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Wireless communications technology

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Содержание

Introduction

Discipline "Wireless technologies" is the subject of the cycle of basic disciplines. The purpose of the course is to teach students the principles of organization and technology of wireless communications, show methods of separation channels, teach methods of diversity signals using optical and radio communication, the technical concept of the construction of wireless communication systems, consider a spread spectrum system, and the principles of the wireless LAN.

The first chapter is devoted to the history of the development of wireless communication systems.

In Chapter 2, the wide coverage of cellular communication systems, which are widely spread in most regions of the country are widely described. Particular attention is paid to the connection process technology, ensuring the authenticity of the identification of the subscriber; determine its location and the organization of roaming in different standards.

The following chapters (3.4) deals with issues related to the process of expansion of communications networks on the basis of trunking and satellite communication systems and description of their standards. The composition of the equipment, considered methods of forming of the working area of the system and the structure of the single-channel and multi-channel trunked networks is present. Presented classification and principles of advanced satellite communication networks, allows organizing personal communications in remote and inaccessible areas.

Chapter 5 discusses methods of multiple access and diversity of signals.

Chapter 6 provides a classification and principles of optical communication systems, as well as the wireless atmospheric laser communication.

The following chapters (7, 8, 9 and 10) are considered to be familiar with the design and construction of standardization and certification of wireless communication systems, as well as the development and convergence of information and mobile networks based on the latest achievements in the field of communications.

In the textbook checklists and tests are given in order to consolidate the material.

The authors hope that this tutorial helps the reader navigate in this rapidly developing field of communication.

The book is intended for students and for a wide range of readers, for anyone interested in modern wireless technologies.

CHAPTER 1

1 Overview of mobile communication networks

1.1 The historical sketch of the development of network technologies

Communications - one of the fastest growing industries in the infrastructure of modern society [1].

Wireless communication network of information, as the name implies, is based on a combination of two groups of technologies - wireless communication and networking. Currently, wireless communication allows for a full range of information services: the transfer of telephone messages, data exchange, the connection to global information networks, reception and transmission of video, television, etc.

Classification of wireless communication systems includes a huge and ever-increasing of the number of species other than the purpose and characteristics. Which accommodate the needs of all humanity.

The inherent advantage of wireless communication is the absence of wires between the incoming network user equipment and the switch. The future of humanity is represented without wireline, and wireless switching means in accordance with the permit to develop the project to save a significant amount of heat, electricity, and ensure to find a person in a convenient information space. In such projects play important role technologies such as Bluetooth, ZigBee, Wi - Fi, WiMAX, DECT, and etc.

Wireless technology originated in the 19th century. In 1892, English scientist William Crookes showed theoretically and described the principles of the possibility of radio communication. In 1893 the scientist Nikola Tesla demonstrated the transmission of low-frequency signals to a distance. Then this event was not caused a resonance, perhaps because Tesla was interested in wireless transmission on a distance of energy, but not information.

From 1878 on the problem of wireless communication worked Alexander Stepanovich Popov, and on the May 7, 1895 at the meeting of the physical department of the Russian Physico-Chemical Society held his historic report, "On the relation of metal powders to power fluctuations." Then A. S. Popov demonstrated his device for recording lightning and suggested the possibility of its use for wireless communication. The first public demonstration of the prototype of all future wireless systems took place on March 24, 1896 at the meeting of the Physical-Chemical Society. A. S. Popov handed over a distance of 250 meters the world's first wireless message, consisting of two words "Heinrich Hertz".

In 1894, G. Marconi successfully experimented with the physical devices to generate and detect electromagnetic waves; he has established communication across the Atlantic.

In 1906, Lee de Forest created the first vacuum tube – it was an opportunity in order to build electronic signal amplifiers. Since wireless communication is developing at an even faster pace.

From 20-ies of the last century began commercial broadcasting (with using of amplitude modulation). Since 1933, when E. Armstrong invented frequency modulation - FM started broadcasting.

In 1946, the Bell system and AT&T companies started the operation of a mobile telephone service (MTS). For half-duplex communication 6 channels are used with width of 60 kHz on a frequency of 150 MHz, but because of the number of co-channel interference the number of channels were reduced to three. The system allows connecting to the local telephone network.

In 1965 was put into orbit and began to work successfully the first communications satellite "Molniya - 1" of the USSR. The era of satellite communications was started.

In 1967, the first communications satellite was launched into geostationary orbit, and an international consortium of satellite communication Intelsat (International Telecommunications Satellite Organization), which has become the largest international organization in the field of satellite communications was established. Today, its services are used in more than 200 countries.

In the history of networking the next stage began in the 60s years of the last century and is connected with the massive advent of computers. There was a need to transfer large amounts of data, at this time was originated the concept of a local area network. The mechanism of switching messages (packets) was created. A big contribution in this area brought the thesis of L. Kleinrock "The information flow in large switching networks."

In 1964 P. Varan published a paper "On distributed switching." It laid down the principles of excess communicative and shows various models of formation of a communication system that can operate successfully in the presence if there is a significant damage. Also was established the first non-local computer network.

In 1962 Kharkevich world's first formulated the basic principles of a unified communication network in order to anticipate the importance of digital methods of transmission and switching of different kinds of information in digital form. Symbolic for networking was 1967-1968 years: developed the first local area network with packet switching. The network operated with a peak speed - up to 768 Kbit / s. The initial plan was presented to the ARPANET network. Leonard Kleinrock built the first node of ARPANET - the prototype of the Internet. In 1970 there was the first packet radio network data (via satellite) ALOHA. It was designed and built by N. Abramson. In 1972 ALOHA connected to the ARPANET network.

This work laid the foundation for future wireless LANs. In 1978, Bahrain telephone company Batelco (Bahrain Telephone Company) began operation of commercial systems of wireless telephony, which is considered to be the world's first real system of cellular communication. The two zones with 20 channels catered 250 subscribers. It uses the equipment of the Japanese company Matsushita Electric Industrial. In the same year in Chicago AT&T start to test cellular system that called

Advanced Mobile Phone Service (AMPS), operating in a range of 800 MHz band. A network of 10 areas covered bond 54 thousand square kilometers. Each event in the field of wireless technologies is hard work and outstanding achievements of experts all around the world. All wireless technologies are continuously evolving towards improved performance and reliability of information transmission networks, the ability to integrate data, voice and video.

The basic wireless networking has become a mass appearance of personal computers, the development of mobile telephony, as well as the rapid development of semiconductor technology (creation of cheap signal processors and microcontrollers, analog microwave integrated circuits). The rapid development of wireless transmission of information related to their strengths:

1) Architectural flexibility, the ability to dynamically change the topology of the network when connecting, disconnecting and moving of mobile users without a significant loss of time;

2) High-speed transmission of data (1-10 Mbits / s and above);

3) Big speed of the design and deployment;

4) A high degree of protection against unauthorized access;

5) Refusal to expensive and not always possible or lease laying fiber and copper cables.

1.2 The purpose and classification of wireless communication systems

Modern life is characterized by increased business activity of the people. The rapid development of modern technologies is due to the improvement of facilities and communication settings. The need for information in the possession of a certain time, the increase in volume of the information and reducing the time it is delivered to the addressee, the possibility of its rapid transmission and reception makes communication an essential attribute of reality [2]. Wireless communication systems are established in order to meet the current global level of needs of their customers in communication services. Classification criteria can be developed quite a lot, they cannot fit into the clear boundaries of a certain class, and with the development of well-established systems may become obsolete. Therefore, below are the most popular rankings of wireless systems are present.

The following features classify wireless communication systems:

a) A primary information processing method:

1) analog;

2) digital;

b) For the purpose:

1) cell;

2) picocells (cordless phone);

3) trunking;

4) satellite;

5) optical;

6) paging;

c) Multiple access methods:
1) frequency division multiple access FDMA;
2) time division multiple access TDMA channels;
3) code division multiple access CDMA;
4) combined;
d) Method of organizing communication channel:
1) simplex;
2) duplex;
3) half-duplex;
e) Transmission bandwidth:
1) narrowband;
2) broadband;
3) ultra wideband;
f) The localization of subscribers:
1) moving;
2) fixed;
g) Geographic extent:
1) personal;
2) local;
3) regional (city);
4) global;
h) By referring to information to be transmitted:
1) system for speech transmission;
2) video data;
3) data transmission.

The main requirements of subscribers and operators for professional wireless communication systems are:

- Providing a predetermined communication service area irrespective of the location of subscribers;
- The possibility of interaction between individual user groups and organization of circular communication;
- Efficiency communication management, including at various levels;
- Providing communication through control centers;
- The possibility of establishing a priority of communication channels;
- Low energy consumption of the wireless station;
- The confidentiality of the negotiations [3].

Mobile computers are small, typically portable devices, which are used at a distance from the office desktop. They represent the fastest growing segment of the computer industry. They all have at least a wireless infrared link. There are computers even smaller and more mobile than PC-class laptop (of knee). Notebooks, subnotebooks, hand (palmtops) and pocket (handholds) computers, tablets, and PDAs (personal digital assistants), which combine the functions of an organizer, pager and cell phone - all are popular, upgraded computers.

Analysts predict a huge growth market for new mobile personal devices called PDA, they are called PDA or smart phones, because they are designed for easy use. Mobile computers often work when the user stands or moving. The user can keep the computer in one hand, as much as possible to keep the folder, notebook or cell phone, and work with the other hand. However, with the computer that called laptop that is not possible. In order to be comfortable and to satisfy the requirements of working with them, mobile computers must be smaller, lighter, stronger and easier to operate. Most of the users alike will need a mobile and flexible access to remote databases and the central computer via demon-wired networks, usually in the form of mobile radio networks that connected to the national and international public switched telephone network of general use.

In order to make mobile computing convenience, there are number of computer and mixed (PC - mobile communications) technologies:

- pen input and speech recognition may lead to the replacement of the keyboard and to make computers more comfortable and functional;
- radio communication allow users to share information within a room, building, city, country or the world;
- compact, more modern microprocessors with enhanced compact memory for storing large amounts of data, and modern digital radio system can process and transmit data more efficiently;
- new manufacturing technology of batteries and efficiency management software allows computers and smart phones run on a single battery charge for longer periods of time.

1.3 Standardization in the field of telecommunications

The most important aspect of the development of modern telecommunication systems is standardization. Standardization is necessary for all inhabitants of the world of telecommunications, including manufacturers of electronic components manufacturers of equipment, development of networks and end-manufacturers. First of all, standardizing means of mass production, this leads to low cost and widespread technology [3].

The main organization in the world in the field of standardization in telecommunication field is the International Telecommunication Union (ITU) working under the auspices of the UN. The Radio communication Sector (ITU-R, ITU) included two sectors: the International Radio Consultative Committee (CCIR) and the International Committee for the registration of radio-frequency (IFRB). The telecommunication sector of the International Telecommunication Union ITU-T (ITU Telecommunication Standardization Sector) has become the successor of the International Advisory Committee for Telephone and Telegraph (CCITT-Consultative Committee for International Telephone and Telegraph). Research Sector ITU-D, has been created and organized in 1989 (Telecommunication

Development Bureau-TDB). It should be noted that the ITU is playing the leading role in the field of international telecommunications standards.

The current structure of ITU is the best reflects the situation in the field of modern telecommunications: the intertwining of technology and union of wired and wireless, analog and digital. A huge role in the approval of international standards plays an International Organization for Standardization ISO (International Organization for Standardization). It can be noted that IEC and ISO divided spheres of influence: IEC - standards in the field of electronics and electrical engineering, ISO - everything else. They use a single numbering system and codes of standards often featured the name of the two organizations, for example, ISO / IEC 8802-3.

It should be noted that ITU, and ISO, and IEC act rather as the most authoritative approval organizations.

Apart standardized in the list of organizations one of the most important standard organization is the Institute of Electrical and Electronics Engineers - IEEE (Institute of Electrical and Electronics Engineers). The IEEE produces its own standards, which have global significance.

Today, domestic experts operate with the international standards - ISO, ITU, and IEEE.

Compatible with almost all technologies in one terminal allowed the new standard (Universal Mobile Telecommunications System), which is now being implemented in the framework of mobile radio telecommunication third and fourth generation. The ability to switch from one range to another, the transition from standard to standard, or from a satellite channel in the cell allows the subscriber to choose the type of service that best suits him. Therefore, UMTS is a multi-mode terminals operating in the networks of several standards.

Control questions:

1) The advantages of wireless networks.

2) What are the existing international standards you know in telecommunication field?

3) List the basic requirements of subscribers to professional wireless communication systems.

4) How can divide all of the wireless communication method for organizing communication channel?

5) What types of wireless technologies you know?

CHAPTER 2

2 Mobile wireless communication networks

2.1 Elements of mobile networks

With the development of technology radiotelephone system improved: reduce the size of devices; new frequency bands were discovered, improve basic and switching equipment.

In the mid 40's Bell Labs research center of the US Company AT & T proposed the idea of partitioning the service area into small plots - cell. Each cell transmitter has been operated with a limited radius of action and a fixed frequency. This enabled without interference using the same frequency again in another cell. But it took 30 years before this principle of organization of communication has been implemented at the hardware level [4].

All the serviced territory can be divided into cells in two ways:

1) based on statistical measurements of the propagation characteristics of signals in the communication system;

2) based on the measurement or calculation of the parameters of the spread signals for a specific area.

In implementing the first method, the entire serviced area is divided into the same cell shape, and then using the laws of statistical physics determine their size and the distance to the other zones, within which the conditions of mutual influence.

For optimal (i.e. without overlap or gaps) in the cell division of the territory can only be used three geometric shapes: triangle, square and hexagon. Most suitable is a hexagon, since if an antenna with omnidirectional set at its center; it will have access to almost the entire cell.

When using the first method, the interval between cells that use the same operating channels, usually creates more required to provide acceptable levels of mutual interference.

The second method is more suitable for separation of service area. In this case, carefully measured or calculated system parameters for the minimum number of base stations that provide quality, satisfactory service to customers throughout the territory, determine the optimal location of the base stations in view of the terrain, the use of directional antennas, passive repeaters and adjacent base stations at the time of peak load, etc.

Principles of construction of digital cellular systems have allowed the organization to use cellular networks in a new way, more effective model of reuse of frequencies than analog networks. As a result, without increasing the total bandwidth of the communication system significantly increased the number of channels per cell.

The group of cells with a different set of frequencies called a cluster.

The decisive parameter is the dimension of the cluster - the number of used frequency in neighboring cells. The dimension of the cluster is equal to seven (see. figure 2.1).

The base stations, in which reuse the selected set of frequencies, spaced by a distance D, called a guard interval.

