17. MOBILE COMMUNICATIONS

17.1 Main features

Most deterministic factor of the mobile communication is that at least one of the connected parties is moving or is changing his location in unpredictable way. As a consequence, mobile communication can be realized only by means of wireless transmission. For this purpose, terrestrial radio waves are the most convenient means. Area radiated by the radio waves is determined by the law of physics, state borders do not play any role here. The radio frequency spectrum is one the one hand a natural treasure exposed to quickly growing demand and on the other hand -because of the enormous evolution of electronics- it is more and more polluted by electromagnetic noises.

17.1.1 Regulations of Mobile Services

Recognizing in time the above problems, a wide international and national co-ordination was established for the utilization of radio frequencies. The highest level of this co-ordination is the International Telecommunication Union (ITU), which publishes and regularly updates the International Radio Regulations (IRR). The most important part of the IRR is the frequency table which shows the distribution of frequencies in the range from 9 kHz to 3000 GHz for three regions of the world, managed by about 30 radio services. As far as mobile communication is concerned, terrestrial, aerial, maritime and satellite services are specified by the IRR.

The next level of international co-operation is regional. On the regional level the frequency distribution is further refined, in certain cases the right of frequency usage is even bounded to observance of detailed technical specification. On this level, frequency bands of various *private* mobile services operated for safety, technological etc. reasons and *public* services accessible by anyone are distinguished.

On the national level, responsible authorities work out a National Frequency Band Distribution Table which -based on the rules of the international distribution- allocates the frequency bands for groups of users (e.g. civil, governmental, etc.) accordingly to the domestic conditions. It is also the responsibility of the national authority to allocate operating frequencies for interested private or legal persons. Such a frequency allocation is valid for a determined time and given location and for equipment specified in detail in separate standards. These conditions aim to avoid mutual interferences and help the economical use of the frequencies.

As we have seen, giving licenses for frequencies and for equipment operating at them is a national authority which has essential influence on the interest of the users, operators, sellers and manufacturers of the communication equipment and systems. These interests are substantially influenced by frequency management practice and system standartization. Due to that, frequency distribution and utilization is focused also by those not belonging to the profession and in more important questions decision can be made only following a wide conciliation of interests. Designers and operators of radio equipment must therefore know several stipulation and specification to be able to solve their task. This is especially true if the equipment is the part of the public communication network which is the greatest synchronized machine of the Earth.

In the following we discuss essential questions of the mobile communication and then we describe various systems, mainly from the users' point of view.

17.1.2. Structure and Operation of Terrestrial Stations

Majority of terrestrial mobile communication services operate in the 30-1000 MHz (VHF) range. In Hungary, civil services use 80, 160, 450 and 900 MHz ranges. Channel spacing at these ranges is 12.5, 20 or 25 kHz. The majority of communications is carried out between a highly located fixed base station and moving stations installed in a vehicle, carried on back, in hand or in pocket.

The position of the moving station is dependent on the kind of vehicle which is generally moving on the Earth surface. Operation of portable and hand-held sets must be provided at any places where persons use to move, i.e. inside building, as well. This is, however, not an easy task since the radio waves are strongly attenuated when penetrating through the walls. The operational range of handy sets is even more limited because of the smaller output power given by the size and duration of the battery.

The simplest mobile communication system is used by the private *dispatch services*. The communication is alternating, called simplex, i.e. the antenna is alternately switched to the transmitter and the receiver by a switch. The carrier frequency could be the same in both directions (base to mobile and mobile to base). This is called the *single-frequency simplex* mode. Practically, however, *two-frequency simplex* mode is used in which the two frequencies differ by at least 2 to 5 percent of the operating frequency (Δf_D, the duplex frequency shift).

