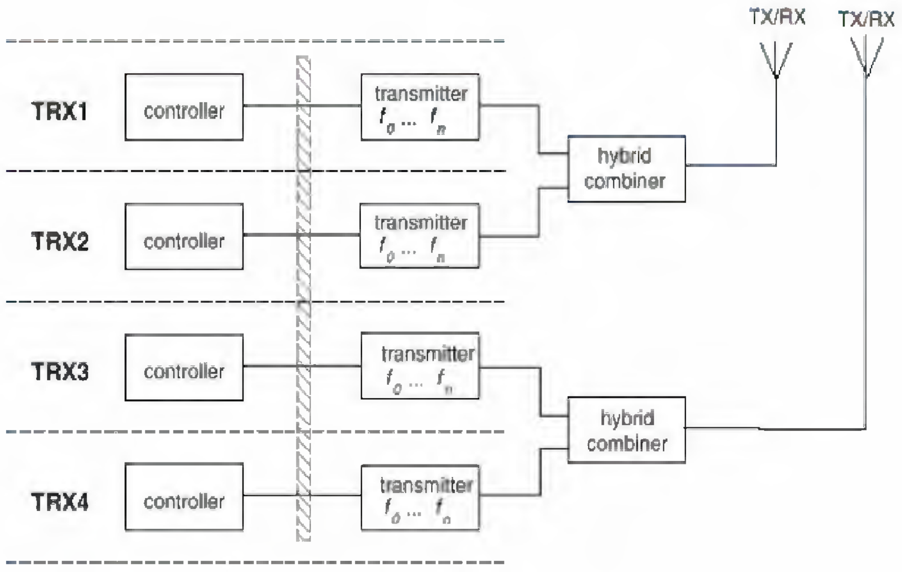
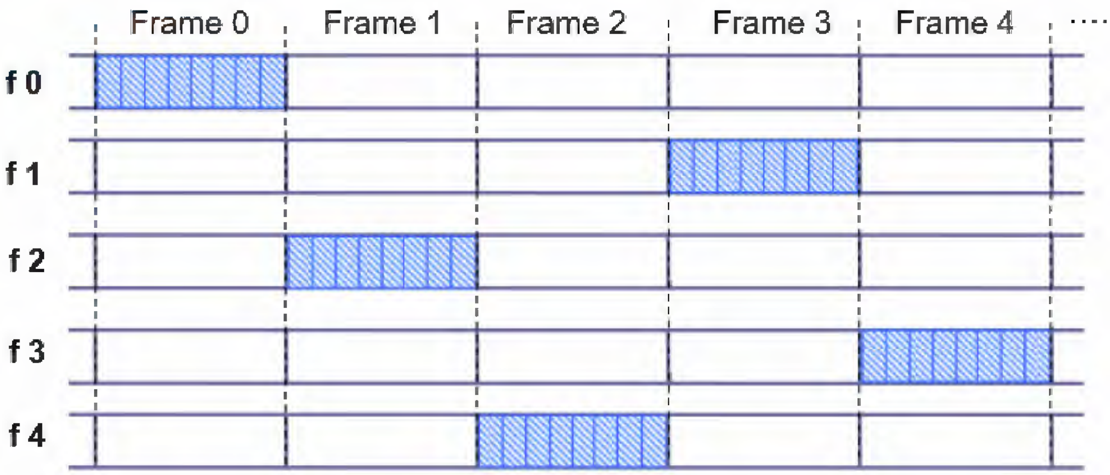


Figure: BB frequency hopping

	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7		
TRX0	No Hopping	No Hopping	No Hopping	No Hopping	No Hopping	No Hopping	No Hopping	No Hopping	(BCCH carrier)	
TRX1									MA={10,15,20}	(TCH carrier)
TRX2									MA={10,15,20}	
TRX3									MA={10,15,20}	

In the same way, it can be classified into two kinds following to the minimum hopping time unite as: Time slot hopping and frame hopping.

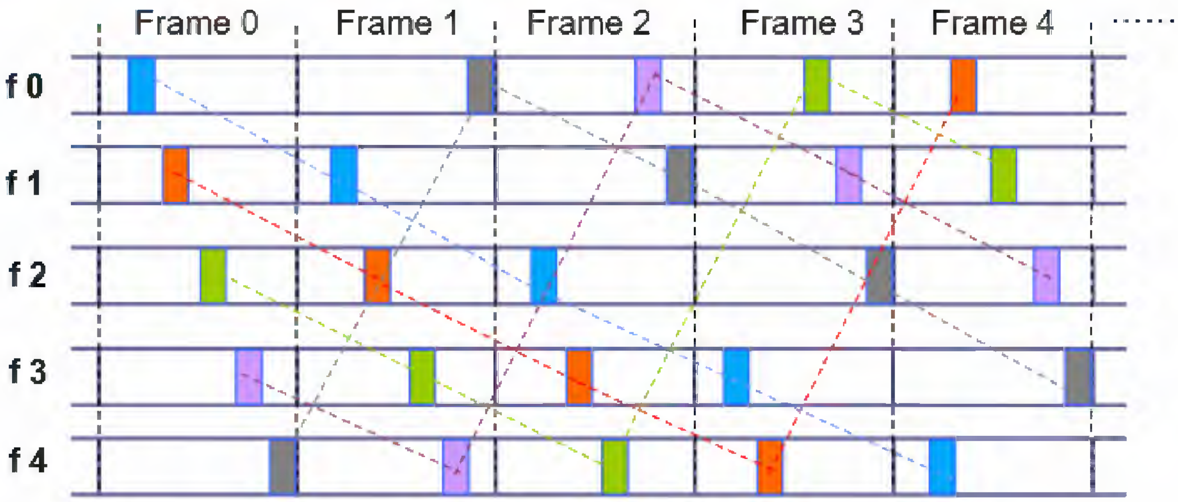
Frame hopping



RF hopping and baseband hopping without BCCH carrier

One TRX (none BCCH carrier) hopping on 5 frequencies

Timeslot hopping: as an example, 5 timeslots on 1 TRX hopping on 5 frequencies



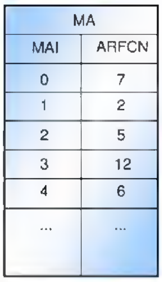
II.5.2 Parameters of frequency hopping

Frequency hopping parameters including frequency hopping rate, frequent set, and frequency hopping width. But in implementation, we have