Adjacent base stations using different frequency channels to form a group of C stations. If each base station is allocated a set of m channels each with a bandwidth Fk, the total bandwidth Fc, occupied by the given cellular system, will be:

$$F_c = F_k \times m \times C; \tag{2.1}$$

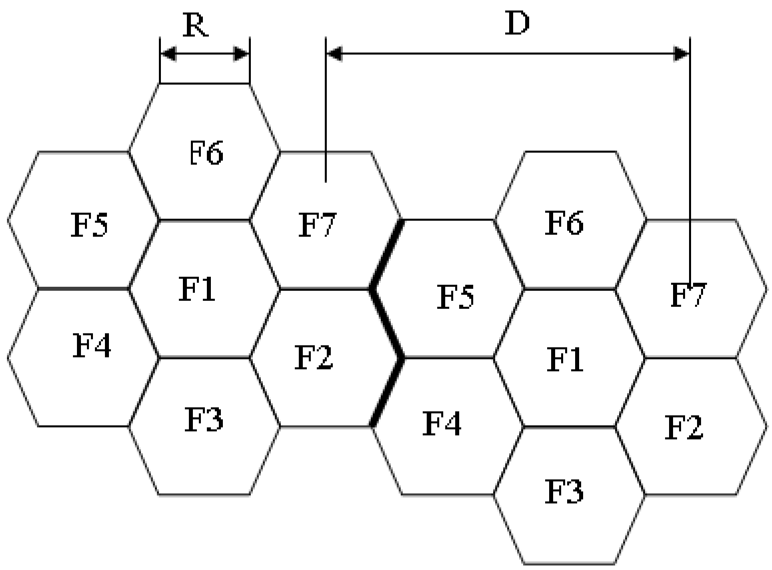
$$m = \frac{1 \times Fc}{C \times Fk} \quad . \tag{2.2}$$

Thus, the value of C determines the minimum number of channels possible systems, and it is therefore called a frequency parameter of the system, or a repeat frequency coefficient. Coefficient C does not depend on the number of using channels, and increases as the cell radius is decreases.

Thus, by using smaller cells can increase the repetition frequency. The best ratio between C and D is provided in a hexagonal cell.

The size of the cell R determines the guard interval D between the cells in which the same frequencies can be reused. D value also depends on the acceptable level of interference and propagation conditions. The size of R is defined as number of subscribers N, able to negotiate throughout the service. Consequently, a reduction of this size will not only improve the efficiency of dedicated bandwidth and increase the subscriber capacity of the system, but also reduce the power of the transmitter and the receiver sensitivity of the BS and the MS.

$q = \frac{D}{R}$ parameter is called the reduction factor co channel interference co channel or recurrence.



(R – cell size; D – the guard interval)
Figure 2.1- Model frequency reuse for seven cells

An effective way to reduce co- channel interference, i.e. interference matching frequency channels may be the use of sector antennas. In the sector of the directional antenna a signal is emitted in one direction, and the radiation level in the opposite direction is reduced to a minimum. Sectorisation of cells allows more frequently used frequency comb while reducing noise.

The next step in the development of cellular mobile communications systems after the introduction of digital technology is the transition to a microcellular structure networks. When the radius of cells is a several hundred meters their capacity can be increased 5-10 times as compared to a macrocell. In addition, the user may use existing standards of digital radio CCS, along with portable low-power radio subscriber stations, which is the basis for the creation of personal communications systems (PCS).

Microcellular structure of MN is organically combined with the microcell. Microcell is based on low-power BS serving the areas of streets and buildings. Microcellular structure can be seen as a development of the equipment the macro BSs controlled by one controller and mutually connected by means of lines with a transmission rate of 64 Kbit/s. Microcells take the load from the slow moving subscribers, such as pedestrians and stationary vehicles.

Design principles established Portable mobile networks differ from existing networks to macrocellular networks. These differences include the lack of frequency planning and handover.

The first difference is due to the fact that under microcellular it is difficult to predict propagation conditions and to assess the level of co channel interference. Therefore, it is practically impossible to apply the principles of frequency planning in the microcell. Fixed channel allocation leads to a low efficiency of use of the frequency spectrum. For these reasons, in a microcellular communication networks operating procedure of automatic adaptive channel allocation (FCA) connection implemented in the European DECT standard for digital cordless telephones of common use.

As for the second difference, in microcellular networks during normal telephone connection between the BS the number of switching increases, and to ensure continuity of communications require new algorithms of fast switching (handover).

In the existing digital PSCN used algorithms of forced switching, referring to a class of distributed algorithms that run much faster than centralized algorithms of analog PSCN. The microcellular structure is not necessary to load the network by measuring the signal strength for the decision to switch. Measurement functions transferred to the mobile station which transmits the results to the BS. SC of mobile communication is not activated until the actual switching will not be done.

First microcell structure of networks has been implemented in wireless phone systems.

Microcellular structure used in the implementation of networks in the concept of personal communications (PCN), which in Europe are based on the DCS-1800 standard that provides for appropriate air interface to GSM standard. The structure of the networks is introduced picocells with a range of 10-60 m, designed to serve customers in urban areas with high population density and in closed areas (underground garages, railway stations and etc.). Application of picocells is another step in order to improve the capacity of PSCN.

Cellular communication systems are constructed as a set of cells, covering the serviced territory. In the center of each cell located a base station (BS) serving all mobile station (MS) within its cell. When moving the subscriber from one cell to another is a transfer of its service from one BS to another. All BS connected to the switching center (SC) of mobile communication via dedicated wired or microwave links. From the switching center there is an access to PTN. A simplified diagram of the composition of the network of cellular mobile communication is shown in Figure 2.2.

A cellular communication system may include more than one of the Central Committee, which may be due to the evolution of the network or the limited capacity of the switching system. One of several of the Central Committee can be called the head, gateway or transit.

In the simplest case the system comprises one SC for which there is a home location register, and it serves a relatively small-enclosed area, which do not border area serviced by other systems. If the system serves a large area, it may contain two or more of the Central Committee, of which only in the "head" has a home location register, but the territory served by the system still does not border on the territories of other systems. In both of these cases, when subscriber move between the cells of a system handover occurs, and when subscriber moves into the territory of another system the roaming occurs.

If the system is bordered by another CCS, then when a person move from one system to another intersystem handover takes place.

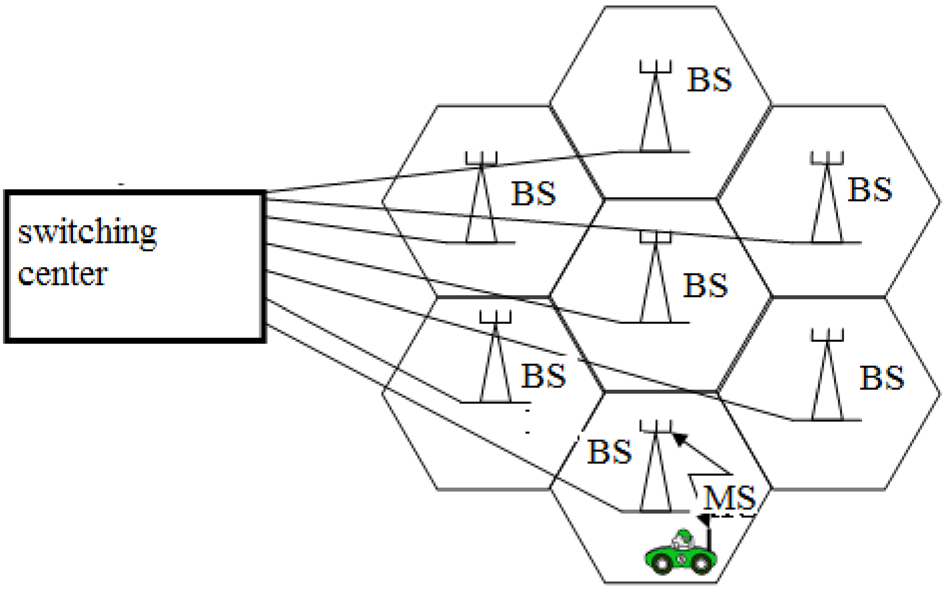


Figure 2.2- Composition of cellular mobile communication network

The structure of the mobile station (MS) includes: a control unit; transceiver and transmitter unit; antenna unit.

BS controller (computer) controls the operation of the station, as well as performance monitoring of all its units and assemblies.

To ensure the reliability of many components and units BS is reserved (duplicate), part of the station includes stand-alone uninterruptible power supply (batteries).

Switching Center is an automatic telephone station of the CCS, which provides all the functions of network management. SC carries out continuous monitoring of MS, organize its handover during which the continuity of the link is achieved when moving MS from one cell to another cell and switching operating channels in the cell when a fault or interference is occurring. SC closes the flow of information from all BS, and through this module exits to other network - station telephone network, the network of long-distance communications, satellite communications, and other cellular networks. The structure of the SC includes multiple processors (controllers).

2.2 Authentication and Identification

Radiotelephone waiting - receiver constantly scans all channels, or only control channels. To make a call by all BSs cellular communication system transmits a call signal to CC. Mobile phone of calling subscriber using this signal corresponds to one of the available CC. BS retaliated signal transmit information about its options to the SC, which switches the conversation to the BS, which recorded the highest level of signal radiotelephone call.

When the user dialing, radiotelephone occupies one of the free channels, where currently signal BS at a maximum. As the distance from the subscriber to BS is increasing or deterioration of propagation conditions, or due to interference, or in the event of fault of the switching equipment the signal level is reduced, the quality of communication is deteriorating.

Improving the quality of conversation is achieved by automatically switching the subscriber to another communication channel. Special procedure for the transfer of call control and relay transmission (handover or handoff) allow to switch the conversation to another free channel BS in the coverage area of which subscriber appeared at this time. To control these situations BS equipped with a special receiver, periodically measure the signal strength of mobile phone talking subscriber and compares it with a margin. If the signal level is less than this limit, information about this is transmitted automatically to the CC on the service channel. The CC instructs the measurement of signal level of subscriber radiotelephone to the nearest to him BS. After receiving the information from the BS about the level of the signal SC switches radiotelephone to BS that has the greatest signal strength.

If the number of available applications of flow channels is exceed as a temporary measure used relay transmission within the cell. Thus there is alternate channel switching within the same BS for providing communication of all subscribers.

One of the most important cellular services – roaming, that allows using phone when traveling to another city, country and etc.

In the MS within the same cell there are four stages with four operation modes: switching on and initialization, standby mode of communication (call), tracking mode of communication (phone call).

MS is switching on (power supply circuit is closed), initialization - initial start-up, i.e., MS is tuned to work within the system of signals, regularly fed to BS by CC, then the MS switches to standby mode. The specific content of the initialization phase is dependent on the standard of cellular communication.

In standby mode, MS keeps track:

- Changing information system, these changes can be associated with a change in the operating mode of the system and the movement of the MS;
- Command system, for example - click to confirm its operation;
- Receiving a call from the system;
- Initialization calls from their own number.

MS can periodically (every 10 - 15 minutes) prove their performance, transmitting appropriate signals to the BS (confirmation of "registration" or location update). In the SC for each of the included MS fixed cell in which it is "registered", this facilitates the procedure for calling a mobile unit. If the MS does not confirm its performance during a certain period of time, the SC considers it off, and entering its call number is not transmitted.

The procedure for communication is dialing, ringing from the MSC, SC sends the BS of the cell in which "registered" MS, or couple BS in the vicinity of the cell, taking into account possible movement subscriber for the time elapsed since the last "registration" was, and the BS transmits it through the appropriate channels of the call. MS, which is in standby mode, receives the call and responds to it through their BS, transmitting simultaneously data required for the authentication procedure. If the result of authentication is positive it assigned to TC (traffic channel). MS reported the number of the frequency channel, and then this channel is configured on a dedicated channel and, together with the BS performs the necessary steps to prepare the communication session. On this step, the MS is adjusted to the specified slot number in the frame, clarifies the time delay, adjusts the power output and etc. The selection of the time delay is performed to temporarily matching slots in a frame (on reception in BS) when organization of communication with the MS located at different distances from the BS. This time delay of transmitted MS packs regulated by commands of BS.

Then the BS issues a message about a signal call (call), which is confirmed by the MS, and the caller subscriber is answers the call (off-hook), MS prompts the request to complete the connection. With the completion of the connection starts the actual conversation - subscribers are talking.

During a conversation MS processes the transmitted and received signals of speech and transmitted along with the speech signals control signals. At the end of the conversation an exchange of signaling messages between the MS and BS (query or command to disable the confirmation) is occurs, and then turn off the transmitter of the MS, and the station goes into standby mode.

Authentication is the procedure to proof the user (the rule of law, the existence of the rights to use the services of cellular communication) of CCS subscriber. Each mobile subscriber at the time of use of the communication system receives the standard subscriber identity number (SIM-card), which contains:

- The international mobile subscriber identification number (IMSI);
- Their own individual authentication key (AK);
- Authentication algorithm (AZ).

Using information that embedded in SIM as a result of mutual communication between the MS and the full cycle of the CCS make a full cycle of authentication and the subscriber is allowed access to the network.

The procedure for checking the authenticity of the network subscriber is implemented as follows.

The network transmits a random number (RAND) to the mobile station. The mobile station determines the value of the response (SRES) by using RAND, AK and AZ:

$$SRES = AK\,[RAND].$$

MS sends the computed value of SRES to the network which compares the received SRES value with the value of SRES, calculated by the network. When the both values are coincidence the MS can transmit messages. Otherwise, the connection is interrupted and the display of the mobile station must show that recognition did not take place.

For privacy reasons the calculation SRES occurs within SIM. Unclassified information is not processed in the module of SIM.

The authentication procedure is shown in Figure 2.3.

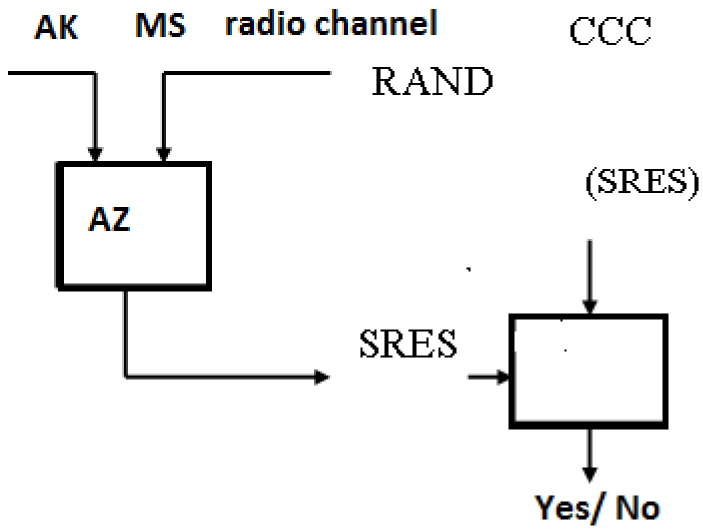


Figure 2.3 – Scheme of authentication procedure

Identification is the procedure of identification of the MS, i. e. the establishment of a procedure belonging to one of the groups that have certain characteristics. This procedure is used to detect lost, stolen or malfunction devices.