The reason of two-frequency operation is to avoid interference among the systems of different users located in the same region. If the transmitting frequencies of all base stations have fallen into the same frequency range, it would be impossible to receive the signal while another base station is transmitting. Thus a gap between the transmitting and receiving frequencies is provided for proper operation of filters at the receivers' input. The two-frequency mode also makes possible simultaneous operation of the transmitter and receiver of the same station (*duplex mode*). In duplex mode the transmitter, receiver and the antenna are interconnected by a selective three-port called the *duplex filter*. In the private systems - because of economical reasons- duplex filter is used only at the base station (*half duplex* mode). By using two frequencies, it is also possible to retransmit the received signal by cascading the receiver and transmitter of the base station. This is called the *mobile relay* mode which is frequently used in private systems.

The aim of *mobile public radiotelephone* system is to provide service analog to the wired telephone so that it is necessarily operating in duplex mode.

Let us remark at this point that for the duplex mode, duplex filter is necessary only in such (analog) systems in which the simultaneous bidirectional communication takes place strictly in real time. In the case of digital transmission, duplex mode can be realized in single-frequency case, as well, since the information of the two communicating parties is transmitted in different time slots.

17.1.3 The Mobile Radio Channel

Technical solutions used in mobile radio systems cannot be understood without the knowledge of the radio channel. For this reason, let us follow the way of the signal from the antenna of the base station up to the receiver of the mobile station. During the propagation, transmitted wave is exposed to several effects. Since the mobile station is close to the ground, the propagation is considerably influenced by the relief, by the building up and by the vegetation of the terrain. The first, well separable effect is the multipath propagation. This effect is caused by elevations , hills, high buildings, etc. which reflect the wave so that it arrives to the receiver from several directions with considerable amplitude and group-delay differences. This effect has already been described by equation (6.7)

$$y(t) = \sum_i a_i x(t - t_i) \; .$$

Propagation delays are defined here as the ***deviation*** from the arrival of the first (direct) wave. Plotting the coefficients a_i against the values of t_i, we obtain the ***group delay profile***. This is usually a continuous curve with local maxima corresponding to the dominant paths. The shape of the curve may strongly differ depending on the specific conditions, but on the average, corresponding to basic physical expectation, a_i has a decreasing tendency with growing values of t_i. Therefore the group delay is usually approximated by a negative exponential function.

Because of the multipath propagation, the transfer function $a(f)$ becomes uneven. For the sake of simplicity, ***coherent bandwidth*** is defined as the frequency band within which the attenuation does not show any significant difference. Supposing exponential delay profile, the coherent bandwidth B_C can be written as

$$B_C = \frac{1}{2p \cdot S} \qquad (17.1)$$

where S is the standard deviation of the propagation delays. According to measurements, the value of S is between 0.25 and 1 μs which corresponds to coherent bandwidth of 160...640 kHz. This value is smaller than the duplex frequency shift Δf_D, consequently considerable difference may exist in the propagation attenuation from base-to-mobile and mobile-to-base transmission, respectively.

Let us assume in the following that an unmodulated carrier is transmitted and the strength of the electric field is observed in a far point where the wave is arriving scattered by multiple reflections from buildings trees and other objects. As the consequence of that, a rather complex standing wave field is formed. Specific feature of this field is that the maxima of the field are following each other every half wavelength on average and that fluctuations as high as 30-40 dB within a quarter of a wavelength are quite common (Figure 17.1).

