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Mobile communication networks

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The course faces GSM evolution (voice); the present GPRS evolution (data) up to the Universal Mobile Telecommunication System (UMTS). The passage to UMTS is mostly considered: this is the real challenge arising in these years for mobile communication systems and services. There are in fact many emerging technologies which may either threat or help (as complementary techniques) the UMTS development.

Economical uncertainty and technical difficulties are anyway characterising the overall evolution path. The emerging technological solutions that deserve some attention are: Wireless Fidelity system WiMax, WiBro.

Many disciplines are touched by the course, starting from the basic radio concepts. The course deals also with the topic of integration between the Information Technology and the Telecommunication field that is arising in the mobile/fixed context.

The course will touch various arguments by starting from a baseline which clarifies the intuitive facts around mobile communication and leaves to specific *extensions* to go into greater technical details. This choice has been done in order to preserve a self-standing meaning of the baseline.

It is well known how the GSM has been and still is one of the major factors of the (almost uncontrolled) growth of mobile communication. This happened in Europe much more than in the US, where the web technologies and the web-based services showed a more significant penetration compared with mobile communication. These two worlds are now significantly converging and this fact will be considered by trying to clarify the key technical issues that are inspiring the going-on evolution.

Mobile Communications

The course structure

1. Basic elements

2. GSM and voice services

3. Data services and General Packet Radio System

4. Universal Mobile Telecommunication System

5. Network engineering

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The course devotes an initial part to the basic elements of mobile communications, by recalling some of the key mechanisms: propagation, coding, interference.

Chapter 2 analyses the main characteristics of the GSM. This will allow to consolidate some basic concepts that will be used in the subsequent parts.

Chapter 3 is devoted to services and solutions used for data communications in the wireless context. Here, the *General Packet Radio System* (GPRS) is playing a fundamental role in that it has anticipated most of the solutions developed for third generation mobile systems.

Chapter 4 describes the UMTS system. For it, the technological discontinuities that arose with respect to the second generation systems will be studied. The UMTS shows a great complexity, often leading to use *edge* technologies mostly in the basic functions the mobile terminal is implementing.

It adopts very advanced solutions for the radio resource management as well as for the IP-integration at the upper hierarchical layers.

The last chapter is devoted to network engineering. In particular, the UMTS planning issue is considered as a key topic, arising whenever scarce resources are to be optimally allocated to a variety of different services (this is the situation arising for the UMTS service environment).

Mobile Communications

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1. Basic elements

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extension

3



evolution path

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The course sequence is based on incremental concepts:

GPRS (General Packet Radio System) is deriving from the GSM infrastructure through an explicit orientation towards the data service requirements.

The UMTS derives from GPRS as far as the core network is concerned and vice versa adopts a completely new radio interface, aiming at a single technology for a variety of circuit and packet-based services.

Extensions will allow to consider in a grater detail some specific topics which deserve greater attention, without threatening the pace of the basic concepts dealt with in the main course chapters.

The chapter devoted to system engineering, plays a *transversal* role with respect to all the others. Its objective is to show how a cellular system can be deployed in a real situation being the loading conditions assigned. This exercise has to be done by trying to minimise the overall cost of the network under given network performance levels (constrained optimisation problem).

Mobile Communications

Basic Elements

1. Basic Elements

➡ 1.1 Basic concepts of mobile communications

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A single chapter for the basic elements, reporting some intuitive and introductory considerations common to all the systems that is considered.

Some fundamentals of the mobile communications are faced. They are considered through some simple considerations that may be anticipated in an intuitive way with respect to the subsequent more detailed parts.

Extensions recall very complex disciplines that are not direct objectives of the course. On the other hand, these basic concepts are dealt with in other didactical modules of the Master Course.

1. Basic elements

1.1 Basic concepts of mobile Communications

radio coverage
frequency re-use
static and dynamic frequency allocation

extensions:  **e1.1 propagation models**  **e1.4 error correction coding**
 **e1.2 interference behavior**
 **e1.3 digital transmission**



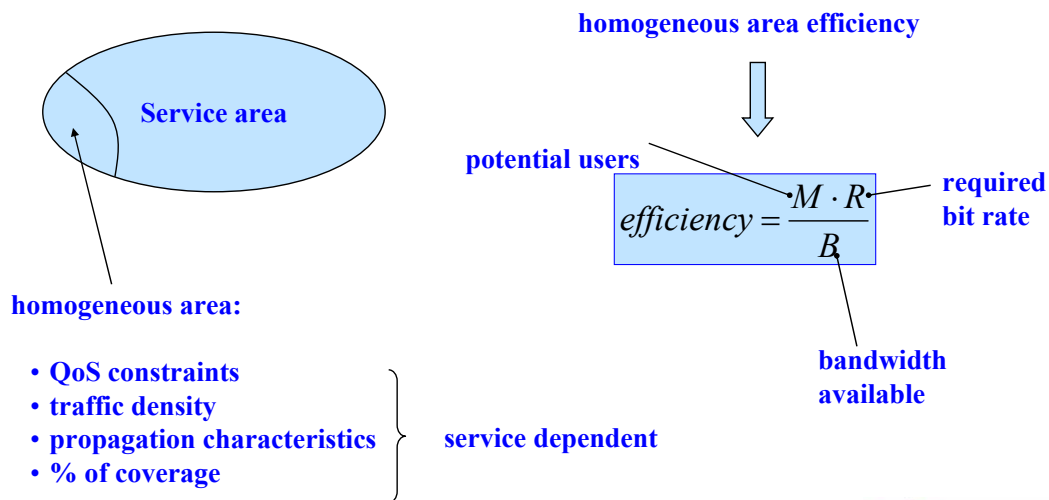
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The themes touched by the Introductory chapter are listed in the figure as well as the extensions associated.