The first-generation analog CCS authentication the MS transferred its identificator (Electronic Serial Number, ESN), and if it was sought among those registered in the home location register, then the authentication procedure is successfully executed.

The idea of a digital authentication procedure in CCS is some encryption passwords, IDs with using quasi-random numbers that are periodically transmitted to the MS and SC, and individually for each MS of encryption algorithm.

Such encryption with using the same source data and the algorithms performed on the MS and the SC (or authentication center), and ending the authentication is considered successful if the two results are the same.

Security data

The protection mechanism is that all sensitive messages to be transmitted in the mode of data protection. The algorithm for generating the encryption keys (A8) is stored in the SIM module. Upon receiving the random number RAND, the MS calculates an encryption key (Kc) using RAND, except response SRES, Ki and an algorithm A8 (see. Figure 2.4):

$$K_c = K_i\,[RAND].$$

The encryption key is not sent over the radio channel. The mobile station and the network calculate the encryption key, which is used by other moving objects. Due to privacy reason calculating Kc occurs in SIM.

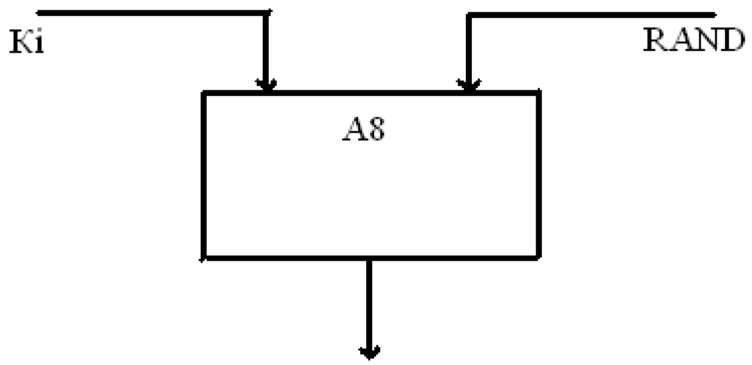


Figure 2.4 - Scheme of calculation of the encryption key

In addition to the random number RAND, CCS sends to the MS the numerical sequence of the encryption key. This number is related to the actual value of Kc and prevents the formation of an incorrect key. The number is stored in the MS and is contained in each of the each first message that is sent to the network. Some networks take a decision on the presence of a numerical sequence of the current encryption key in case if it is need to start the recognition, or if the recognition of preliminary recognition is performed by using the correct encryption key:

- Set encryption mode;
- Ensuring the privacy of the subscriber;
- To ensure secrecy in the procedure for adjusting the location;
- Handover.

2.3 Systems of GSM cellular communication

The standard of GSM (Global System for Mobile Communication) is the European standard for digital cellular mobile communications developed by the European Telecommunications Standards Institute - ETSI. Currently, the GSM cellular network function in all countries of the world. This standard owns about 70% of the subscriber base (over 130 countries). In the GSM system, there are three types of interfaces: for connection to external networks; between different network equipment of GSM; between the GSM network and the external equipment. They are fully compliant with the recommendations of ETSI / GSM 03.02 [5].

In GSM 900 standard in order to transmit information using the direct channel band 935 ... 960 MHz, and reverse - 890 ... 915 MHz, i.e. duplex spacing frequency is 45 MHz. One *f*-frequency channel occupied bandwidth of 200 kHz. Total in complete GSM frequency band, taking into account the guard bands located 124 frequency channels. Each frequency channel is used for organizing 8 digital channels. Each digital channel is a separate physical channel. Using time division multiplexing, based on the 124 radio channels it is possible to receive 992 (124x8) physical channels.

The center frequency of the channel (in MHz) is related to its number N of the ratio:

- reverse channel: $f = 890{,}200 + 0{,}200\ N$, $1 < N < 124$;
- direct channel: $f = 935{,}200 + 0{,}200\ N$, $1 < N < 124$.

One of the features of signal generation in GSM standard is the use of slow frequency hopping in the communication session. The main purpose of such jumps (SFH - Slow Frequency Hopping) is to provide frequency diversity in radio channels operating in conditions of multipath propagation. SFH is used in all mobile networks, which improves the efficiency of the coding and interleaving during slow movement of subscriber stations. The principle of formation of slow frequency hopping is that a message sent to the subscriber in the selected timeslot TDMA frames (577 microseconds) in each subsequent frame is transmitted (received) on a new fixed frequency. In accordance with the structure of the frame time for tuning the frequency is about 1 ms.

During frequency hopping 45 MHz duplex spacing between transmit and receive channels is constantly kept. All active subscribers that are located in the same cell are assigned to form the orthogonal sequence, which eliminates interference when taking messages to their subscribers within a cell. Parameters of frequency switching sequence (frequency-time matrix and the initial frequency) are assigned by each mobile station during the establishment of the channel. Orthogonality of frequency hopping sequences in a cell is provided by the initial frequency offset and in the same (by the algorithm formation) sequence. The adjacent cells use different forming sequence.

The GSM standard uses a Gaussian minimum shift keying (GMSK). In fact, this is MSK modulation. The term "Gaussian" in the title modulation method corresponds to an additional filter modulation bit sequence relatively narrow band Gaussian filters; this GMSK additional filtering method differs from the MSK method. The filter bandwidth B by the level of 3 dB is chosen to be B = 0,3F, where F is a frequency of the modulation bit sequence. In the GMSK standard F = 270,833 kHz, band of Gaussian filter B = 81, 3 kHz. Introduction of the Gaussian filter narrows the main lobe and lower side lobes of the spectrum at the output of modulator, which ensures acceptable level of interference to adjacent frequency channels.

2.4 Cellular communication with code-division multiplexing (CDMA standards)

Currently multiple access technique with a code division of channels is implemented in several standards. These standards differ significantly from each other by means of coding and channel spreading method.

Under standard cellular communication networks usually implies cdmaOne network standard CDMA IS-95A and IS-95B.

IS-95 A network provides subscribers with voice services and data services based on the channel switching with a data rate up to 64 kbit / s. IS-95B standard allows increasing a data rate of up to 115 kbit / s through packet switching. The main advantage of Standards IS-95A and IS-95B is that air interface is compatible with the CDMA 2000 1X. It highlights certain features in the evolution of standards. Thus, the mobile terminal IS-95 can work in CDMA 2000 1X. This is possible thanks to the unification of the use of frequency resources, since the width of the carrier is the same for all standards and is approximately 1.25 MHz. Cdma 2000 standard networks are networks of the IMT-2000 standard with an IMT-MC radio interface, which, in turn, is divided into two phases - cdma 2000 1X and cdma 2000 3X. Transition from cdma 2000 1X to cdma 2000 3X includes cdma 2000 1X EV-DO and cdma 2000 1X EV-DV standard CDMA. The evolution of networks of CDMA standard is shown on Figures 2.5 and 2.6.

Figure 2.5 - Evolution of the IS-95 A to the standards of the third generation

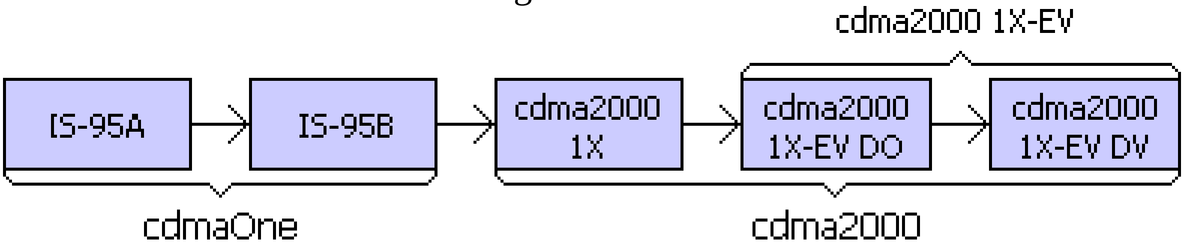


Figure 2.6- Evolution of CDMA standard

Cellular network standard of cdmaOne

CdmaOne communications system operates in the frequency bands of 824-849 MHz (return channel) and 869-894 MHz (direct channel) with a duplex spacing of 45 MHz. The total bandwidth occupied in the air -1.25 MHz [6].

Voice and data are transmitting according to IS-95 standard and carried with a 20ms frames. The rate of transmission within a communication session can vary from 1.2 to 9.6 Kbit / s, but during one frame communication session remains unchanged. If the number of errors in the frame exceeds the permitted limit, the distorted picture is deleted.

In CDMA standard the transmitted information is coded and the code is converted to a wideband noise-like signal (WNLS) so that it can be recovered again, only placing the code on the receiving side. At the same time over a wide frequency band can transmit and receive multiple signals that are not interfere with each other.

Broadband is a system that transmits the signal, which occupies a very wide bandwidth that significantly exceeding the minimum bandwidth that is actually required for transmission of information. In broadband system, the modulating signal source (e.g., a signal of the telephone channel) with a bandwidth of only a few kilohertz is in the partitioned band, whose width may be a few megahertz. This is accomplished by a dual carrier modulation transmission information signal and a wideband encoding signal. The main characteristic of the broadband signal is in its base B, defined as the product of the spectral width of the signal F at its period T. The result of multiplying the pseudo-random noise signal source with the energy of the last information signal is distributed in a wide band i.e. expands its range (see. Figure 2.7).

The information may be entered into a broadband signal (BBS) in several ways. The best-known method is to impose information on broadband modulating code sequence before the modulated carrier for BBS.

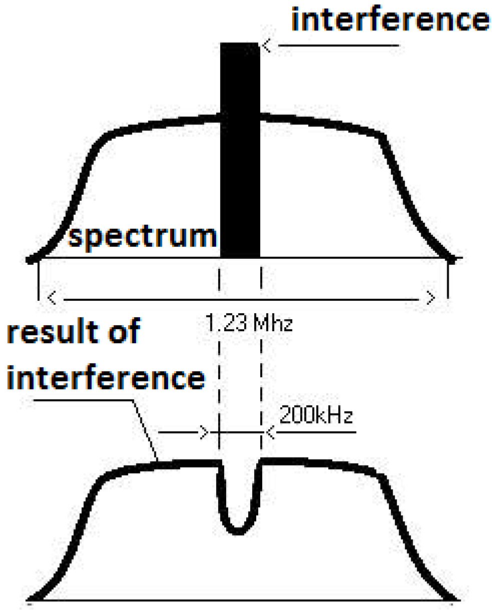


Figure 2.7 - The range of noise-like signal

A narrowband signal is multiplied by a pseudorandom sequence (PRS) with a period T, consisting of N bits. In this case, the base BBS numerically equal elements of the PRS. This method is suitable for any wideband system in which for spreading the RF signal using the digital sequence.

The essence of broadband is to increase the bandwidth of the signal, transmission of BBS and extract the useful signal from it by converting the received BBS spectrum into the original information signal spectrum.

Multiplication of the received signal and a signal of the same source as a pseudorandom noise (PRS) that was used in the transmitter, compresses the spectrum of the useful signal while expanding the range of the background noise and other sources of interference noise. The result of the gain in the signal / noise ratio at the receiver output is a function of the relationship bandwidths of broadband and basic signals: the greater the expansion of the range, the greater the gain. In the time domain - a function of the ratio of flow rate of the digital radio channel to the base rate of the information signal. For IS-95 standard, this ratio is 128 times, or 21 dB.

This allows the system to operate at the level of the interference noise exceeding the level of the useful signal by 18 dB, since the signal processing of the receiver output requires signal level exceeding the overall noise level by 3dB. Under real conditions, the noise level is considerably smaller. Furthermore, the expansion of the spectrum of the signal (up to 1.23 MHz) can be considered as application of frequency diversity reception. Signal propagation in the radio link-subjecting is fading due to multipath propagation of nature. In the frequency domain, this phenomenon can be represented as the effect of the notch filter with variable bandwidth notch (usually not more than 300 kHz).

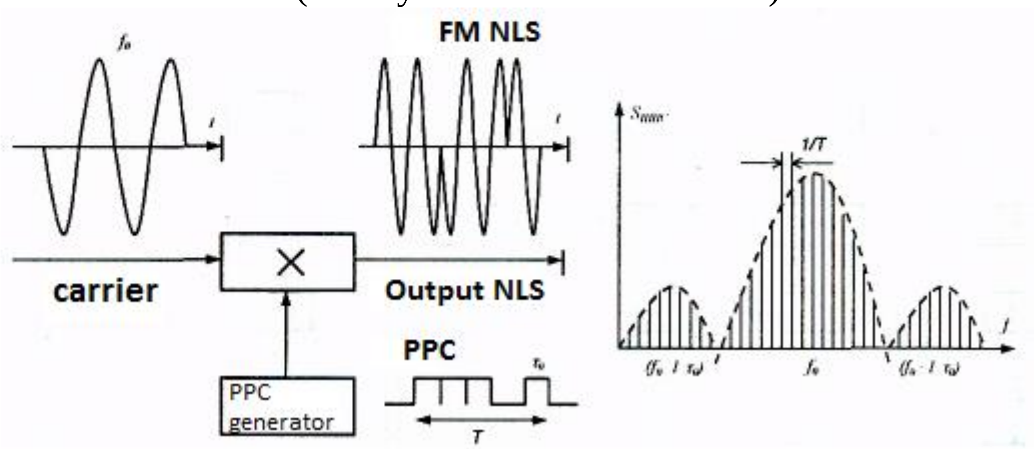


Figure 2.8-scheme of spread spectrum digital communications

The CDMA standard for code division multiple uses orthogonal Walsh codes. Walsh coding is used on the forward link (base station to user terminal) to separate users. In systems using the IS-95 standard, all the speakers operate simultaneously in the same frequency band. The matched filter receivers BS quasioptimality in a mutual interference between users of the same cell, and are very sensitive to the "far-near" effect. To maximize the subscriber capacity of the system it requires that all subscribers of the terminals of the emitted signal of such power would provide the same level of the received BS signals. It is understandable that the more precise power control, the greater subscriber capacity of the system.