Hopping sequence number (HSN): the HSN range （0～63）

- HSN=0 : used for cyclic hopping.
- HSN≠0 : (1~63) are pseudo random sequences that are used for random hopping.
- HSN of neighbor sites should be different to minimize the interference.

Mobile allocation set (MA): MA is defined as the available frequency bands for hopping. The maximum length of the MA list is 64 frequencies, which also includes the BCCH frequency, and therefore the maximum number of hopping frequencies on the list is 63. In the table, the relation between the different MAI numbers and the corresponding ARFCN.



MA	
MAI	ARFCN
0	7
1	2
2	5
3	12
4	6
...	...

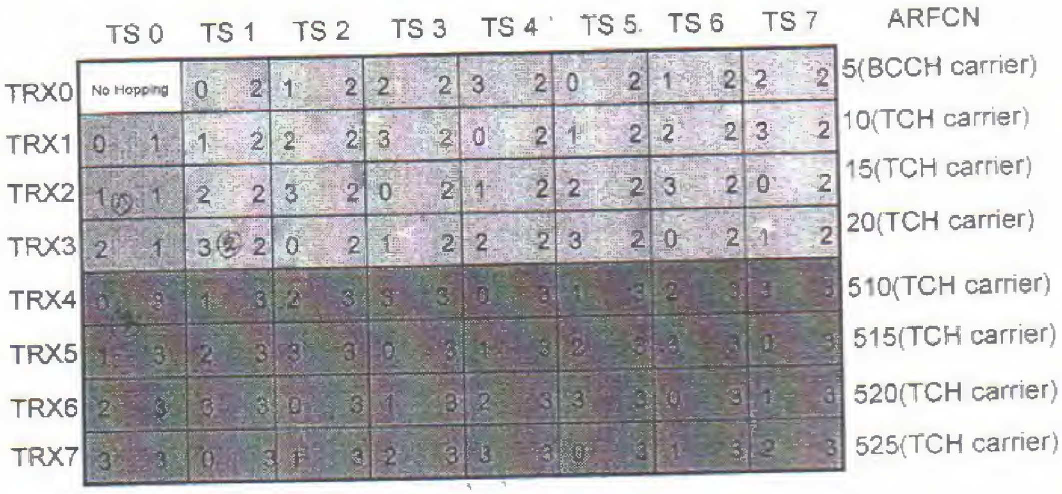
Mobile allocation index Offset (MAIO): This parameter is developed to avoid different TRXs using the same HSN to transmit simultaneously at the same frequencies.

MAIO is used to define the initial frequency of the hopping (ensures that those TRXs start to transmit at different frequencies).

Mobile allocation index (MAI):

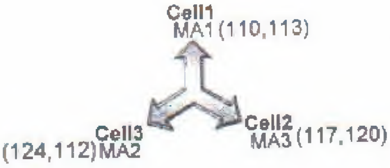
- At the radio interface, the frequency used on a specific burst is an element in MA set. MAI is an index number, which is used for indication, referring to the correct element in the MA set to determine the corresponding ARFCN.
- MAI is the function of TDMA FN, HSN and MAIO

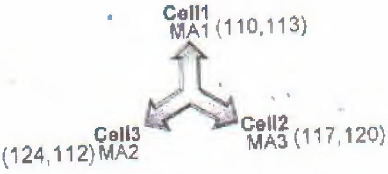
Example of MAIO

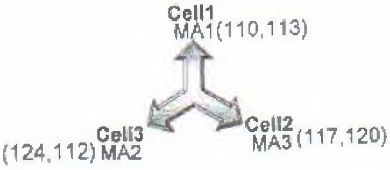


	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7	ARFCN
TRX0	No Hopping	0 2	1 2	2 2	3 2	0 2	1 2	2 2	5(BCCH carrier)
TRX1	0 1	1 2	2 2	3 2	0 2	1 2	2 2	3 2	10(TCH carrier)
TRX2	1 ⓪ 1	2 2	3 2	0 2	1 2	2 2	3 2	0 2	15(TCH carrier)
TRX3	2 1	3 ② 2	0 2	1 2	2 2	3 2	0 2	1 2	20(TCH carrier)
TRX4	0 3	1 3	2 3	3 3	0 3	1 3	2 3	3 3	510(TCH carrier)
TRX5	1 3	2 3	3 3	0 3	1 3	2 3	3 3	0 3	515(TCH carrier)
TRX6	2 3	3 3	0 3	1 3	2 3	3 3	0 3	1 3	520(TCH carrier)
TRX7	3 3	0 3	1 3	2 3	3 3	0 3	1 3	2 3	525(TCH carrier)

MA1={10,15,20}
MA2={5,10,15,20}
MA3={510,515,520,525}







		MAIO
CELL1(MA1)	110 113 116 119 122	0,1
CELL2(MA2)	111 114 117 120 123	2,3
CELL3(MA3)	112 115 118 121 124	4,0

II.6 Power control