Radio coverage, frequency re-use and radio channels allocation to the cells are the major topics.

Propagation models and the interference behaviour (extensions *e1.2* and *e1.2*) will be partially analysed, while the other extensions will be just briefly recalled.

An overall view of the mobile service needs



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The overall needs to ensure an effective mobile service are summarised in the figure.

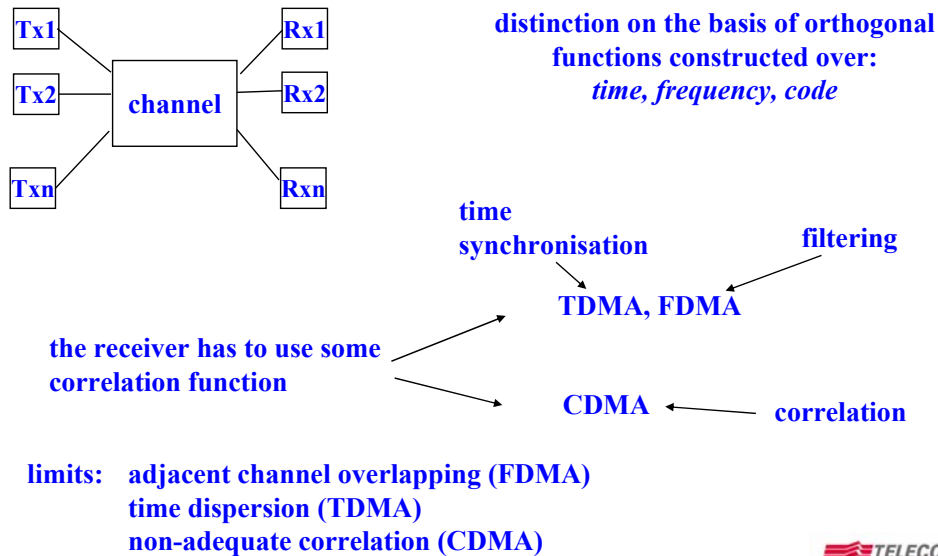
The service area extends wherever a sufficient degree of quality is offered by the system for a given service. It depends in general from the technical characteristics and requirements of the service itself.

A service area is called *homogeneous* service area where the basic coverage, traffic and performance characteristics can be assumed as uniform all over the area.

A rough measure of efficiency can be adopted in function of potential users, (average) required bit rate and the available bandwidth.

M users have their own statistical behaviour. The statistical behaviour of any source as well as the resulting behaviour of the multiplicity of sources are usually represented as stochastic processes.

Needs for orthogonal channels



The key topic to be solved to ensure that a multiplicity of *connections* can take place simultaneously within the same bandwidth assigned to the (any) system, is to make available orthogonal channels for these communications. The orthogonal character is allowing the receiver to distinguish (to isolate) a single channel (communication) from all the others arising at the same time.

Time, Frequency and Code are the *dimensions* to be used in order to create this orthogonal characteristics.

Three basic techniques are used in this sense, namely Time, Frequency, Code Division Multiplexing (TDMS, FDMA, CDMA).

The system characteristics on which these techniques may be realised are listed in the figure.

Three kinds of efficiency pursued

- N:** # of orthogonal functions
- B:** bandwidth
- B₀:** B/N bandwidth needed for each active user
- M:** potential users (active and non-active)
- M_N:** potential users related to N

frequency [bit/s/Hz] time [users/Hz] space [users/users]

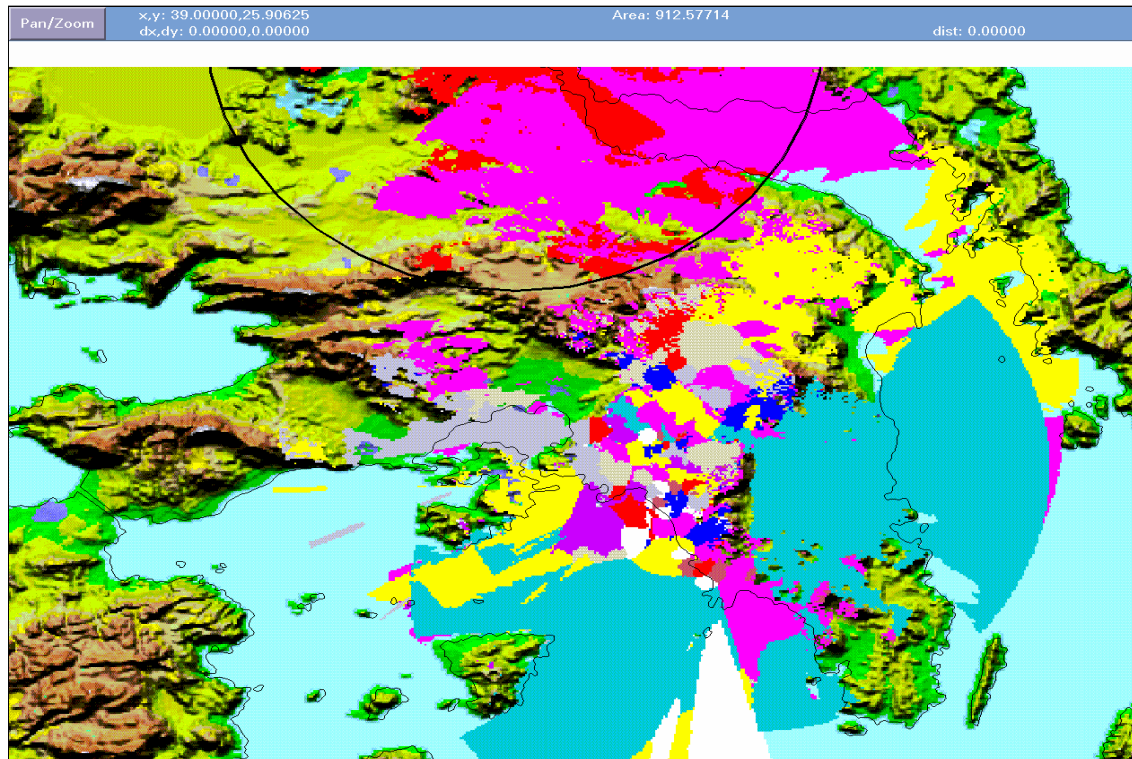
$$efficiency = \frac{M \cdot R}{B} = \frac{R}{B_0} \cdot \frac{M_N}{N} \cdot \frac{M}{M_N}$$