In the technical solutions of Qualcomm Company the expanding of the range provided by the signal modulation of pseudo-random sequence with a discrete repetition rate of 1.23 MHz. More precisely, this frequency is 1.2288 MHz and 1228.8 = 9,6x128, so that when the frequency of the information bit sequence is 9.6 Kbit / s the duration of one bit corresponds to 128 discrete pseudo random modulation sequence. Band spread spectrum signal by 3 dB is 1.23 MHz, and by using of a digital filter formed a spectrum close to rectangular.

For modulation of the signal, there are types of functions that are used: a "short" and "long" the PSR and Walsh order functions from 0 to 63. All of them are shared for the base and mobile stations; however, they implement different functions. In the direct channel modulation signal Walsh functions (binary phase shift keying) is used to distinguish different physical channels of the BS; Modulation of "long" PSR (binary phase shift keying) - for the purpose of encrypting messages; Modulation of "short" PSR (quadrature phase shift keying two PSR of the same period) - to expand the band and distinguish the different signals BS.

Distinguishing signals of different stations, provided that all BSs use the same pair of short PSR, but with a shift to 64 increments between different stations, i.e. there are 511 codes in a network, wherein all physical channels of a BS have the same phase sequence.

On the BS there are 4 types of channels are formed: a pilot channel (PI), a sync (SYNC), calling channel (PCH) and traffic channel (TCH).

The signals of different channels are mutually orthogonal, ensuring that no interference between them on one BS. Intersystem interference mainly arises from other BS transmitters operating on the same frequency, but with a different cyclic shift.

Pilot signal radiation occurring continuously. For this transmission using a Walsh function with zero order. The pilot signal is a carrier signal which is used MS to select the working cell (for the most powerful signal), and also as a reference signal for synchronous detection of signals of the information channels. Usually pilot signal radiates about 20% of the total power, which allows the mobile station to ensure the accuracy of selection of the carrier frequency and carry out coherent detection signals.

In the sync channel (SYNC) the input flow rate of 1.2 Kbit / s recorded in stream having a rate of 4.8 Kbit / s. Synchromessage contains process information necessary for establishing the initial synchronization at the mobile station (MS) information on the exact system time, the speed transmission of PCH channel, parameters of short and long code. Sync channel transmission rate is lower than in a paging (PCH) or traffic channel (TCH), thereby increasing reliability of it. Upon completion of the synchronization procedure MS tunes to the paging channel PCH, and it constantly monitors it.

When transmitting a signal from the BS uses convolutional coding with rate R = l / 2 and a code constraint of K = 9. To combat fading in the IS-95 standard provides per-block interleaved symbols allowing decorrelate burst errors. The speed of transmission over a TCH may vary from 1.2 to 9.6 Kbit / s, which allows the flexibility to adapt the traffic to the conditions of radio wave propagation. For receiving signals used RAKE-receiver having a plurality of channels for parallel processing.

In IS-95 allowed the use of several types of speech codecs: CELP (8 Kbit / s), QCELP (13 Kbit / s) or EVRC (8 Kbit / s). Typical quality assessment of MOS scale for CELP algorithm score is 3.7 (9600 bit / s) and 3.0 points (4800 bit / s). Insertion algorithm CELP delay does not exceed 30 ms. Voice quality in the QCELP (Qualcomm CELP) vocoder is very close to the quality of transmission over wire lines (4.02 points).

In the reverse channel (from the mobile station to the base) short PCR modulation signal is only used for spreading, and all mobile stations use the same pair of sequences of the same (zero) bias. The modulation signal of long PCR, except the encrypt messages, contains information about the mobile station (MS) as its coded individual number and provides a distinction between the different signals from different MS of one cell by individual station for each shift sequence.

In MC, there are two types of information exchange: Access (ACH) and traffic (TCH). There is no a pilot signal in a reverse channel, therefore synchronous detection is not used, the BS performed an incoherent signal processing, and the noise immunity is provided mainly by the spatial diversity.

In the MS codecs the orthogonal Walsh codes are also used, but not for multiplexing of channels (like on the BS), they are using in order to improve noise immunity. For this purpose, the input data stream of 28.8 Kbit / s is divided into packets by 6 bits, and each of them is assigned a unique one of 64 Walsh sequences. As a result, the encoded stream rate at the modulator input increases to 307.2 Kbit / s. This encoding is the same for all physical channels and used at the receiving end 64 of parallel channels, each of which is set to a Walsh function, and these channels detect (decode) the received 6-bit characters.

On the reverse path as in the forward error protection used convolutional coding constraint length 9, but at a speed 1/3 (i.e. with twice redundancy - a measure of the lack of compensation of the synchronous detection) and interleaving interval 20 ms. As a result, the encoding rate in the data channel is increased to 28.8 Kbit / s. The principle of operation of a cellular CDMA standard is based on the Walsh coding information signal, then mixed with a carrier, the spectrum of which is expanded beforehand by multiplying with a pseudorandom noise signal source. Each information signal is assigned Walsh code, and then they are combined in the transmitter, passed through a filter and the transmitting antenna emits the total noise-like signal.

The input of the receiver receives the useful signal, the background noise, and interference from neighboring BS cells and from MS of other subscribers. After RF filtering signal is supplied to the correlator, where despreading occurs and isolating of the useful signal in the digital filter by a predetermined Walsh code. Interference spectrum is expanded, and they appear at the output of the correlator in the form of noise. In practice, the MS uses several correlators for receiving of signals with a different propagation time or the radio link signals transmitted by different BSs.

The number of subscribers in a CDMA system depends on the level of interference. Matched BS filters are highly sensitive to the effect of "near-far" (far-near problem), when the MS is located near the base, it operates at high power, creating an unacceptably high level of interference with reception of other "far away" signals, which leads to lower bandwidth of the system as a whole. This problem exists in all mobile communication systems, but the greatest signal distortions occurs exactly in-CDMA systems operating in a common frequency band, which use orthogonal noise-like signals. If these systems lacked power adjustment, they are significantly inferior in characteristics to a cellular network based on TDMA. Therefore, a key challenge in CDMA-systems can be considered as individual control of each power station. The effective operation of the system with code access is only possible if the signal alignment of different customers at the entrance to the base station. Moreover, the higher alignment accuracy, the greater the coverage of the system. It should be noted that the direct channel is less susceptible to signal distortion due to self-interference and multipath fading, since the BS is always have a supply of power. Therefore, the main problems arise in the power control in the reverse channel - from the subscriber to the BS.

The higher accuracy of power control, the lower the level of interference. The standard IS-95 power control of MCS is performed in a dynamic range of 84 dB with 1 dB steps, i.e. with accuracy of ± 0.5 dB. The interval between adjacent measurements is 1.25 ms. The power control bits are transmitted on the traffic channel at 800 bits / sec, separate processing multipath signals with subsequent adding provides the required signal / noise ratio by 6-7 dB. Using multiple parallel channels running in separate processing beams allows a "soft" switching mode when switching of user from one cell to another.

The user capacity of the cell CDMA system optimized algorithm adjustment, which limits the power emitted by each UT, to the required level in order to obtain an acceptable probability of error. The system provides three-power control mechanism: in the direct channel - open loop; in the direct channel - closed loop; in the reverse channel (RC) - outer loop control.

The process control transmitter power in the RC (from the subscriber to the BS) is as follows. Each MS transmits continuously information about the level of error in the received signal. Based on this information, the BS allocates the transmission power between the subscribers so that in each case provide acceptable speech quality. Subscribers on the path to which the radio signal experiences greater attenuation, are able to emit high power signal. The main purpose of the adjustment capacity in the RC is the optimization of the cell area.

In the process of power control on the forward link (from the BS to the subscriber) there are two possibilities of regulation: on the open loop and closed loop. In the open loop MS is looking after the signal of BS. After synchronization of the MS on the measurement signal is produced, and its capacity is calculated and transmitted power required to provide a connection with the BS is calculated. Calculations are based on the fact that the sum of the perceived power of the emitted signal and the received signal power must be constant and equal to -73 dB. This process is repeated every 20 ms, but it still does not provide the desired accuracy of the power control, since the forward and reverse channels operate at different frequency bands (frequency spacing of 45 MHz) and, therefore, have different levels of attenuation in the propagation and differently exposed interfered.

When a closed loop it is possible to accurately adjust the power of the transmitted signal. BS continually assesses the likelihood of errors in each of the received signal. If it exceeds a predetermined threshold program, the BS instructs the corresponding MS to increase the power of the radiation. Adjustment is carried out in steps of 1 dB. This process is repeated every 1.25 ms. The purpose of this regulation process is radiated to each MS the minimum signal power required to provide acceptable speech quality. Due to the fact that all the MS emit signals required for the normal operation of the power, and no more, their mutual influence is minimized, and the subscriber capacity of the system is increased. MS must ensure the control of the output power over a wide dynamic range of - 85 dB.

When the procedure of soft handover (moving the subscriber from one service area into a zone of another BS) the power control scheme is a bit different. MS receives multiple power control commands from different BS (usually two) and compares them with each other. If all commands indicate the need to increase capacity, the MS sequentially increases its power by 1 dB.

Main characteristics of CDMA Qualcomm Company listed in Table 2.1.

The CDMA system of Qualcomm firm is designed to operate in the 800 MHz band. The system is based on a method of direct expansion of the frequency spectrum on the basis of 64 kinds of sequences formed under the law of Walsh functions. To convert the analog voice signal into a digital the CELP algorithm is used with conversion speed of 8000 bit / s (9600 bit / s channel). There are possible modes at speeds of 4800, 2400 and 1200 bit / s. The channels in the CDMA system apply convolutional coding rate 1/2 (the forward link) and 1/3 (reverse channel) Viterbi decoder with soft decision and interleaving the transmitted messages. The total bandwidth of the communication channel is 1.25 MHz.

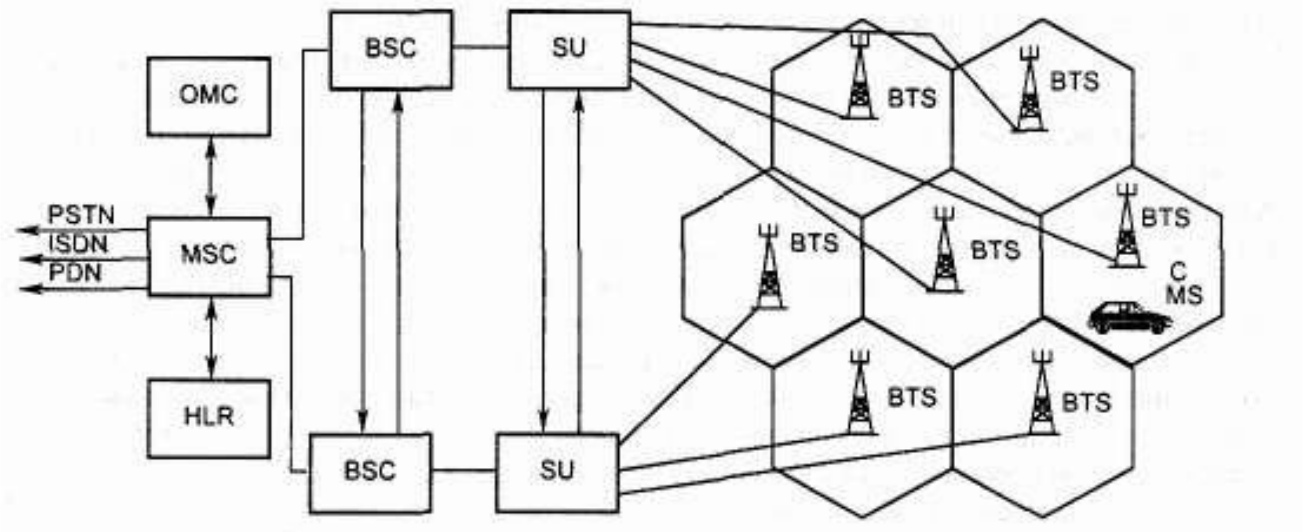
Table 2.1 - Basic specifications of CDMA

Characteristics	Value
The range of transmission frequencies of MS, MHz	824,040-848,860
The frequency range of the transmitter BTS, MHz	869,040-893,970
The relative instability of carrier frequency of BTS	$\pm 5x10^{-8}$
The relative instability of carrier frequency of MS	$\pm 2,5x10^{-6}$
Type of modulation of the carrier frequency	QPSK (BTS), O-QPSK (MS)
The spectral width of the emitted signal, MHz: - The level of - 3 dB; - The level of - 40 dB.	 1,25 1,50
PS clock speed, MHz	1,2288
The number of channels on a single carrier of BTS	One pilot channel, one signaling channel, seven paging channels, 55 channels
The number of channels MS	1 access channel 1 communication channel

The data rate bit / s: - in a synchronization channel - in a channel paging and access; - in communication channels.	 1200 9600, 4800 9600,4800,2400, 1200

Composition of CDMA network equipment is largely similar to the structure of the equipment of networks of GSM and includes an MS and a BS, digital switches, and a service management center, various additional systems and devices.

Functional coupling elements of the system are carried out through a number of interfaces. The configuration of the CDMA network is shown in Figure 2.9.



MS –moving station.
BTS– base station.
SU – selection frame device.
MSC – mobile switching center.
BSC – base Station Controller.
OMC – facility management and maintenance.
DB –data base.
PSTN –public switch telephone network.
ISDN – Integrated Services Digital Network.
PDN – packet data network.

Figure 2.9 - Configuration of the CDMA network

One of the important requirements for the system is flexible technology and the possibility of gradual development, the provision of packet services. To do this, the controller must be retrofitted with a BS router. The specifications provided for the qualitative improvement of the standard of service performance by reducing losses in the transition of subscriber from one BS to another, as well as improving the accuracy of power control to 0.25 dB, the organization of channels priority access and other improvements.

Control questions:

1) Describe the general principles of operation of cellular networks.

2) What are the standards of cellular communication systems operating in Kazakhstan?

3) Tell us about the network configuration and the characteristics of standard CDMA.

4) Decode the terms "cluster", "authentication", "identification," guard interval ".

5) Why the optimal division of the territory in the cell is the "hexagon"?

CHAPTER 3

3 Trunking communication networks

3.1 Basic provisions

Trunking communication system firmly taken its place in the overall structure of the professional communications tools.

Trunking - is one of the concepts in mobile radio systems. The term "trunking" refers to the method of equal access subscribers to dedicated channels with automatic distribution among subscribers. The term "trunking" comes from the English Trunking, which can be translated as "union in a bun" [7].

Worldwide, the main clients of this service are state and municipal structures, interested in the operational management of those or other objects in real time. Depending on the purpose of trunking systems can be divided into two categories:

- Commercial (public) - RAMR;
- Special applications (professional) - PMR.