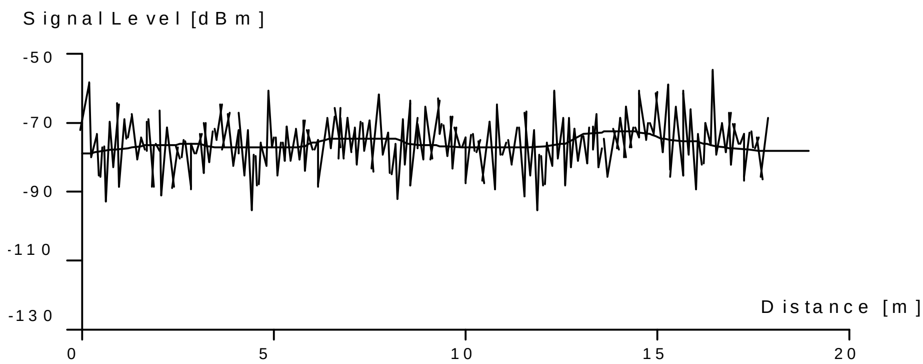

Figure 17.1. Short Distance Field Distribution of a Mobile Communication

Since the physical model used above (the sum of several vectors of incidentally different magnitude and phase) is described by the Rayleigh probability distribution, the signal fading is called the Rayleigh (or fast) fading. The effect has not take place if there is no moving object between the base station and the observed point and slow atmospheric changes are neglected. The field is steady in that case until the receiver antenna starts to move.

If the station is moving, the Doppler effect shall be taken into consideration, too. The Doppler frequency shift is

$$f_D = \frac{v}{c} f_0 \cos\alpha = \frac{v}{\lambda}\cos\alpha = f_{D\max}\cos\alpha \ , \qquad (17.2)$$

where f_0 is the transmitted frequency, λ is the wavelength, v is the velocity of the mobile station, α is the angle of wave incidence with respect to the direction of the moving vehicle and $f_{\mathrm{Dmax}}=v/\lambda$.

Since the waves arrive practically from all directions in an urban area, as the consequence of the Doppler effect, spectral component f_0 will broaden to a continuous band having the width $2f_{\mathrm{Dmax}}$. If, for instance, v = 15 m/s (54 km/h) and f = 900 MHz (λ = 0,33 m), then f_{Dmax} = 45 Hz which is not disturbing in voice quality transmission since the bandwidth of the modulating signal is 300...3400 Hz, so that the spectrum of the modulated signal is initially 300 Hz from the carrier. However, if the velocity of the vehicle is much greater (e.g. aero service) or the carrier frequency is increased then the Doppler and the modulated spectra may overlap which can be avoided only by complex frequency controlling procedures. Besides other, this is the reason why the mobile communication shall not be used above 3 GHz.

As the result of the effects described above, modulated signal appearing on the antenna of the mobile station is given as

$$u(t) = \mathrm{Re}\,[r(t)\exp(\mathrm{j}\omega_0 t)] \qquad (17.3)$$

where $r(t) = \sum A_{\mathrm{m}}(t)\, e(t-\tau_{\mathrm{m}})$

$A_{\mathrm{m}}(t) = \sum c_{\mathrm{mn}}\exp[-\mathrm{j}(\Theta_{\mathrm{mn}}+\omega_{\mathrm{mn}}t)]$

$e(t)$ is the complex envelope of the transmitted signal

$A_{\mathrm{m}}(t)$ is the amplitude of the *m*-th wave

c_{mn} is the *n*-th spread component of the *m*-th wave

Θ_{mn} is the phase of the spread component

ω_{mn} is the angular Doppler-frequency of the spread component

Equation (17.3) describes well the signal in proximity of a given location but gives no information about the signal changes as functions of the distance from the transmitter, of the heights of antennas and of the operating frequency. This parameters are treated by theoretical models discussed in Chapter 9. (line-in-sight propagation, multipath propagation), these, however, can not take into consideration with adequate accuracy all physical phenomena affecting the propagation. Thus in mobile communication the above mentioned main installation parameters are determined by empirical or semiempirical models.

If the propagation is blocked by such an object which can be geometrically well modelled, then the attenuation can be computed in deterministic way with a relatively good approximation on the base of the diffraction model described in Chapter 9. Mobile stations operate mostly on wavy terrain possibly shadowed by trees or on urban areas. Influence of such factors is impossible to describe by deterministic models, hence statistical approach based on series of measurements is used instead. A typical result of such a measurement of the electrical field strength is shown in Fig. 17.2.