modulation synchronisation re-use

The efficiency previously introduced may be re-written as indicated.

The first factor of the product defines the spectral efficiency; the second one reflects the degree of multiplexing; the third one is tied to the re-use of the available frequency band.

These concepts will be explained and used throughout the subsequent part of the course.



This is a typical radio coverage of a geographical zone. The zone is covered (in the sense that service is supplied in all its points) through elementary coverage spots named *cells*. Different cells are assigned different colours in the figure. Each cell is generated by a specific antenna. In a given cell, the level of the radio signal generated by the related antenna, is high enough to guarantee that the cell *broadcast* channel is correctly received by any mobile terminal roaming in that cell.

The cell layout depends on the emission power, on the antenna gain, on its orientation and on the terrain morphology (or, in the urban zones, on the building height and shaping). In function of the above characteristics, it is possible to evaluate the intensity of the electromagnetic field by making use of appropriate empirical models.

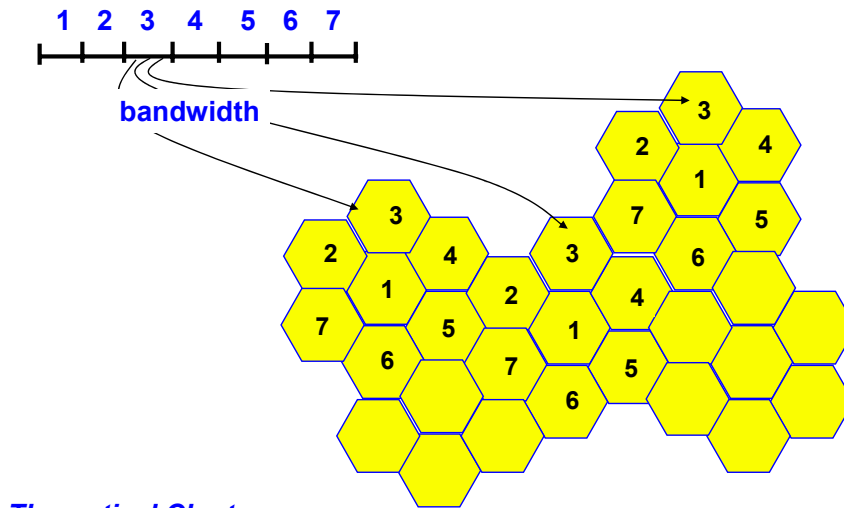
As for the propagation models, a distinction has to be made between the macro cellular and microcellular case.

For a macro cellular coverage (as the one depicted in the figure) the territorial features are often based on satellite-based measurements, supplying territorial characteristics like:

- urban areas extension
- sown fields extension
- dense trees (including the trees characteristics)
- scattered trees
- rocky areas.

The propagation model is based on statistical considerations. The *non-overlapping* condition, which is implicitly assumed in the figure, implies that each *pixel* is assigned the *colour* of the station which generates the maximum field intensity in that pixel.

Cellular System - Frequency Reuse



Theoretical Cluster

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The propagation theory and related models are out of the scope of the Seminar. As far as the radio and network functions are concerned, the specific profile of the cells is not so important. In fact, typically, the coverage layout is represented as in the figure above, where cells are given a regular structure.

In the figures, these cells are non overlapping, while, in the real environment, the mobile station is receiving the signal of several antennas in each point of the zone. The non overlapping character is due to the fact that the coverage area of a single cell is identifying the region where the signal of the homologous antenna is the highest among those received by the surrounding antennas (best server concept). This implies a disjunction between cells in the graphical representation as already said for the previous figure.

Cellular systems are based on the frequency reuse principle: the frequency (set of radio channels) used in a give cell is re-used in another cell, provided that the interference occurring between the two cells is below a given threshold.