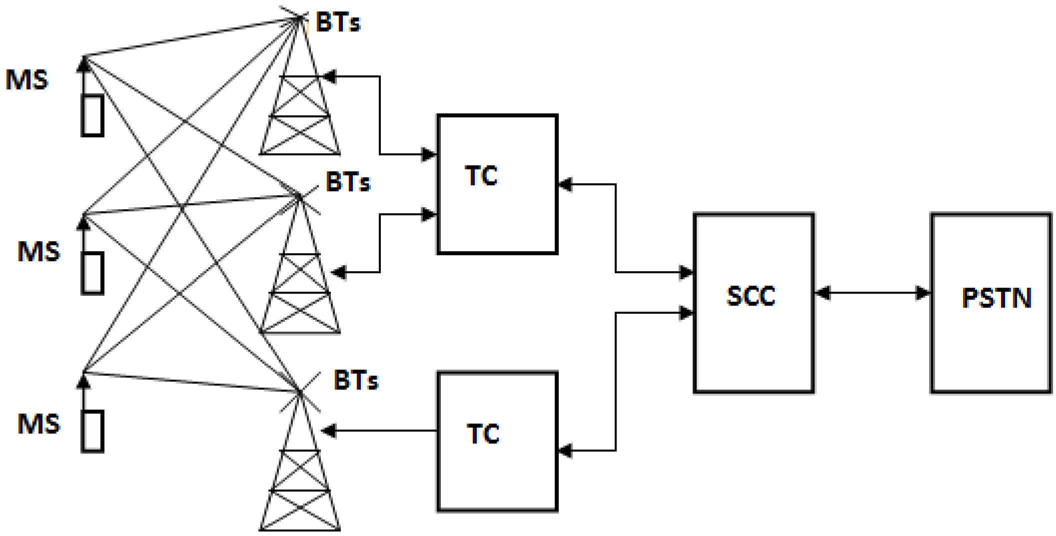
Commercial systems PARM differ with constant high capacity in areas where there is effective demand for mobile radio services. Another feature of these systems is the need for interfacing with the PSTN to a large number of subscribers; the subscriber station must provide full duplex.

Professional PMR system must meet the requirements to ensure that in special periods (emergency, event public security forces, a large manufacturing operation, and etc.) simultaneous operation of a large number of subscribers. Modern trunking systems provide group, individual radio with different priorities, emergency and circular calls for the entire system and for its parts, a cryptographic transformation of voice messages and data. Time communication in trunking communication networks is less than 0.3 with an order of magnitude less than in the cellular systems.

Currently the world produces a range of trunking systems: from the simple analog (Smart Trunk, LTR, ESAS) to digital (TETRA) [8].

The communication algorithm in most of the trunking systems are the same. During dialing radio station takes one of the free channels, wherein the signal level of the base station at the moment is maximal. As the distance from the base station and subscriber is increasing or in connection with the deterioration of propagation conditions the signal level is reduced, which leads to deterioration of the quality of communication. Improving the quality of communication is attained by automatically switching the subscriber to another channel. This occurs as follows. A special procedure called transfer call control or handoff allows the switch to free conversation channel with another base station within the range of which appeared at this time subscriber. Similar actions are being taken with a decrease in the quality of communication due to interference or if there is fault of switching equipment. If the signal level is less than this limit, information about this is transmitted automatically to the service switching center by the communication channel. After receiving the information from the base stations about the level of the signal, switching center switches the transceiver to the one where the greatest level of signal has appeared. This happens so quickly that the user did not notice these switches [9].

Professional systems are designed for the corporate user groups: ambulances, emergency, fire, Ministry of Emergency Situations, the police, etc. A mobile communication system with free and equal access of mobile stations to a common frequency band allows subscribers to work on any negotiation channel network



MS – mobile station;
BTS –base transceiver station;
TC – telephone channel;
SCC – switching center communications;
PSTN – public switch telephone network.

Figure 3.1 - A simplified structure of the trunking mobile communication system

Using a central organizing principle of an individual control channel determines the need for messaging through rendered transceiver (base) station. This disadvantage is eliminated in the pan-European standard trunking «TETRA», which provides direct connection mode subscribers without center. To do this, the mobile stations are built special microprocessors, allowing them to scan the programmed frequency network to transmit whenever the airing of its own code, log in and the local phone number.

The general trend of development of professional mobile radio systems is the transition from analog to uniform standards of international digital standards to protect the confidentiality and quality of communication, more efficient use of the frequency range roaming for all subscribers and the ability to transfer data at high speed.

Mobile communication system provides its subscribers with high-quality communication not only within a single area (city, state, etc.), but also on a global scale (country, continent). This mode of operation is called roaming (from eng. roam - to wander). To organize roaming requires that the system use the same standard or have special equipment that allows subscribers of different standards systems communicate with each other. [10]

According to the principle of organization there are three types of roaming:

- Manual - easy exchange of one means of communication to another;
- Semi-automatic when the subscriber must first register with the local operator;
- Automatic; provides subscribers with the ability to get in touch "at any time and in any place."

The first digital trunking system EDACS (Enhanced Digital Access Communication System) has been developed and implemented in the Nordic countries for the police service.

The transition to digital transmission techniques will provide:

- The simultaneous transmission of voice and data in a standard format of digital signals;
- Joint information transmission and control signals without mutual interference;
- Integration (at sufficiently low cost) with existing radio networks with newly developed;
- A consistently high level of intelligibility of transmitted speech messages in a whole range of the communication range;
- Reliable and technically simple protection of transmitted messages from eavesdropping;
- Continuous quality control channels of communication.

3.2 Advantages and disadvantages of trunked radio systems

Modern trunking communication system designed to build local and many regional networks that provide a variety of services and high quality communications. In particular, it supports voice communications between subscribers and groups of subscribers, access to departmental telephone networks and data networks (telemetry, alarms, digital data) [11].

Trunking radio communication has many advantages over other types of mobile communication systems, especially in production and processing, and corporate security systems. Experts called more than a dozen trunking systems advantages over other types of mobile communications:

- Instant connection;
- Minimal probability of a busy line (channel);
- Compliance with «Military» standard;
- The possibility to organize group or individual call;
- Administration prioritized;

- Provide radio communication with access to the local telephone network;
- Faxing and call forwarding;
- Continuous communication in the normal mode, the radio station;
- Fast deployment;
- The organization of independent dedicated networks;
- Protection against listening;
- Efficient use of the radio spectrum;
- Reliability;
- Centralized management system.

Group calls are used for simultaneously establish a communication session between all users belonging to this group. This is the fastest and most economical way to communicate with the management of crew and transport. Group call is made in the entire area of the trunked radio system, no matter what coverage area it has.

Administration with prioritized ensures regulated access to the public network with access to the local telephone network, the manager can restrict this right in its sole discretion (possible ban on any user of international, long-distance calls or even a ban on access to the city or the internal telephone network).

Radio stations can be provided with access to the public telephone network, and implemented a number of service functions such as dynamic re-form composition of groups, automatic roaming, call forward, digital paging, voice mail, and others.

To protect the transmitted information from unauthorized interception trunking protection is provided on two levels. The first - the technology organization session - communication channels are assigned randomly. Messages are transmitted on one of a plurality of channels, which is currently free. This makes it difficult to intercept, as it is necessary to control the broadband frequency range or time to switch to the desired channel. The level of system security can be further promoted by using digitally coded audio channels [12].

The second level is the use of special equipment (scramblers) for closing of the communication channel. Scrambler - an optional card that is inserted into the radio station to encrypt the transmitted and decryption of received messages.

Radio spectrum is a very limited resource that requires an economical and efficient use. The effectiveness of the use of the radio spectrum is dependent on two main factors:

- People are using all the channels of the system, there are no users assigned to work on a particular channel;
- Channels will never remain free if there is an urgent need for communication - a central controller immediately assigns a free channel on request.

Trunking communication system is highly reliable. Suppose that in the conventional channel radio system fails. All members of this channel cannot receive the connection until they are not switched to the other channel. Such a situation never occurs in trunked radio systems. If one or more repeaters fail, the central controller detects the failure and does not assign them to communicate as long as they will not be restored. As channels are assigned where necessary, and no groups of users depending on a particular channel, the failure of the relay will not substantially observed for the user.

Centralized management system based on the fact that the central controller, mobile and portable radios equipped with microprocessors. This allows very precise control of the entire system as a whole, to serve a greater number of users without the use of additional channels. A central controller allows managing the system centrally from one location.

Increasing the number of subscribers' trunking systems is an indicator of the business.

Disadvantages of trunking communication systems:

- The presence of small systems that are not connected with each other;
- The problem of choosing the frequency range;
- The problem of "twins";
- The problem of roaming.

3.3 Classification of trunked radio systems

Different trunking communication systems have a lot in common, and in some ways different from each other. Trunking system can be classified into several groups of symptoms [13].

Virtually all existing trunking communication systems can be divided according to the following parameters:

- A method of transmitting voice messages;
- The organization of access to the system;
- Method of (retention) of the channel;
- Network configuration;
- A way of organizing a radio channel;
- Appointment;
- The number of subscribers;
- Used protocols.

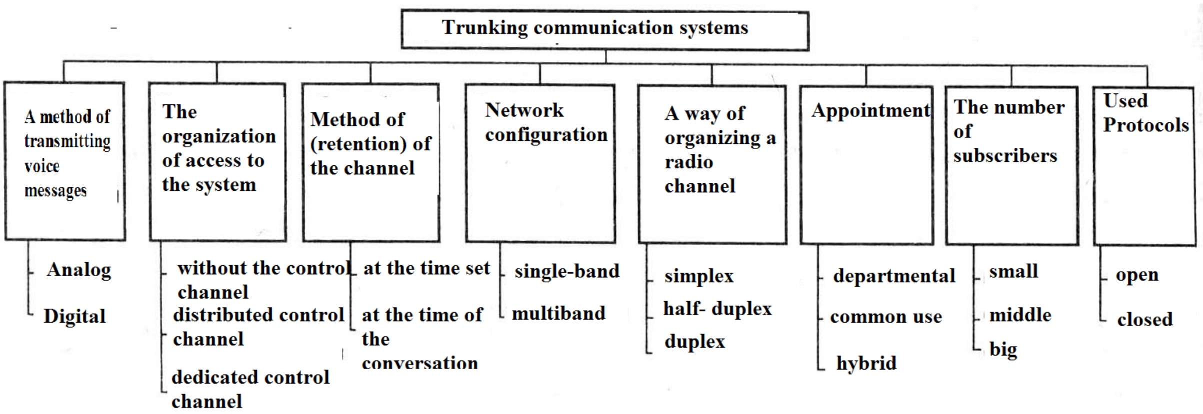


Figure 3.2 - Classification of trunked communication systems

The method of transmission of voice information

By the method of transmitting voice data trunking systems are divided into analog and digital. Speech transmission in a radio channel analog system is performed using frequency modulation, and the frequency grid is typically 12.5 kHz or 25 kHz.

For transmission of speech in digital systems use different types of vocoders, which converts the analog voice signal into a digital bit stream at a rate not more than 4.8 Kbit / s.

Number of zones

Depending on the number of base stations and a common architecture distinguish single site system and multi-zone system. The first have only one base station, the second - multiple BS with the roaming possibility.

The method of combining the base stations in multiphase systems

Base stations in trunking systems may be combined with a single switch (system with a centralized switching) and also connected to each other directly or via a public network (systems with distributed switching).

Type of Multiple Access

The vast majority of trunking systems, including digital systems, are using frequency division multiple access (FDMA). For FDMA system there is a relation "one carrier - one channel."

The single site TETRA system uses time division multiple access (TDMA). At the same time, the multi-zone TETRA system uses a combination of FDMA and TDMA.

A method of searching and channel assignment

By way of search and channel assignment distinguish the systems with centralized and decentralized management.

In systems with a decentralized management the free channel search procedure performed by subscriber radio stations. In these systems, the base station repeaters typically are not associated with each other and operate independently. A feature of systems with decentralized management is a relatively long time to establish connections between subscribers, increasing with the number of repeaters. This dependence is due to the fact that the subscriber station continuously forced to sequentially search the channels in search of ringing (which can come from any repeater) or freedom-foot channel (if the caller sends a call to itself).. The most typical representatives of this class of systems are SmarTrunk protocol.

In systems with centralized control list and assigning a free channel is performed at the base station. To ensure the normal functioning of these systems are organized channels of two types of workers (Traffic Channels) and a control channel (Control Channel). All requests for connection are sent on the control channel. According to the same channel, the base station informs the subscriber units on the appointment of the working channel, rejecting the request, or on the formulation of the request in the queue.

Type of control channel

In all trunking systems control channels are digital. Distinguish systems without a control channel with a dedicated frequency control channel and system with distributed control channel. In systems of the second type data transmission in the control channel is performed at a speed up to 9.6 Kbit / s, and for resolving conflicts using protocols such as ALOHA.

Dedicated Control Channel has all trunking system of MRI 1327 protocol, systems from Motorola (Startsite, Smartnet, Smartzone), EDACS system from Ericsson and others.

In systems with distributed control channel information on the status of incoming calls and distributed subchannels between low-speed data transmission, combined with all the working channels. Thus, in each frequency channel of the system, not only speech is transmitted, but also data control channel. To organize this partial channel in analog systems typically is used subtonal frequency range (O - 300) Hz. The most typical representatives of this class are the systems protocol LTR.

Trunking systems without a control channel.

In such systems, the radio station calling itself when looking for an unoccupied channel and takes it. Radio stations of this system are simple and cheap. These systems can be completely independent of BS channel from each other, because of their association in common TCP (trunking radio system) takes place at the subscriber radio station. However, such stations have a number of fundamental flaws. As the number of channels increases rapidly the duration of a connection in a system is also increasing. Really the duration of the search for a free channel calling station is added. In addition, there is a difficult implementation of many of today's requirements, including multi-zone, flexible and reliable system of priorities, setting to turn in the employment system or the called subscriber and etc. Thus, this type of radio is ideal as a small (1-8 channels up to 200 subscribers) single site communications system that meets the minimum requirements.

Trunking systems with distributed channel.

In such trunking systems of this type, control information is transmitted continuously on all channels, including the busy channels. This is achieved using for transmission frequencies below 300 Hz. Each channel is a control for the station assigned to them. In standby mode, the station listens to a control channel. In this channel BS continuously transmits the number of free channels that can be used for radio transmission. If on any channel begins transmission addressed to a radio station, information about this is transmitted on the control channel, causing the radio station switches to a channel where there is a call. These radios have a number of advantages with TCP to the control channel, without requiring the same time for a frequency allocation. In the LTR system a connection is so fast that it is carried out every time when turn on the transmitter stations, i.e. pauses in the conversation channel is not busy.