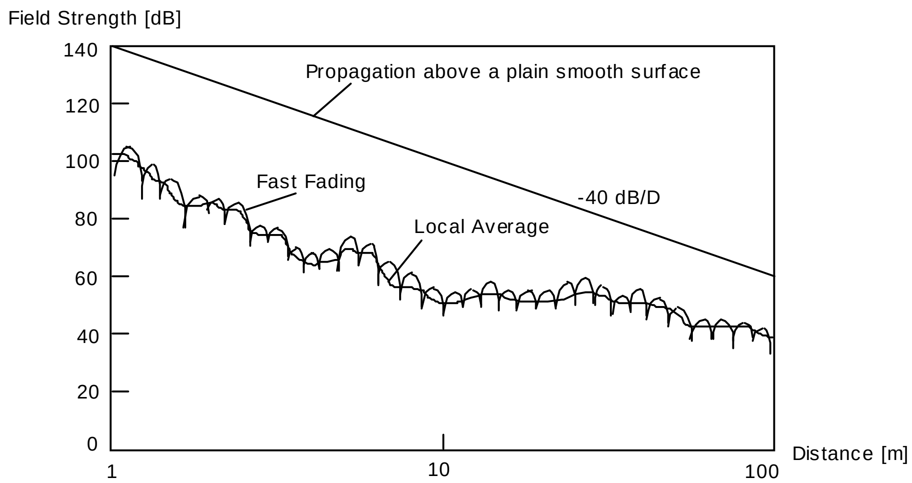

Figure. 17.2. Distribution of the Electrical Field in a Mobile Connection

On Fig. 17.2., three different phenomena causing the change of the electrical field strength when moving off the transmitter can be observed. The fastest change is the Rayleigh fading which, smoothed by averaging, results in the dashed line representing the local average. Ripples in the local average are due to the shadowing effect caused by different obstacles and by the vegetation. Besides the ripples of the local average, a monotonous decrease of 40 dB/decade proportional to the distance can also be noticed. This corresponds to the attenuation slope of multipath propagation described in Chapter 9., with about a 20-30 dB attenuation surplus. The general equation describing this monotonous decrease is

$$E = A - B \lg d \quad \text{dB/V/m}, \tag{17.4}$$

where, for the above figure, A = 140 and B = 40. If the dashed curve obtained by measurement is approximated by the line described by equation (17.4) then the values of A and B can be computed. Besides that, the deviations of local averages from the line can be determined. Since these deviations -if expressed in dB- are in good accordance with the normal distribution, field changes caused by the shadowing is called *lognormal fading*.

Median value of deviations from the regression line is zero to a certain distance. This means that within this region approximation of the attenuation by a single line is fairly good and that the lognormal fading is characterized by its standard deviation. If we want to keep this property even for greater distances, then two or more regression lines of different slope have to be used.

Values *A* and *B* obtained from the regression depend on the height of the transmitter and that of the receiver antenna, on the waviness and on the degree of urbanization of the area and on the frequency. Since the frequency bands used for mobile communications are relatively narrow, the frequency dependence can be neglected within a given band.

In practical computations the communication is characterized by the section attenuation between the two given antennas. Providing the field is described by equation (17.4.), the section attenuation is given as

$$a = C + B \lg d \quad \text{dB}. \tag{17.5}$$

Example: For the frequency range around 900 MHz, antenna heights h_B = 50 m and h_M = 1,5 m in densely urbanized areas the section attenuation for distances from 1 to 40 km is:

$$a(50) = 123{,}3 + 33{,}7 \lg d \quad \text{dB}. \tag{17.6}$$

The same for the 1800 MHz range:

$$a(50) = 133{,}2 + 33{,}8 \lg d \quad \text{dB}. \qquad (17.7)$$

In equations (17.6) and (17.7) d is given in km and the result is the median value of the lognormally distributed section attenuation. The standard deviation of the lognormal distribution at 900 MHz in urban areas is s = 6 ... 6,5 dB, while in open rural areas s = 8 dB. It is also worth mentioning that changes caused by meteorological factors can be neglected up to distances of about 30 to 40 km.