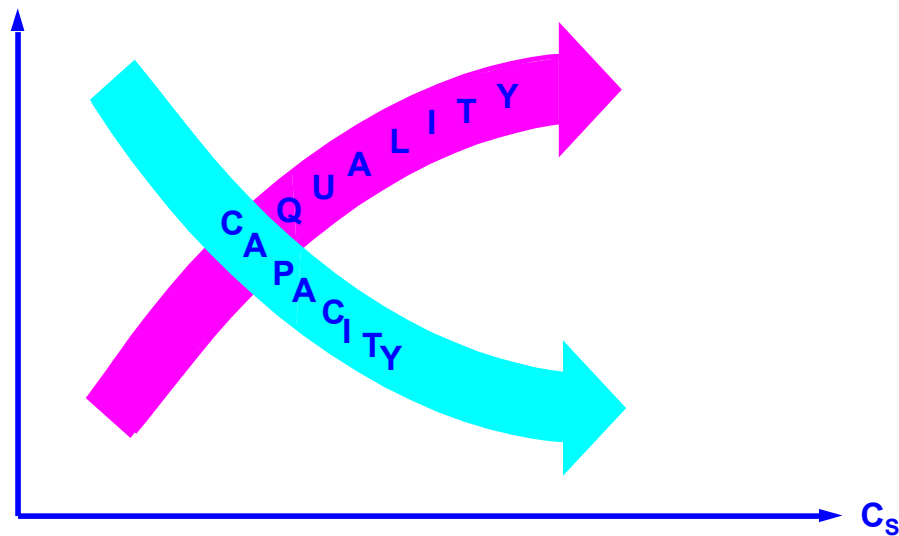
The figure shows how this re-use can be performed in a regular cellular layout. The cluster represents the set of cells over which the available bandwidth (frequencies) has to be distributed in order that a regular repetition of the same frequency assignment scheme is respecting the interference constraints. The scheme can of course be repeated until the entire service area is covered.

The cluster concept has just a conceptual meaning: in the real world, as anticipated, the cellular layout is all but regular and in addition, the inter-cell interference does not follow a regular scheme. The last part of the Seminar, dealing with network engineering issues, will clarify how in a practical situation, the assignment of frequencies can be done on the basis of a pure interference-based relation.

Two elements are affecting the re-use distance that can be adopted:

- the robustness of the system to interference (with respect to the interference constraints)
- the selectivity of the filters on the receiving side

Choosing The Cluster Size



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The possibility of re-using frequencies, solves the basic mobile communication problem, namely it makes radio channels indefinitely available over the service zone, in spite of the spectrum scarcity.

On the other hand, the cellular layout and the associated possibility of re-using frequencies poses two classes of mobility-related problems which are completely new with respect to those typically faced in the fixed networks, where the traffic sources always maintain their network point of attachment:

- the problem of maintaining the connection continuity while the mobile is passing from one cell to another (where different radio channels are used) (handover)
- the problem of localising the mobile terminal and updating its position within the cellular topology.

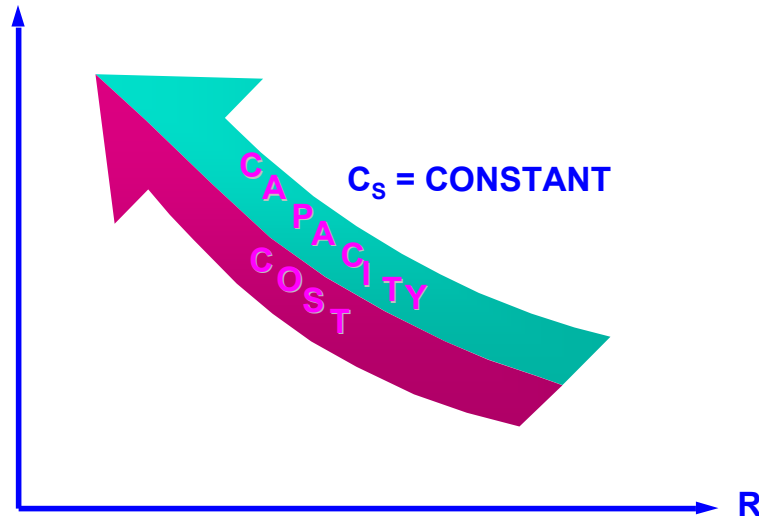
These problems will be considered later.

Now, looking at the re-use mechanism, it can be noted that, with a given bandwidth available, the cluster size (the number of cells over which the overall bandwidth is distributed according to the explained criteria) is a measure of the efficiency of the re-using mechanism. In fact, if the size of cells is kept constant, the lower the cluster size, the higher the density of radio channels available (number of radio channels available per square kilometre).

On the other hand, clusters of greater dimension imply a better quality, in that they reduce the level of inter-cell interference.

The cluster size depends on the inherent interference robustness of the adopted access technique.

Choosing The Cell Size



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The other key element determining the radio channels usage in the service zone, is the cell size, which can be formally represented by the average cell radius.

Still with a fixed available bandwidth (number of radio channels), assuming that a given cluster size C_s is adopted, the system capacity (channel density) is increasing with the reduction of the average cell size.

Of course, reducing the average cell size implies that the number of antennas to be allocated in the service zone has to grow, giving rise to higher costs of the cellular network.

This mechanism makes evident how the cell size is reduced (high antenna density) in urban contexts with respect to the rural zones (low antenna density). In fact, as the traffic increases (and this typically happens in urban areas) the channel density has to increase as well and the cell size must be tuned accordingly.