However, in case of failure of any channel in the LTR system fails all stations for which it is managing. Furthermore, TCP transmission rate control information is extremely limited. This hampers the implementation of many of the requirements for a modern TCP, including multi-zone. The transmission of information at frequencies below 300 Hz, simultaneously with the speech makes such systems very critical to the accuracy of adjustment. All this has led to the fact that TCP with distributed control channel is not currently developed. The only exception is ESAS, which uses the principle for the sake of compatibility with the LTR.

Trunking systems with a dedicated control channel.

For analog systems, it is a frequency channel, for digital systems - the temporary channel separation - a temporary rally. In these channels, radio station continuously listens control channel closest to her BS. When a call is received, the BS transmits information about it on the control channel, called radio station acknowledges receipt of the call, after which the BS allocates one of the conversational channel to connect and inform the control channel for all those involved in the radio connection. Thereafter, they are switched to a specified channel and remain there until the end of the connection. At that time, when the control channel is free, the radio stations can transmit to their connection requests. Some types of calls (for example, the transmission of short packets of data between radios) can be carried out without taking voice channel. TCP with a dedicated control channel is in the best modern standards. They are easy to implement a multi-zone (station selects BS with the best control channel) and other functions. Among them is a call on all in the employment system or the called party. This in turn results in such class of TCP systems failure at the employment class of systems with waiting. This not only increases the comfort of the user, but also, more importantly, increases the system capacity. In systems with a failure in the employment to ensure an acceptable quality of service at any time should stand at least one channel in order to the subscriber can make a call. In the systems with the expectation can be downloaded all channels. At the same time the caller will have to wait on line.

However, the allocation of a separate control channel has its drawbacks. Firstly, this is the worst use of frequency resources. In most systems, this disadvantage is mitigated by the possibility of transfer of the control channel in a conversational mode when the system is overloaded. Second, the dedicated control channel is a weak spot TSR- in the absence of special measures, equipment failure in a BS for this channel means the failure of BS. The appearance of interference in the frequency control channel receiver BS leads to the same. For this reason, the development of TCP with a dedicated control channel automatic control of the work equipment of BS paid a special attention. When a fault is detected or prolonged noise on the receive frequency the BS makes managing other defective channel.

Dedicated control channel provided by most modern standards on TCP - both private and public (MRT1327), as well as for radio stations with a prospective TETRA standard.

A way of keeping a channel

Trunking systems allow subscribers to keep the communication channel throughout the call, or only during transmission. The first method, also called trunking messages (Message Trunking), is the most traditional of communications, and always used in all applications of duplex communication or connection with PTN.

The second way is to hold the channel only during transmission and it is called transmission trunking (Transmission Trunking). It can be realized only by using half-duplex radio stations. In the last the transmitter is activated only on the time when there is a conversation phrases. In the pauses between the end of phrases per user and the beginning of the response phrases of other transmitters both radios are off. Some of the trunking systems effectively use such breaks, releasing the working channel immediately after the end of the transmitter subscriber station. To response replica working channel assignment will be made again, with the replica of the same conversation are likely transmitted by different channels.

The price for a more efficient use of the system as a whole, when using trunking transmission lead to decrease of comfort negotiations, especially during high load hours. Working channels to continue the conversation begun at these times will be provided with a delay of up to several seconds, leading to fragmentation and fragmentation call.

Organization of a channel

Simplex - radio communication in which one frequency is used for both reception and transmission.

Duplex - radio communication is carried out simultaneously on two frequencies. In one - the reception, and the other - the transmission.

Half Duplex - radio communication is performed using two frequencies transmitting and receiving, but compared to the duplex, not simultaneously but sequentially. The signal is received at one frequency and transmitted to the other. At one time the subscriber can be located either in the "receiving" or - "transfer" mode.

3.4 Architecture of trunking communication systems

Tracking systems are called radial-zonal systems of land mobile radio, performing automatic allocation of communication channels repeaters between subscribers. This is a rather general definition, but it contains a set of features that combine all trunking systems, from the simplest SmarTrunk to advanced TETRA [14].

Single-band system

Key architectural principles trunking systems easily viewed on a generalized block diagram of single site trunking system shown in figure 3.3. Infrastructure of trunking system is represented by the base station (BS), of which, in addition to the radio-frequency equipment (repeaters, the unit combining radio, antenna), also includes a switch control unit and interfaces to various external networks.

Repeater

Repeater (PT) - a set of the transmitting equipment serving one pair of carriers. Until recently, in the vast majority of TCS, one pair of bearing means one traffic channel (TC). Currently, with the advent of TETRA systems and EDACS ProtoCALL system, providing a temporary seal, one PT may provide two or four TC.

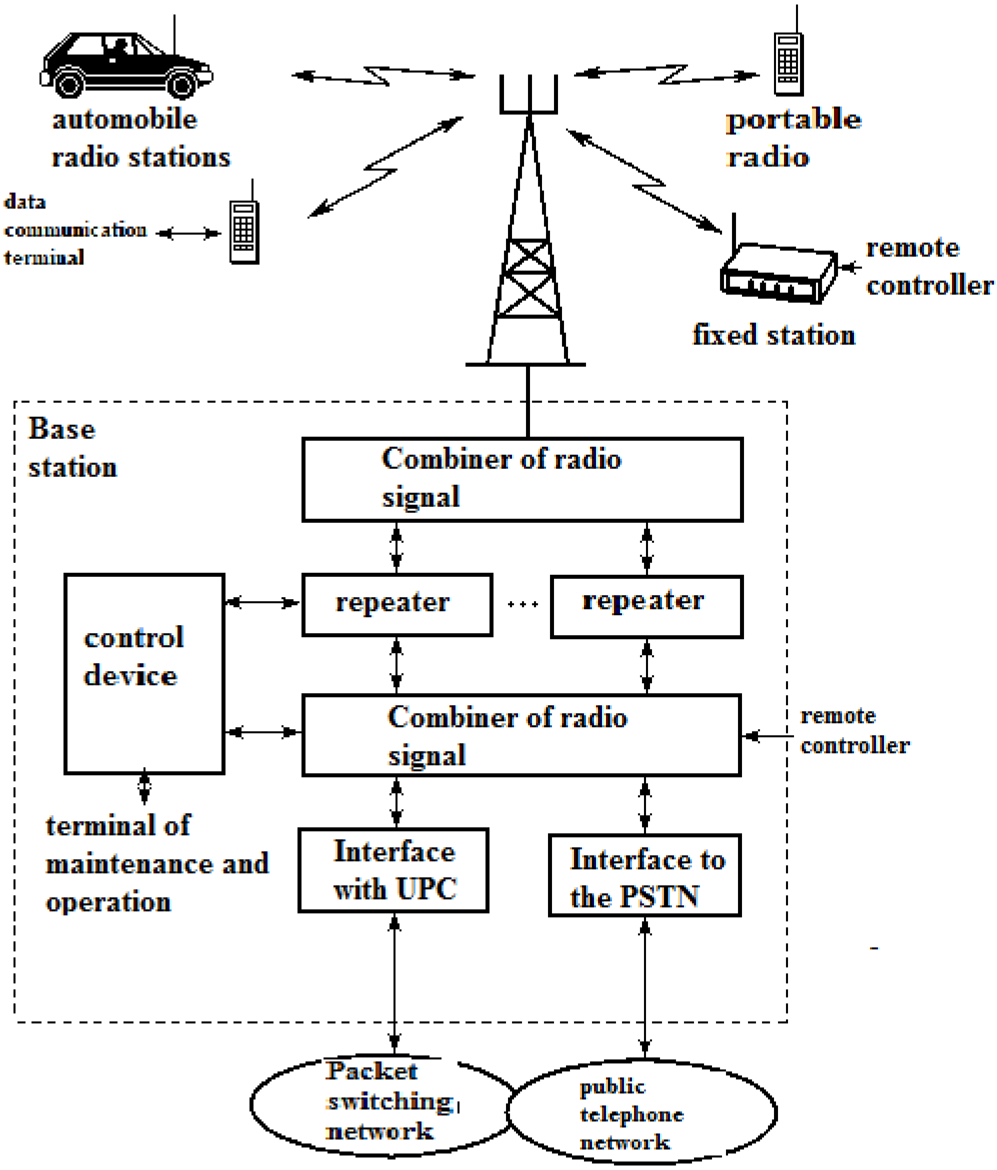


Figure 3.3 - Block diagram of single site trunking system

Antennas The most important principle of the trunking systems is to create a coverage area as large as possible. Therefore, the base station antennas are usually placed on high masts or structures and have omnidirectional antennas. Of course, when placing the base station on the edge the directional antennas are used. The base station may have as a single reception antenna, and separate antennas for transmission and reception. In some cases, one mast may be arranged a plurality of receiving antennas for combating fading caused by multipath propagation.

Combiner of radio signals can be used the same antenna equipment for simultaneous operation of transmitters and receivers on multiple frequency channels. Repeaters trunking systems only operate in full duplex mode, the frequency separation of transmission and reception (duplex spacing), depending on the working range and is from 3 MHz to 45 MHz.

Switch to single site trunking system serves all of its traffic, including the connection of mobile subscribers to the telephone network (PSTN), and all the challenges associated with data transmission.

Control device provides interaction of all units of the base station. It also handles calls, authenticates the caller (check "friend or alien"), queuing calls and making entries in the database time payment. In some systems, the control unit regulates the maximum duration of the connection to the telephone network. Generally, there are two regulation options: shortening of compounds predetermined peak hours or adaptive change of duration of the connection depending on current load.

PSTN Interface has trunking systems implemented in different ways. In the low-cost systems (e.g., SmarTrunk) connection can be made by a two-wire dial-up lines. More modern TCS are a part of the interface to the PSTN equipment direct dialing DID (Direct Inward Dialing), providing subscribers access to trunk network using a standard ATE numbering. Some systems use digital PCM connection with ATE equipment.

Terminal of maintenance and operation (TMO terminal) it is usually single site on the base station network. The terminal is designed for system monitoring, fault diagnosis, accounting information, changes to the database of subscribers. The vast majority of manufactures and develops trunking systems have the ability to remotely connect TMO terminal through the PSTN or PSN.

Control room Optionally, very characteristic elements of infrastructure systems are trunking dispatch consoles. The fact that the trunking systems are used primarily by consumers, whose work cannot be completed without the controller. These services are law enforcement, ambulance, fire service, transport companies and municipal services. Dispatch consoles may be included in the system by the subscriber radio channels or dedicated lines to connect directly to the switch of the base station.

It should be noted that in a single trunked system can be arranged several independent networks, each of which may have its own control room. Members of each of these networks will not notice the work of neighbors and, last but not least, will not interfere with other networks.

User Equipment of trunking systems includes a wide range of devices. As a rule, the most numerous are half-duplex radio, as they are best suited for use in closed groups. Most of these stations with a limited number of functions are have no numeric keypad. These users tend to have the ability to bind only to subscribers within its working group, as well as to send an emergency call to the dispatcher. However, this is quite enough for the majority of consumers of telecommunications services trunking systems. Also half-duplex radio with lots of features and a numeric keypad are produced, but they are being more expensive and intended for a narrow circle of privileged users.

In trunked systems, especially designed for commercial use, also apply talkie rather reminiscent of cell phones, but has much greater functionality compared to last. Duplex radio trunking systems provide users with a full connection to the PTN.

As for group work in a radio network, it is made in half-duplex mode. In enterprise networks trunking talkie used primarily for senior staff management.

As the half-duplex and full-duplex trunking radio stations produced not only portable, but also in the automobile performance. Typically, the transmitter output power car of radio stations is 3-5 times higher than in portable radios.

A relatively new class of devices for trunking systems is data terminals. In analog trunking systems, data terminals - a special radio that support the appropriate air interface protocol. For digital systems, more typically embed data interface to the subscriber stations of different classes. The structure of the car terminal data sometimes include satellite navigation receiver system GPS (Global Positioning System), designed to determine the current position and then transferring them to the remote controller.

In trunking systems are used as fixed stations, mainly for connecting dispatch consoles. Output stationary of radio stations transmitters is approximately the same as the car of radio stations.

Multi-zone systems

Early standards of trunking systems did not provide any mechanisms of interaction between different service areas. Meanwhile, consumer demands have increased significantly, and although the equipment for single site systems is still being produced and successfully sold, therefore all newly developed trunking systems and standards are multi-zone.

Architecture of the multi-zone trunking systems can be based on two different principles. In the event that the determining factor is the cost of equipment it is used distributed zonal switching. The structure of such a system is shown in Figure 3.4.

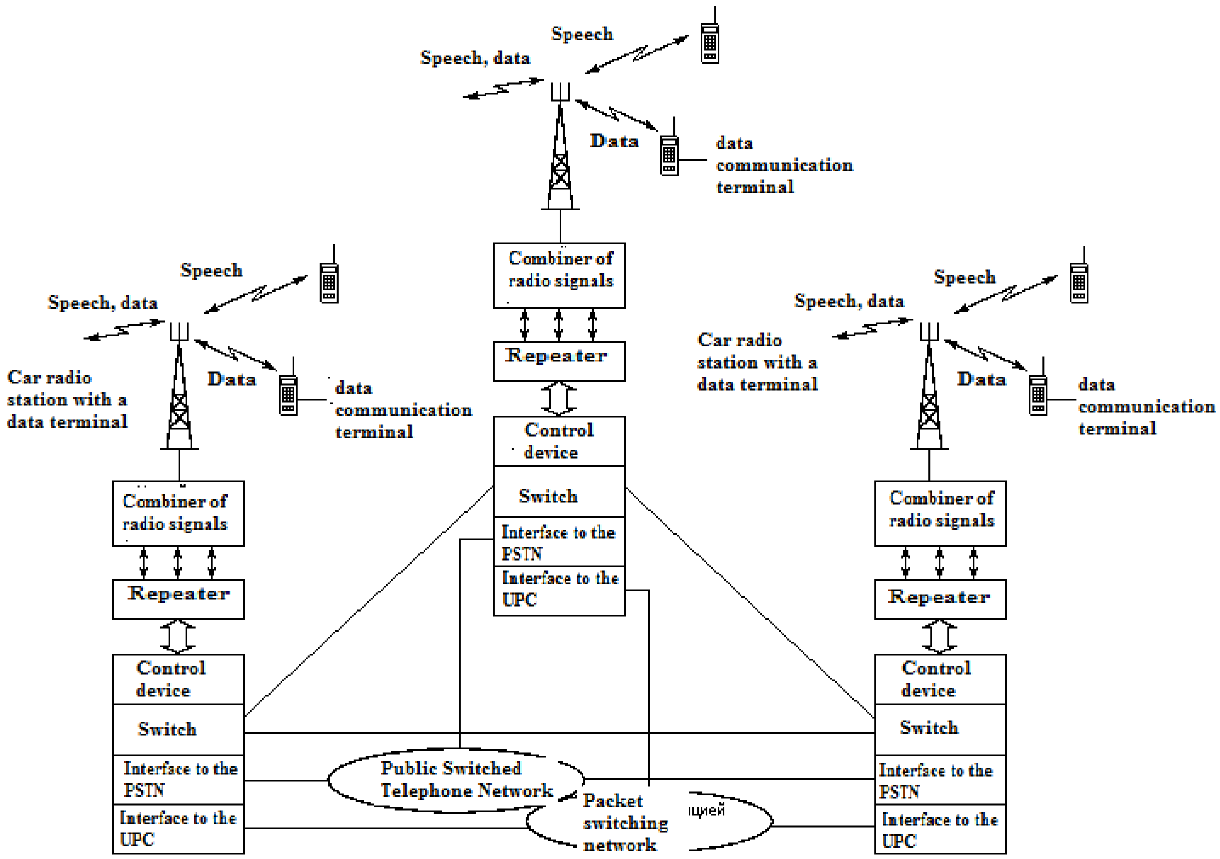


Figure 3.4 - Block diagram of trunk network with interzonal distributed switching

Each base station in such a system has its own connection to the PSTN. It is already enough for the organization of multizone system - if necessary call from one zone to another, it is made through the PSTN interface, including the procedure of dialing a telephone number. Furthermore, base stations may be directly connected via dedicated physical communication lines (often used small channel microwave links).