17.2. Private Systems

The purpose of a private (or dispatch) service to co-ordinate the operation of a group of people who are generally moving while working. The simplest of such a service can be formed out of a base station and some mobile or handy radio stations. The dispatcher is usually in the proximity of the base station and his control panel is connected to the base station transceiver via a four-wire audio circuit and some further lines required for the control functions. Traffic is carried out generally in half duplex mode which for the mobile stations has the advantage of interrupting the transmission of the base station in the case of emergency. In half duplex mode, the dispatcher's transmission is usually heard by the all mobile stations while transmissions of the mobiles are received only by the dispatcher.

If the dispatcher is located far from the base station, leased line or a dedicated radio connection is used to connect the control panel to the transceiver. Since such solutions are expensive, mobile relay mode is rather used instead, i.e. the dispatcher is equipped by the same mobile set as the mobile stations. Unlike in the half duplex mode, in mobile relay mode all the station are mutually hearing each other which, in certain services (e.g. taxi), can be encountered as an advantage.

To decrease the risk of mutual interferences, it seems reasonable to activate the base station transmitter (carrier) only for the time of the message (modulation). To make the dispatcher's work easier, in half duplex mode this used to be done by a voice-operated automatic switch, while in mobile relay mode carrier incoming to the receiver is sensed.

It may occur that several independent private services are operating on the same area and their individual traffic is much less that what can be carried by one base station. In such a case, it is more economical to assign a single common base station to these services. The drawback of this solution may be that the mobile stations have to listen to messages not concerning them. This can be avoided by selective group-call, the simplest solution of which is assignment of an audio frequency code to each group and to activate by them the (otherwise idle) mobile receivers of the group belonging to the code. Of course, the same method can be used for personal selective calling if the nature of the services requires such a feature.

Installing personal selective code transmitters to the mobile stations, it is possible to automatically identify the mobile station. This can be advantageous not only for security reasons but also for shortening the communication overhead (verbal introduction to the dispatcher and acknowledgements of dispatcher's messages). Instead of, it is enough to send the identification code taking time of about 0.3-0.4 s which, in the case of short messages, results in significant decrease of traffic. As an example to this solution, the average holding time of a taxi service has been decreased by this method from 30 s to 15 s so that the number of cars serviced by one base station could be doubled.

17.3 Public Mobile Telecommunications

17.3.1 Specific Features and Devices

The obvious aim of mobile telecommunication is to provide services similar to the wirebound communication even if the user is moving or changing frequently his location. Public mobile services are sorted according to the nature of their use as follows:

- public mobile radio systems,
- cordless telephone sets,
- radiopaging systems,
- mobile data transmission systems.

The aim of the public mobile radio telephone systems is to connect "anyone to anybody", from "anywhere to anywhere" at "any time". Concerning this specification, former systems had several limitations, especially the area of motion was strongly limited, usually at least by the state borders.

Cordless telephone sets have been developed to provide the user with the freedom of motion within some dozens of meters from the base set connected to the PSTN.

On the contrary, the public radiopaging systems can be used on great area (usually throughout a whole country), if only for limited data transmission.

Depending on the data transmission rate and the network structure (point-to-point, point-to-more points, etc.), several variations of mobile data transmission systems have been developed.

Similarly to the general trends in telecommunications, the mobile telecommunication systems can also be characterized by following tendencies:

- wide usage of digital solutions,
- effort for regional and global unification, respectively,
- emphasize to the personal character of the communication.

Personal character of the telecommunication can be supported one the one hand by the pocket size of the mobile set, on the other hand (when a terminal of greater size is used), by a identifier card (smart card). Word-wide standardization is the clue for further expansion of the area of motion. Not negligible consequences of that shall be the considerable increase of production volume and decrease of prices.