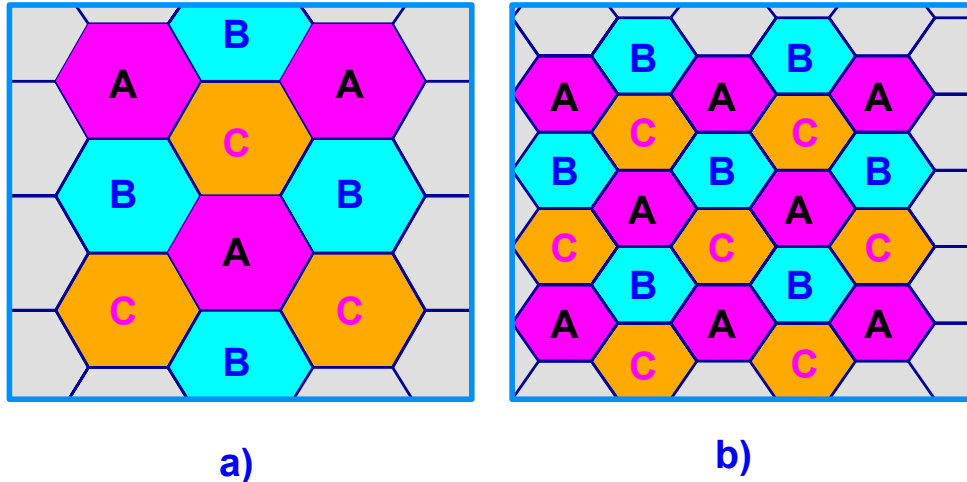
So, the cell size becomes one of the basic elements driving the cellular network dimensioning in terms of number of equivalent radio channels per square kilometer.

If the cluster size remains constant, the same interference conditions can be guaranteed and the frequency re-use mechanism can take place according to the same topological scheme previously explained.

As far as the antenna sites are concerned, several arrangements can be used, depending on the physical availability of locations and coverage requirements. The coverage can be ensured either by omni-directional antennas or may rely on sector antennas (e.g. 120 degrees). The latter solution reduces the number of needed sites and in general is characterised by lower network costs.

The choice of antenna solutions and related sites allocation, is one of the basic variables to be considered to optimise the cellular network under defined traffic conditions.

Cell Size



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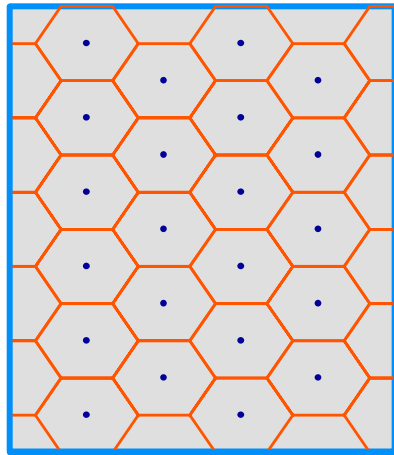
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The figure illustrates the role played by the cell size in establishing the real number of radio channel available per square kilometres. The figure assumes that the same cluster cardinality (3) is adopted in both examples.

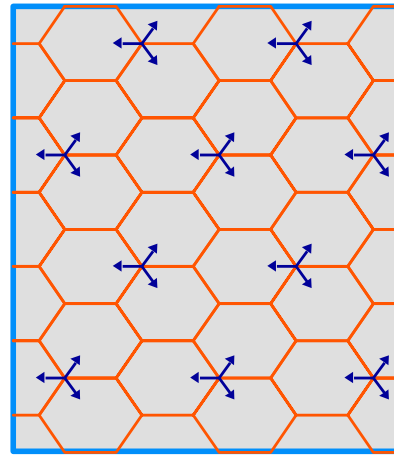
Cases a) and b) reflect two different operation conditions, driven by two different traffic requirements. The same cluster dimension is used, namely the same frequency re-use topology.

These schemes have just a didactic purpose: considering the real situation means facing the real interference conditions arising in that particular geographical and service characteristics.

Antenna solutions for cellular coverage



a)



b)

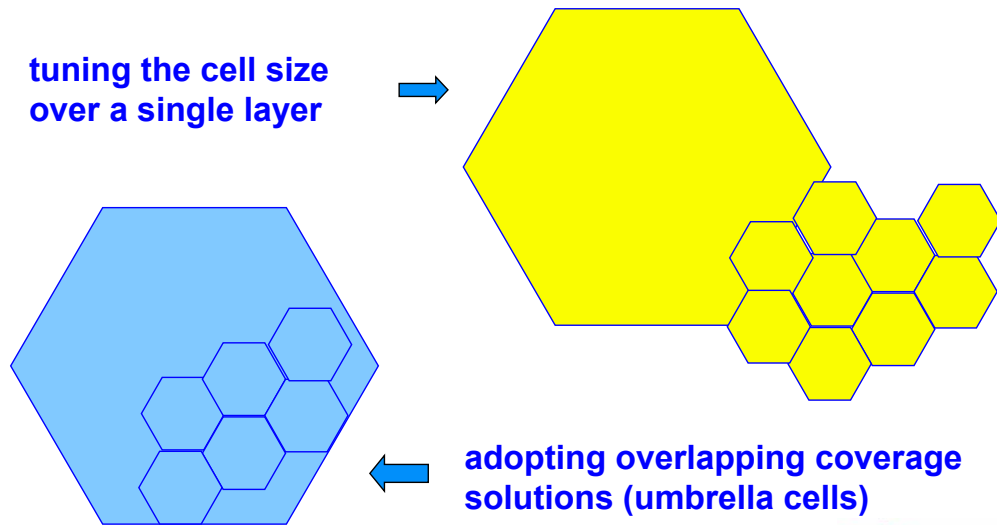
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The sites where the antenna is located can bear either omni directional antennas or sector antennas. The latter solution is much more economical as for the capital expenditures needed for the network roll-out. In fact it reduces the number of necessary sites able to ensure the appropriate coverage and capacity.