Each BS in such a system has its own connection to the PSTN. If necessary, a call from one zone to another, it is made through the PSTN interface, including the procedure of dialing a telephone number. Furthermore, the BS may be directly connected via dedicated physical links.

Using a distributed switching interzonal is advisable only for systems with a small number of areas and with low requirements for real interzonal calls (especially in the case of connection through the PSTN dial-channels). In systems with a high quality service used architecture with the MS. The main element of this scheme is interzonal switch. It handles all kinds of zonal calls, i.e. all interzonal traffic passes through one switch coupled to BS via dedicated lines. This provides faster processing of calls, the ability to connect a centralized CR. Information on the location of system users with the MS is stored in a single place, so it is easier to protect. In addition, the interzonal switch also performs the functions of centralized interface to PSTN and PSN, which allows to fully controlling the vehicle as the voice traffic and traffic of all applications DT associated with external PSN, such as the Internet. Thus, the system with the MS has a higher controllability.

Conclusion

So, there are several important architectural features inherent in the trunking system.

First, it is limited (and thus inexpensive) infrastructure. The multi-zone trunking systems, it is more developed, but still does not go to any comparison with the power infrastructure of cellular networks.

Secondly, this is a great spatial coverage of service areas of base stations, which is explained by the need to maintain the group work on large areas and requirements to minimize system cost. In networks where infrastructure investments quickly pay for themselves and the traffic is constantly growing, the base stations are placed more tightly, and the radius of coverage areas (cells) is reduced. When deploy trunking systems, everything is a little different - the volume of financing is usually limited, and to achieve a high efficiency of capital investments it is necessary to serve with a single set of base station equipment as possible a vast territory.

Third, a wide range of user equipment allows trunking systems to cover virtually the entire spectrum of corporate needs of the consumers in the mobile communication. Serviceability heterogeneous functional purpose devices in a single system - is another way to minimize costs.

Fourth, the trunking system allows on the basis of its channels dedicated organizing independent communication network (or, in recent years it also can say, virtual private networks). This means that several organizations can work together to deploy a single system rather than installing individual systems. This delivers tangible savings of radio frequency resources, as well as reducing the cost of infrastructure.

All of the above indicates the strength of the positions trunking systems in the corporate sector of the market systems and mobile communications.

3.5 TETRA trunking network standard

The system of TETRA standard (Trans- European trunking system) is a set of specifications developed by ETSI and determining the digital trunking communication system (TCS).

The TETRA standard is based on a GSM technical ideology. The TETRA standard includes two specifications: TETRA Voice + Data (TETRA V + D) and TETRA Packet Data Optimized (TETRA PDO). TETRA V + D - is the standard for integrated voice and data services, TETRA PDO - a standard that describes a special version of the TCS, focused only on the DT [15].

The air interface of TETRA involves working in a standard grid frequency of 25 kHz increments. Spacing for systems TETRA standard is 10 MHz. The radio channel used by the relative phase modulation π / 4-DQPSK type with constant envelope. Thus, each modulation symbol corresponds to the transmission of two bits of information. For speech conversion of TETRA V + D standard used codec CELP algorithm. Flow rate digital speech codec output is 4.8 Kbit/s. Prior to the input of the modulator is added to the speech flow correction code, and then made intergrain interleaving.

The total bandwidth of one channel in the standard TETRA V + D is 7200 bit/s. TETRA PDO standard provides DT of 28.8 Kbit / s. PD can be made on a "point to point" and "point-to-dot." In addition, the TETRA standard includes support for X.25 protocol for custom applications. The presence in the standard specifications for ISDN gateway and PDN provides interoperability with external systems data transmission.

TETRA standard specification does not impose restrictions on the architecture of the communication network. Thanks to modular design that can be implemented in a variety of network configurations with different geographical spread.

TETRA network standard requires distributed infrastructure management and switching, which provides fast transfer of calls and preservation of the local health system in case of failure of its individual elements. The main elements of TETRA networks are the base and mobile stations, the control unit of BS, BS controllers, control room (CR), terminals maintenance and operation (TMO).

The TETRA standard provides not only direct connection between the UT, it also can be used like antibodies as a repeater to extend the coverage area. TETRA system can operate in the following modes: trunking communication with open channel, direct communication.

In the trunking mode the served area is overlapping with BS coverage area. The TETRA standard allows building as a system with a dedicated control channel frequency of CC and distributed. When working with a dedicated communication network CC transceiver stations provide subscribers with more frequency channels, one of which (CC) specially intended for the exchange of service information. When operating with distributed network CC service information is transmitted either in a dedicated time channels (one of the 4 channels being organized into a single frequency), or in a control frame of multi-frame (one of 18).

Channels of communication might be allocated in accordance with the following methods:

1) Trunking messages. The channel is assigned at the beginning of the session and released at the end of it.

2) Trunking transmissions. The channel is assigned only one transaction at a time (the period during transmission / reception), after which it is discharged. For the next transaction may be allocated a new channel.

3) Kvazitranking transmission. Channel as well as in the transmission trunking is released after the transaction, however, with some delay, thus reducing the number of control signals.

In the open channel mode the user group has the ability to connect "one point to a lot of points," without the installation procedure. Any subscriber after joining a group may at any time use this channel. In this mode, radio station (RS) running in a two-frequency simplex. In direct mode (direct) connection between the terminals installed two- and multi-point connections over a radio channel not related to CC network without signaling through the BS.

In the TETRA standard systems the mobile stations can operate in a "Dual Watch» mode, which provides a welcome message from someone who works in both trunked and direct communication. The TETRA system supports voice and data.

Moreover, the speech and data are transmitted simultaneously from the same terminal on different logical channels. For voice service using a voice communication in order to provide the following modes:

- Voice communication with an individual subscriber call (dial-up point to point connection between the two MSC, or between the MSC and stationary terminal in order to provide direct two-way communication in duplex mode or two-frequency simplex);

- Multilateral voice communication, suggesting the group call subscribers (dial-multipoint bi-directional connection between the calling party and multi-caller using the simplex communication mode);

- Circular connection with the broadcast calls (one-way transmission of voice data from the calling party to several of the callers).

All modes provide for voice transmission as an open voice information and speech, and as protected by specific encryption algorithms.

The standard describes the following types of PD:

- PD with switched circuits. This type of transmission modes is similar to voice communications (two-point and multi-point connection, broadcast). Baud Rate is determined by the number of time slots allocated for the connection, and the class of error protection;

- Switched data packets. Broadcast on virtual circuits or in the form of datagrams. In the first case, only two-point connections, in the second - multipoint and broadcast connections;

- Short messages (up to 2048 bit). Transmitted promptly regardless of voice and data.

Trunking communication system provides users with a number of additional services:

- Call an authorized controller (mode in which the calls come only with the approval of manager);

- Priority access (in the case of network congestion available resources are assigned in accordance with a priority scheme);

- Priority call (call assignment in accordance with the priority scheme);

- Selective listening (interception of an incoming call without affecting the operation of other subscribers);

- Remote listening (remote activation of UR to transfer the situation to listen to the subscriber);

- The dynamic rearrangement (dynamic creation, modification and removal of user groups);

- Identification of the calling party (the possibility of obtaining information about the personal identity of the caller), and etc.

The TETRA standard provides two levels of security of transmitted information: standard, using the air interface encryption (provided the level of protection of information, similar to a GSM cellular communication system); High using through encryption (from the source to the recipient). Protective equipment for air interface of TETRA subscriber includes authentication mechanisms and infrastructure to ensure the confidentiality of traffic by flow aliases and specified data encryption. Certain additional protection of information provided by the ability to switch data channels and CC in the process of communication.

The functional circuits of the various trunking communication system of TETRA standard are represented as a set of network elements connected by certain-specified interfaces. The TETRA network contains the following main elements:

1) Base transceiver station (BTS) - provides a link to a particular area (a cell). BS performs the basic functions associated with the transmission of radio signals: the pairing with the mobile station, encryption of communication lines, space-diversity reception, control of power output of mobile stations, a radio link control;

2) The control unit BS (BCF) - an element of the network with switching capabilities, which operates several BS and provides access to external networks ISDN, the PTN, PDN, PABX, and is used to connect terminals DP and TMO;

3) BS controller (BSC) - a network element with large, compared with the device BCF switching capabilities to share data between multiple BCF. Just as BCF and provides access to external networks. BSC has a flexible modular structure allows to use a large number of different types of interfaces. In TETRA networks BS controllers can act as interface with other networks TETRA and management of centralized databases;

4) Control room - a device connected to the controller of the BS wireline and information-sharing between the operator (network controller) and other network users;

5) The mobile station (MS) - a radio station used mobile units;

6) The stationary radio station (FRS - Fixed Radio Station) - PC, used by the subscriber in a particular place;

7) TMO Terminal - terminal connected to the control unit (CU) and BCF base station designed for system monitoring, fault diagnosis, recording rating information, etc. With these terminals control function of LAN (LNM - Local Network Management) is implemented.

It is possible to centrally manage the network. The possible way of construction of such a network is shown in figure 3.5

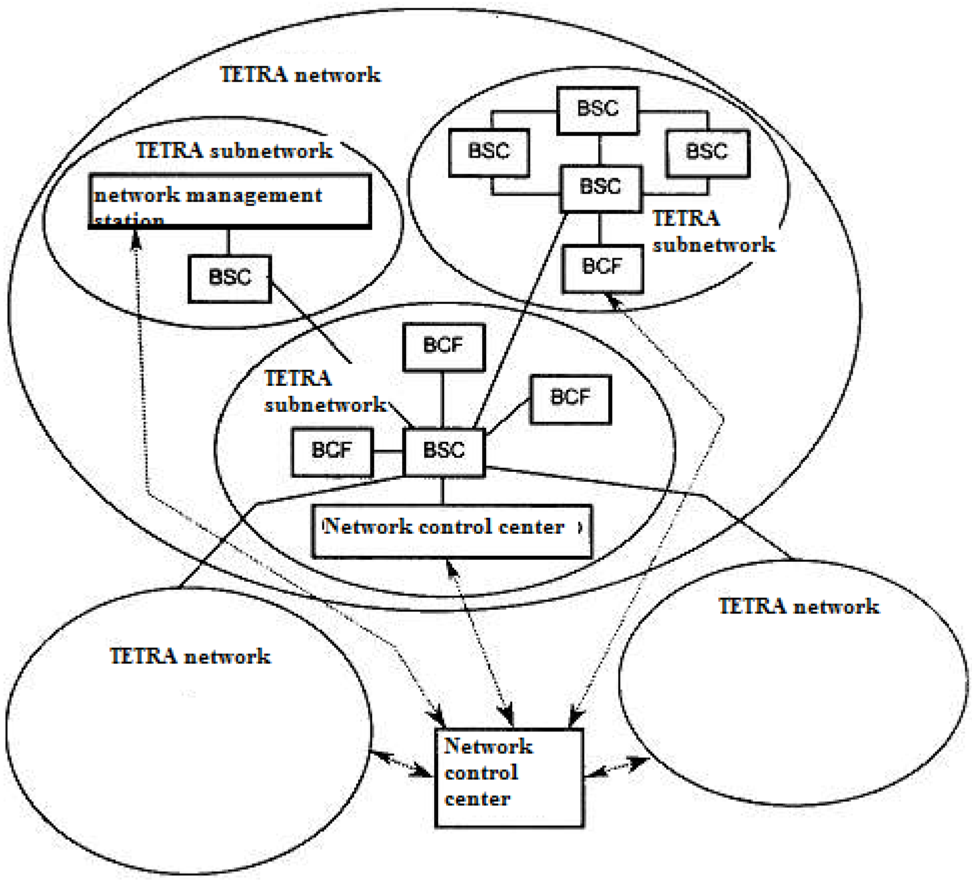


Figure 3.5- TETRA network structure

The modular design of equipment, TCS TETRA standard may be implemented with different hierarchical levels and different geographic extent (from local to national). Database management functions and switching are distributed throughout the network, which offers fast data calls, and the preservation of the limited network performance, even at a loss with regard to its individual elements.

At the national and regional level the network structure can be realized on the basis of relatively small TETRA subnetwork, connected to each other via inter-system interface ISI for creating common network.

Each TETRA subnet carries out the functions of management and switching, and provides the ability to centrally manage the network at higher levels. Subnet structure depends on traffic and performance requirements of communication.

In the TETRA standard trunking communication network provides various methods of providing resiliency to allow in case of failure of individual network elements retain full or partial operation, possibly with the deterioration of a number of parameters such as the time of connection establishment and etc. For networks at the national level tend to use several alternative routes to connect networks at the regional level by connecting BS controllers. In addition, in regional networks provide a mutual backup database in BS controllers.

In systems standard TETRA V + D TDMA method is used. On a single carrier frequency four voice channels is organized. Each frame has duration of 56.67 ms and comprises four time slots. A sequence of 18 frames forms a multiframe a duration of 1.02 seconds. One TDMA frame in multiframe is in control; 60 multiframes form a hyperframe.