17.3.2 Pan European Mobile Telecommunication System

As a result of unification, a first regional (European) system called the Global System for Mobile Communication (GSM) has been developed by the countries of the European Community and adapted also in several other countries (e.g. Australia, China, India).

To cover the area of telecommunication, GSM uses the well proven cellular principle (see Fig. 17.3.).

As can be seen from the figure, the whole area of interest is divided into cells of hexagonal shape each covered by one Base Transceiver Station (BTS), marked as A, B, ... G in the figure.

The whole system (Fig. 17.4.) consists of Base Transceiver Stations, Base Station Controllers (BSC). Mobile Switching Centre (MSC) and Operational and Maintenance Centre (OMC). The MSC is connected to the Public Switched Telephone Network (PSTN).

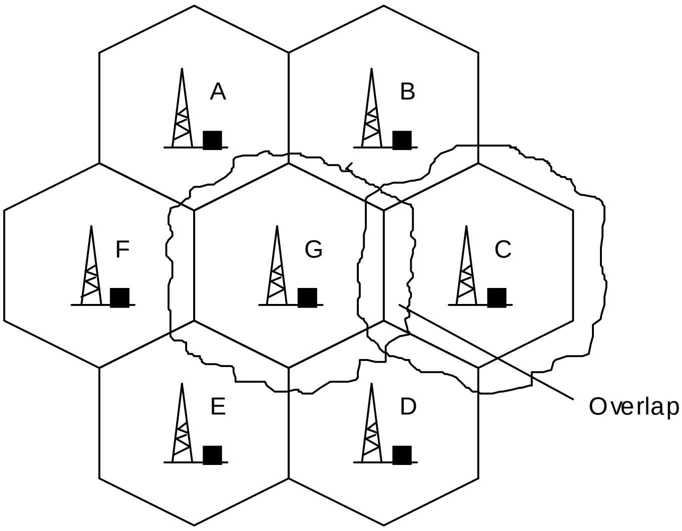

Figure 17.3. Cellular Division of the Communication Area

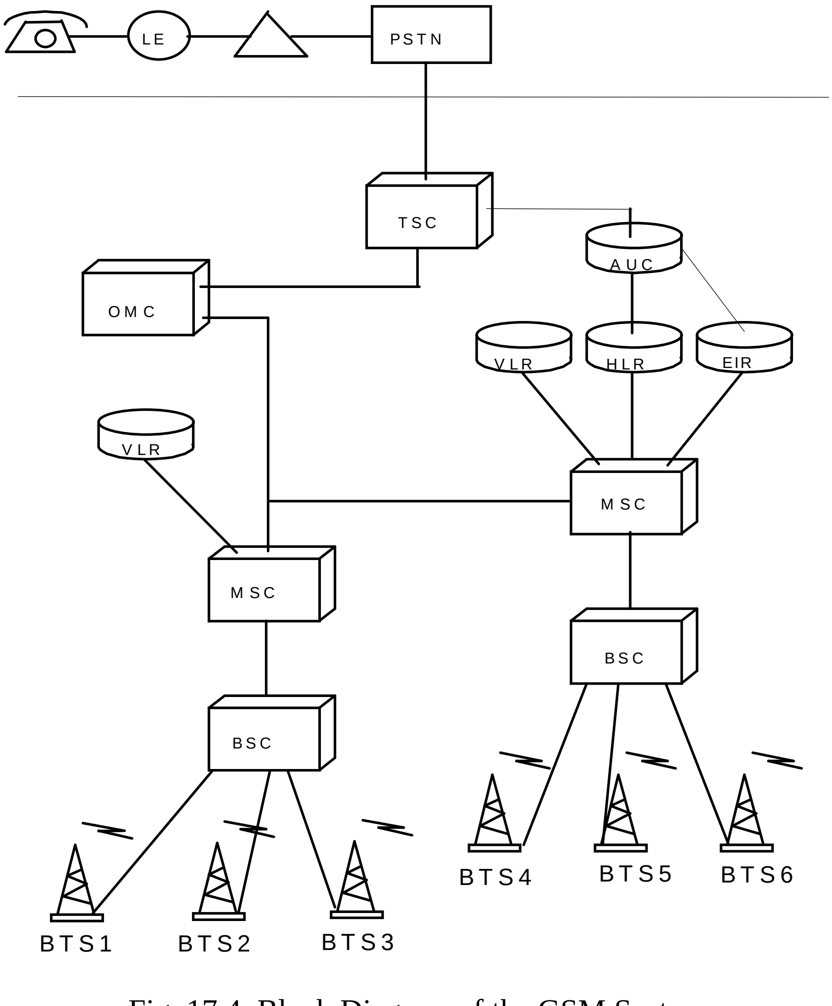

Fig. 17.4. Block Diagram of the GSM System

Every mobile station is assigned to an MSC and its data are stored there in so called Home Location Register (HLR). Data of a roaming mobile station (belonging to another MSC but currently being in the area under consideration) are written through the signalling channel into the Visiting Location Register (VLR).

The security and safety of both the service operator and the user is provided by Authentication Centre (AUC). Another register called the Equipment Identity Register (EIR) prevents from illegal usage in the case the mobile set is stolen or it reports an invalid identification number (a fake).

Main parameters of the GSM system are as follows:

- Operating frequency range, Mobile to BTS: 890 ... 915 MHz
- BTS to Mobile: 935 ... 960 MHz
- FDMA channel bandwidth: 200 kHz
- TDMA in each FDMA channel 8 timeslots, 270,83 kbit/s
- Modulation scheme: Gaussian Minimum Shift Keying
- Frequency hopping: 270/s
- Error controlled source coding: 13 kbit/s, 22.8 kbit/s
- Transmit-to-receive delay: 1.15 ms
- Transmitter power: 20; 8; 5; 2; 0.8 W

In parallel to the GSM, a personal mobile radio system working at about 1800 MHz has been developed. This system is much alike the GSM and is called the Digital Cellular System (DCS 1800). Detailed description of the above systems is beyond the limit of this book. The interested reader may refer to the bibliography.