The choice of the kind and location of the antenna must of course follow coverage and traffic requirements. This will be discussed extensively in chapter 5.

Planning the cell size and layout a matter of channel/Km² requirements (traffic constraint)



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Cell dimensions can be regulated in such a way that traffic requirements can be fulfilled according to pre-assigned QoS figures.

The number of mobile terminals camping within a given cell is a random variable, often characterised by non-stationary behaviour. For this reason, associated to coverage requirements, often multiple layout schemes are adopted. The multiple layout scheme is used when separate bands are available for a given Operator. For instance, GSM adopts two typical bandwidths around 900 and 1800 MHz respectively. The former is suited for a *macro cellular* coverage, the latter for a *microcellular* coverage.

Frequency re-use mechanisms hold independently for each layer of coverage.

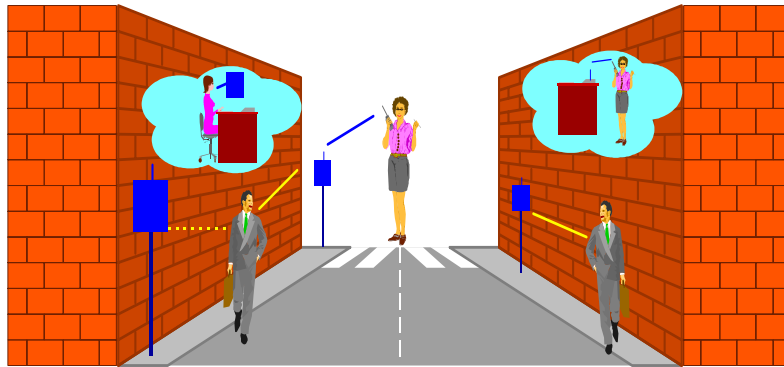
The wider cell (the *umbrella* cell) accepts the traffic coming from the smaller cells or, even, the traffic generated by the mobile terminals showing the highest speed.

In fact, a multi-layer coverage may satisfy different requirements:

- radio coverage optimisation
- reduction of the handover rate
- coverage completion (extension of the coverage surface, not necessarily fully guaranteed by micro cells).

Microcellular environment

new conditions for propagation



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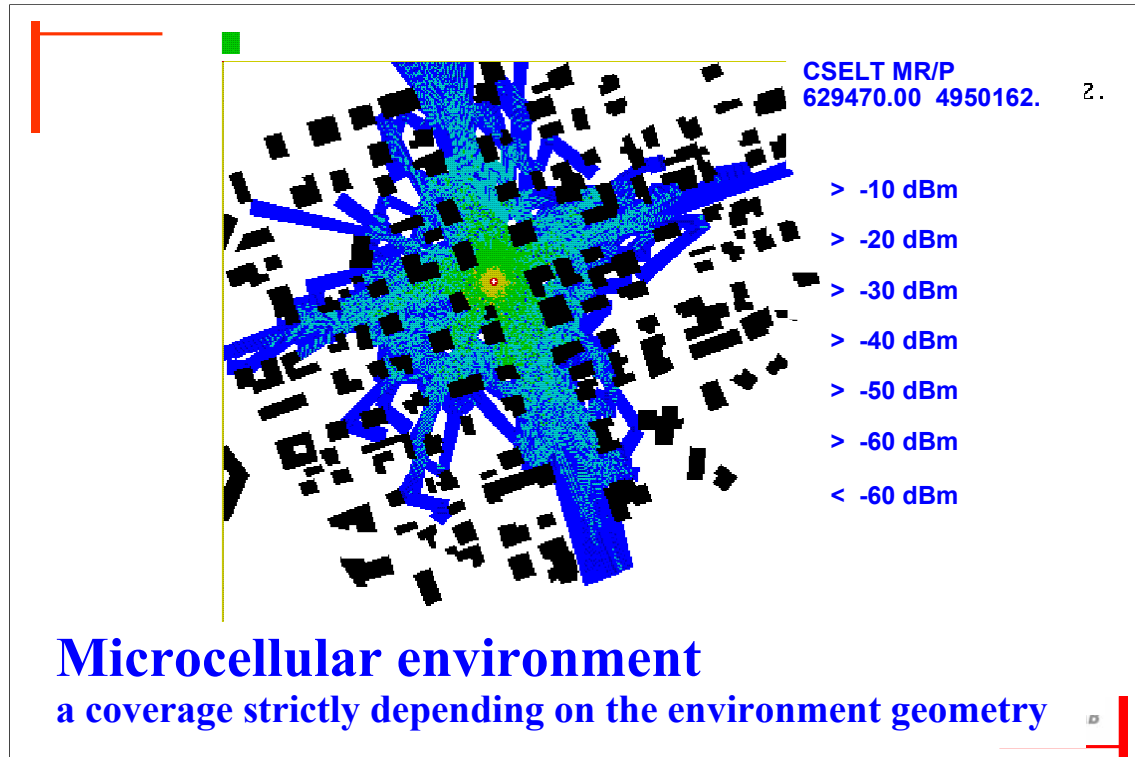
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What has been considered so far refers to a macro cellular situation, where propagation behaviour (and hence the cellular coverage) can be considered as statistically dependent on the terrain (and possibly urban) characteristics. This in general applies to antennas placed much higher than the natural obstacles of the electromagnetic signal.

In many cases, due to the high traffic requirements registered in the urban environments, cells must be reduced in size, and the only way to do so is to introduce low-power antennas that are placed below the height of the building roof (that are able to cover for instance a segment of a road). This is a micro cellular configuration, where the small cells coverage is normally complemented by a superimposed macro-cellular coverage.

The propagation models to be used in a micro-cellular environment is directly dependent on the geometrical situation of buildings and roads surrounding the antenna. Geometrical models are used, where *multi path* behaviour has to be represented by considering direct, reflected and diffracted rays.

The urban morphology must be known at a much greater detail with respect to the macro-cellular case. This implies higher costs in data acquisition, storage and management of data.



This is an outcome of a radio coverage evaluation performed through a geometric approach.

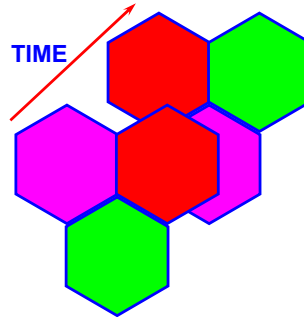
The resulting electromagnetic field has been evaluated in each standard visual areas (pixel). On each pixel, the field intensity has been calculated by integrating the various contributions deriving from the application of the geometrical ray-tracing technique previously recalled.

The resulting field is represented through a colour code whose meaning is reported in the figure. The same tool can perform an evaluation of the delay spread in each elementary area.

The application of the above propagation models and the relevant coverage prediction represent the only way to identify and verify the antenna allocation in the planning phase. These models also give the necessary input elements for the tools adopted to verify the network traffic performance, which are often carried out through simulation models.

So far, the radio coverage and the frequency allocation problems have been considered. Before going on, it is anticipated that the allocation of frequencies to the cells can either follow fixed or dynamic mechanisms. The former scheme assigns frequencies to cells in a permanent way, in the network planning phase; in the latter, the frequencies assigned to any single cell can vary from time to time, in function of the system status (namely the connections in progress and the related interference situation).

Dynamic channel allocation



Radio resource dimensioning
and frequency plan are :

- AUTOMATIC
- EMBEDDED IN THE PROCESS OF
RADIO CHANNEL ASSIGNMENT TO CALLS

The TDMA radio access systems used for local mobility applications in microcellular environments, are often characterised by a Dynamic Channel Allocation (DCA) scheme.

The dynamic channel allocation scheme assigns the single base station the possibility of using any radio channel belonging to the available frequency band. In practise, all the concepts discussed about frequency re-use are still valid, but the *permanent* character of the frequency plan. In a DCA system, the plan is set-up and changed in time in function of the system status (connections in progress) and the interference conditions. In practise, the frequency plan is progressing implicitly with the real time channel acquisition process, which is driven by the interference conditions.

In particular, least interfered channels are used either for establishing new connections or to perform handover (either within the same cell or between different cells). In practise, the frequency plan evolves with the acquisition/release process of the radio channels as well as with the position of the terminal and the configuration of the received powers. The least interfered channels are used either to activate new connections or to accept connections already in progress through the handover mechanism.

The system is self-adapting against the actual interference conditions, therefore no frequency plan is needed.

Autonomous assignment

C : CHANNEL
BS : STATION

N : NEW
A : ACTUAL

$$C_N = \begin{cases} C_A & \text{IF } (BS_N = BS_A) \wedge \left(\frac{C}{I_A} > \frac{C}{I_{\min}} \right) \\ C_i & \text{IF } \left[(BS_N \neq BS_A) \vee \left(\frac{C}{I_A} < \frac{C}{I_{\min}} \right) \right] \wedge \\ & \left[\exists C_j \mid \frac{C}{I_j} > \frac{C}{I_{\min}} \right] \end{cases}$$

ELSE :
BLOCKING

$$i = K \mid \frac{C}{I_K} = \max_j \frac{C}{I_j}$$

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The Dynamic Channel Assignment scheme can find several implementations. In the example, it is simply adopting the following scheme:

- the radio channel which has been set-up for the actual connection, remains unchanged until *both* the reference station remains unchanged *and* the channel related quality lies above a given threshold
- the radio channel is changed if one of the following events takes place:
 - *either* the reference station has changed *or*
 - the connection quality drops below the threshold; in this case, *at least* one channel must exist able to ensure the needed quality; the best channel is chosen for the connection (among those offering the needed quality).

The above scheme is named *autonomous assignment* since it is simply based on a *Max* operator.

The autonomous assignment scheme can create some problems, due to the fact that the channel choice is done locally, just on the basis of a local optimisation of the channel to be used. No attention is devoted to the effects that this local choice is inducing on the neighbouring connections in progress. This may cause instability behaviours, in fact, the acquisition of a channel can induce bad interference conditions in other connections which are then forced to handover to other channels.

Segregation scheme

IN BS

$\begin{cases} P(K) \text{ CHANNEL } K \text{ PRIORITY} \\ N(K) \text{ N}^\circ \text{ OF TESTS ON } K \end{cases}$

- 1 $S \equiv \{ c_i \mid c_i \text{ NOT USED IN BS} \}$
- 2 LISTEN TO $c_K \in S$ WITH MAX PRIORITY
- 3 c_K ACCEPTABLE QUALITY FOR USE
 INCREASE $P(K)$ and $N(K)$
 STOP
- 4 c_K NON ACCEPTABLE QUALITY
 DECREASE $P(K)$; INCREASE $N(K)$
 GO TO 2
- 5 $S \equiv \emptyset$
 CALL BLOCKED
 STOP