17.4 Expected Evolution Trends

Recently mobile communication is one of the fastest developing areas of telecommunications and for that it is hard to estimate precisely what can be expected. Just because of the fast progress, current projects are focused on systems in which old and new solutions work together. Digital systems offer a suitable base to that compatibility since the various formats of digital data can easily be converted among each other.

Since 1987 the International Telecommunication Union (ITU) is working on Future Public Land Mobile Telecommunication System (FPLMTS). This system will unify all public systems so far operating separately and probably offer a solution for the private systems, as well ,since being suitable for group calls and other dispatcher services.

CEPT is working out a Universal Mobile Telecommunication System (UMTS), with the aim to put to a common platform the

- Private Mobile Radio (PMR) services,
- public mobile services (e.g. GSM),
- personal radio, services (e.g. DCS 1800),
- cordless telephone sets
- public radio paging services,
- satellite mobile services.

As it turns out from above, the two concepts do not differ to much from each other and although neither of them have been standardized, several elements of the European system are already in use. Therefore, it is important to keep an eye on the European trends when forming domestic systems.

Control questions

1. Which national and international organizations are involved in frequency management and what is their role?
2. What is the meaning of frequency distribution, frequency allocation and frequency licence?
3. What are the mobile services according to International Radio Regulations?
4. What is the structure of a private mobile service?
5. What kind of transmission modes are used in mobile services? What are their advantages and drawbacks?
6. Describe the model of the mobile channel and give its main properties!
7. What types of fading can have a signal of a mobile radio channel?
8. Describe the various public mobile communication systems!
9. Depict the GSM system and name its main elements!

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