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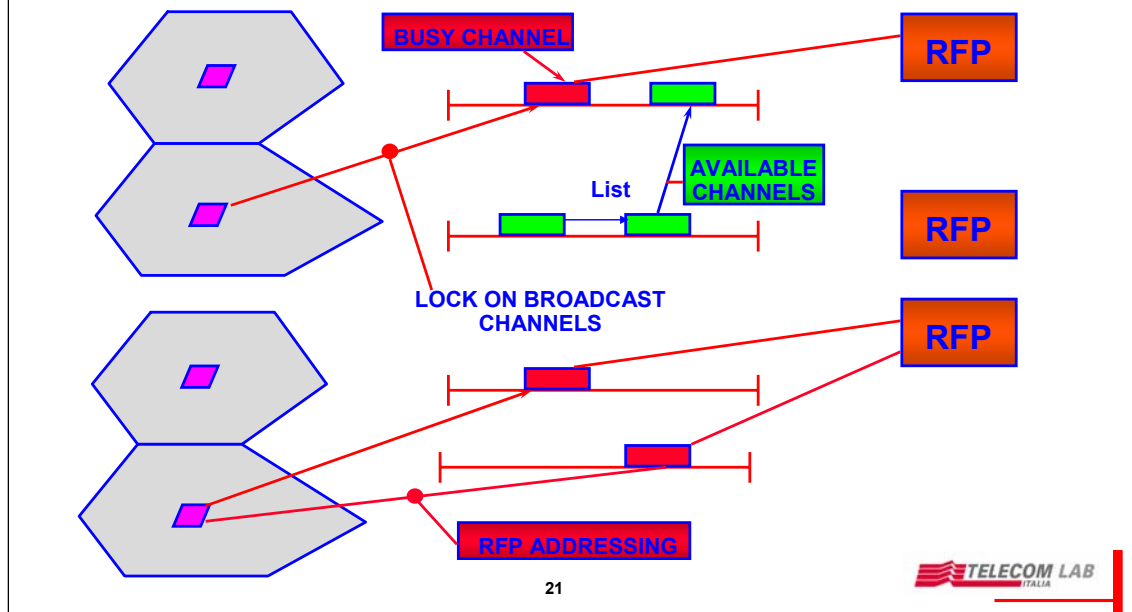
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The *segregation* mechanism can reduce the instability effects of a completely autonomous assignment.

The scheme proposed tends to assign a priority to the channels available (potentially all) in a given Base Station. This priority is a direct consequence of the ability of any single channel to ensure a good condition for being used in that cell (hence, it depends on the past *goodness* of that channel in being used in that cell).

The assignment process arranges the actual frequency plan on the basis of traffic requirements and the previous assignment story. In practise, segregation schemes are reducing the dynamic behaviour of the assignment mechanism: the frequency plan is still changing but with a higher *viscosity*.

DECT – channel acquisition - handover



Digital Enhanced Cordless Telecommunication (DECT) adopts a dynamic allocation mechanism. The figure describes the relevant channel acquisition algorithm.

DECT uses a TDMA scheme with a Time Division Duplex (TDD) arrangement for the duplex transmission. This means that the two-way communication is realised over the same radio channel (carrier) through transmission and receiving phases. Within each phase, channel multiplexing is performed in a time divided manner.

The mobile terminal keeps track of the less interfered channel over all the available channels. To do so, it scans over all the available carriers and within each carrier, over all the received time slots.

At the same time, it extracts from the strongest busy channel, the information concerning the Base Station where it is roaming. This can be done because, in addition to the connection data, each busy channel carries an associated *system* channel, bearing all the needed information for stand-by terminals.

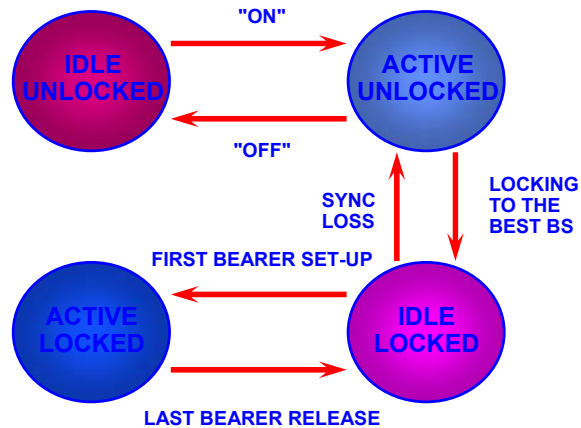
Hence, in each instant the mobile knows the base station where it is roaming and the list of preferred channels (frequency and time slot) where an access can be possibly done. The access eventuality *activates* that specific frequency (in that time slot) on the cell.

Since the channel scan and the described acquisition scheme is active also along a connection in progress, this mechanism implicitly triggers an handover procedure whenever needed.

Dynamic Channel Allocation in DECT

THE HANDSET:

- Selects the BS from which it receives the strongest signal
- Compiles a list of least interfered channels
- Starts the set-up procedure to the strongest BS on the least interfered channel
- Starts the handover procedure when it finds a better channel



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The state diagram describes the possible evolution of a DECT terminal from the *idle unlocked* to the *active locked* state.

From the *idle locked* state, the terminal can set-up a bearer towards the strongest base station. The passage to this state is performed through the scanning of all the system channels (time and frequency scanning) and preparing a list of the busy channels perceived as the strongest ones. The BS label is read on the *system* part of the busy channels.

The bearer is set-up by making use of a list of the less interfered channels. The latter is obtained through a similar scanning of all the system channels (both in time and in frequency).