Each time slot in the frame structure comprises of 510 bits of which 432 are information (two blocks of 216 bits). At the beginning of time interval radio user transmitted packet (RU) (control radiated power, 36-bit), followed by the first information block (IB) (216 bits), then - SYNC synchronization sequence (36 bits) and the second IB. Adjacent time slots divided guard intervals (GP) 0.167 ms duration, which corresponds to 6 bits.

Control questions:

1) Feasibility of trunking systems, why we need trunking systems.

2) List the advantages and disadvantages of trunked communication systems.

3) What standards of trunking systems do you know?

4) What the difference between single zone trunking system and multi- zone trunking systems?

5) Which of the multiple access methods used in TETRA standard?

6) The difference between the trunking systems "without control channel" from the system with a "dedicated control channel."

7) What is roaming, what kind of roaming you know?

CHAPTER 4

4 Satellite communication networks

4.1 Basic principles of satellite communication systems

Personal satellite communication systems have a number of advantages over previously considered mobile communication system. This type of connection is not limited in relation to specific areas of the Earth, as well as in many regions of the world demand for communications services can be satisfied only by means of satellite systems, for example:

- The transfer of information on a global scale;
- In the waters of the ocean;
- In areas with low population density;
- In places breaks ground infrastructure.

Depending on the type of services provided by the SCS can be divided into three main classes: speech (radio) communication; packet data (PDI); positioning (coordinates) of clients [16].

When telephone service in the SCS use digital messaging, thus must comply with international standards. In such systems, a delay signal on a line should not exceed 0.3 seconds and the user's call should not be interrupted during the communication session. Customer service must be continuous and occur in real time (RT). For this it is necessary to equip the satellite attitude control system for a high-precision retaining their antenna beam in a predetermined direction; the number of satellites in the system must be sufficient to ensure continuous and uninterrupted coverage service area; to provide enough communication channels should be used multibeam antenna systems. This requires a large number of nodes (gateway) stations (SHS) with expensive switching equipment.

System Packet Data (SPD) has a speed of from a few to hundreds of kilobytes per second. Stringent requirements for efficiency of message delivery usually do not show. In this mode the "electronic mail" (received information is stored on-board computer and delivered to correspondent at a predetermined time of day).

To determine the location of the subscriber used the standard navigation equipment GPS (Global Positioning System - Global Positioning System), which has a very high positioning accuracy of the consumer and the special equipment, which signals satellite personal communications and or loops to determine the coordinates of the consumer, but with less accuracy.

Based satellite Communications Company laid a fairly simple idea. The satellite is the active repeater PSCN. For a given orbit the satellite is moving for a long time, receiving power from the solar panels installed on its platforms or small nuclear power plants.

On the satellite repeater there is special antenna system and receiving transmission equipment, carrying out the reception, conversion processing (such as gain, changes in carrier frequency and so forth.) and the transmission of signals in the direction of earth stations (ES) - radio communication stations located on the Earth's surface intended for their own communication. The structure of satellite communication systems is present on a figure 4.1.

Mobile satellite communication systems are classified according to two criteria: the type of used orbit and differences in the areas of service and accommodation of ES.

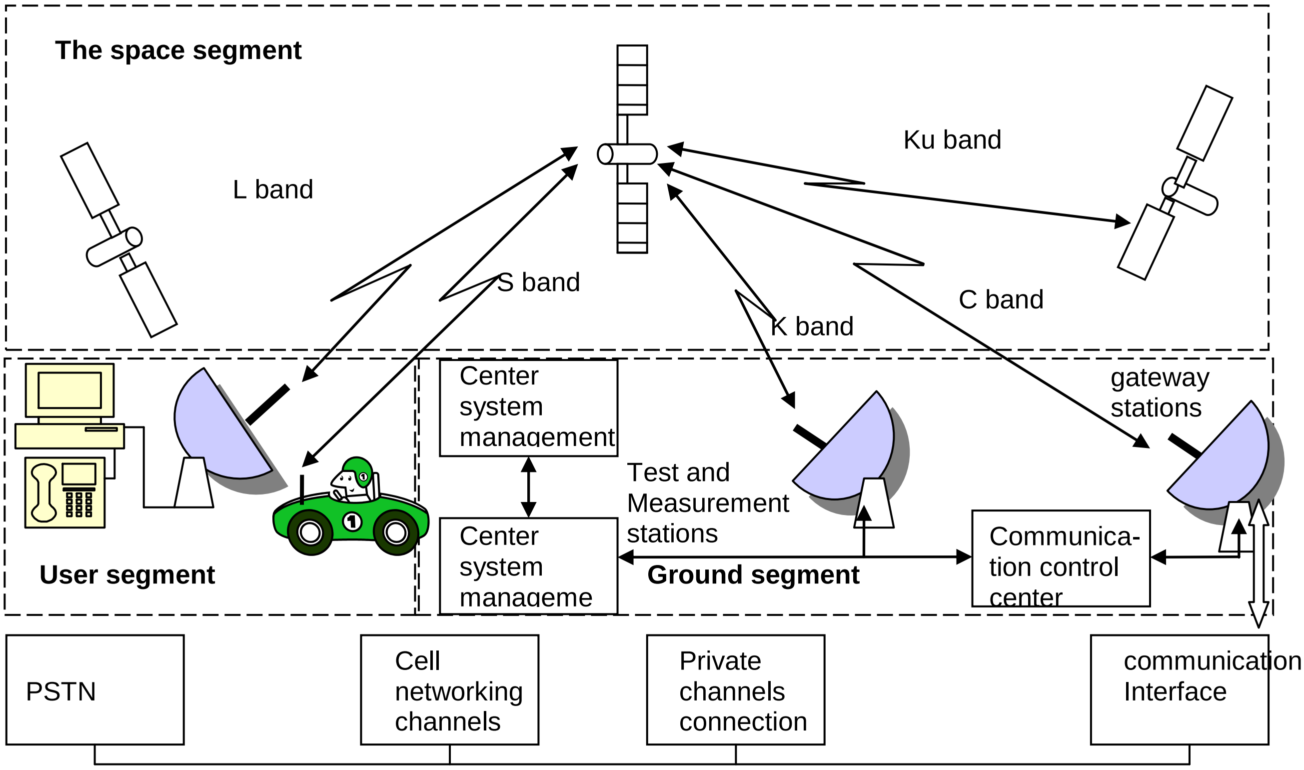


Figure 4.1 - Structure of satellite communication systems

Many important properties of SCS are directly dependent on the height and type of orbit spacecraft. The height of the spacecraft orbits is selected based on the analysis of many factors, including the energy characteristics of radio links, with the propagation delay, the proximity to the orbit of radionuclide of the Van Allen belts, size and location of the served areas. In addition, on the height of the orbit influence are way to communicate and requirements to ensure the required value elevation satellites. Technical issues related to the use of the frequency and location of the relay spacecraft on orbit, providing the absence of interference with each other, solved within the IRCC (International Radio Consultative Committee) and the IFRB (International Frequency Registration Board). For satellite systems are allocated frequency bands listed in Table 4.1.

Table 4.1 - Frequency bands for the satellite range.

Range	C	S	C	Ku	Ka	K
The frequency band GHz	1,452-1,500; 1,61-1,71	1,93-2,70	3,40-5,25; 5,725-7,075	10,70-12,75; 12,75-14,80	14,40-26,50; 27,00-50,20	84,00-86,00

4.2 Classification of satellite communication systems. Parameters and types of orbits

SCS system configuration depends on the type of artificial Earth satellite, communication type and parameters of the earth stations. For the construction of the SCS system used mainly three types of artificial earth satellites, shown in Figure 4.2, on a high elliptical orbit (HEO), the geostationary orbit (GEO) and low-altitude orbit (LAO). They are also used the medium-orbit satellites (MOS). Each type of artificial earth satellite has advantages and disadvantages [17].

An example of an AES with HIEO satellites can serve as companions of the "Lightning" with circulation period of 12 hours and an inclination of 63 °, an apogee over the northern hemisphere 40 thousand km, perigee - 500 km. The movement of the artificial earth satellite in the apogee is slowing down; with the duration of the radio coverage of 6 ... 8 hours. The advantage of this type of artificial earth satellite is a large size of service area coverage at high latitude subscribers. The disadvantage is the need for HIEO tracking antennas for the slow drift of the satellite and redirects them to the setting on the satellite uplink, in addition, quite pronounced Doppler effect.

The unique orbit of a geostationary orbit is a circular orbit with an orbital period of the artificial earth satellite of 24 hours, lying in the plane of the equator, with a height of 35,875 km from the Earth's surface. The orbit is synchronous with the rotation of the Earth so that the satellite is stationary relative to the Earth's surface.

Advantages of the GSO: coverage area of about a third of the earth's surface, three satellites is sufficient for almost global communication, there is practically no Doppler effect, earth station antennas require little or no tracking systems. However, in the northern latitudes the satellite is visible at small angles to the horizon, and is not seen in the polar regions, because of the great length of the track echoes arising from inconsistencies in points of transition from the 4-wire circuit for 2-wire, may pose a serious talk interference (required to use echo-layers).

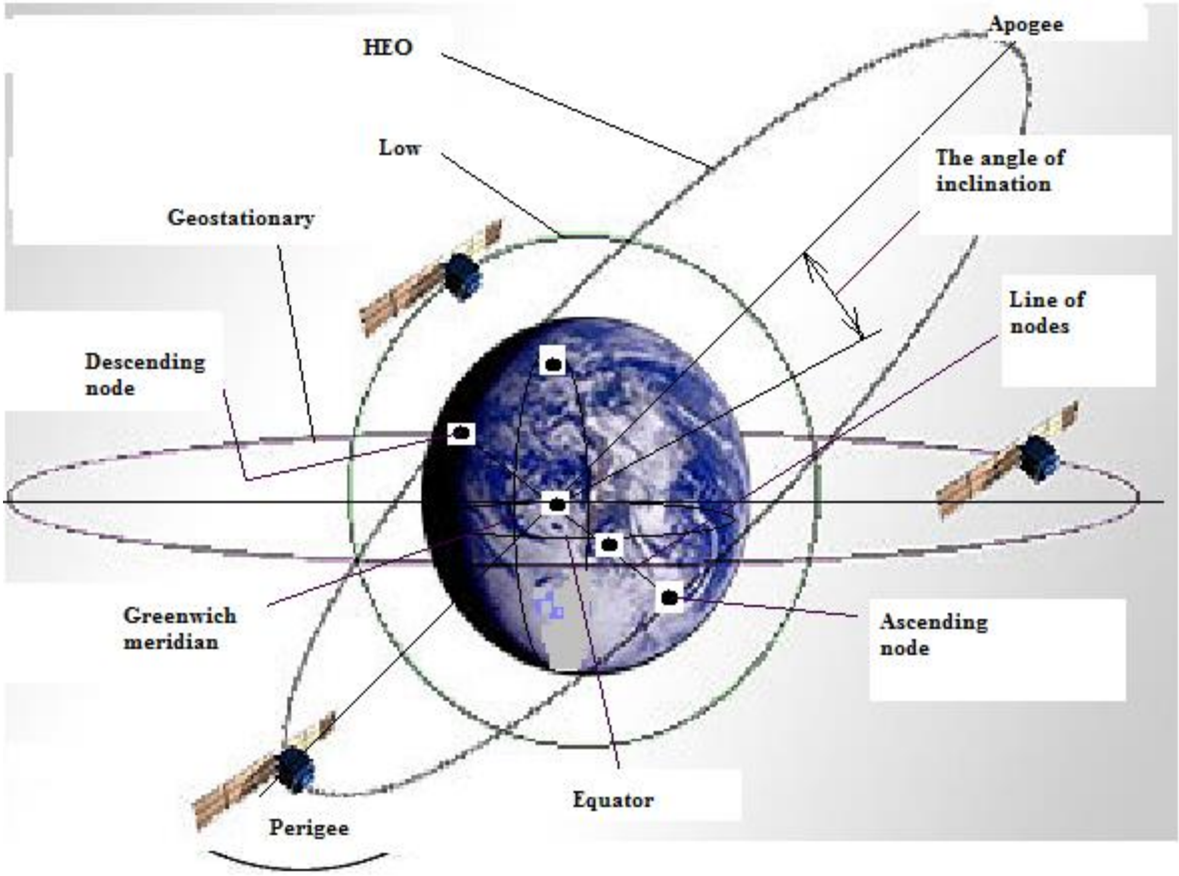


Figure 4.2 - Types of artificial earth satellite orbits

“Nizkolety” run on a circular orbit, the plane of which is inclined to the equatorial plane (polar and quasi-polar orbit) with a height of about 200..2000 km above the Earth's surface. Starting lung of artificial earth satellite in low orbit can be implemented using inexpensive launchers. However, the speed of the artificial earth satellite relative to the Earth's surface is large enough, as a result of the duration of the session from sunrise to its approach of the satellite does not exceed a few tens of minutes.

Operating frequency range of SCS systems regulated the ITU-R are different for plots of land-AES and AES-to-ground and lie in the range of 2..40 GHz.

For SCS systems, there are some features of signaling:

- Delay of signals - for geostationary orbits about 250 ms in one direction. It is one of the causes of the echo signals in telephone conversations;

- The Doppler effect - the change in frequency of a signal received from a moving source. For speeds much less than the velocity of light $v_r / c << 1$ change in frequency is $f = f_0 / (1 \pm v_r / c)$. The strongest Doppler effect manifests itself for the AES using non-geostationary orbits.

Characteristics of a number of orbits are shown in Table 4.2.

T a b l e 4.2- Features of orbits

Orbit type	GEO	MEO	LEO

Orbit height, km	36000	5000-15000	700- 1500
Number of spacecraft (SC) for continuous global coverage	3	8-12	48-66
The area of coverage of one in% ($\varepsilon = 5$ °)	34	25-28	3-7
The residence time of the spacecraft in the radio coverage zone, hour	continuously	1,5-2	0,2-0,25
Delay in the transmission of speech, ms	> 500	80-130	20-70
Elevation at the edge of the service area, °	5	25-30	10-15
Circulation period of the spacecraft around the Earth, min	1440	360	100

Depending on the purpose of the SCS and the type of earth stations ITU regulations differ in the following services:

- Fixed-satellite service for communication between stations located at specified fixed points, as well as distribution of television programs;
- Mobile-satellite service for communication between mobile stations, are placed on vehicles (airplanes, ships, cars and so on.);
- Broadcasting-satellite service for direct transmission of radio and television programs on the terminals located at the subscriber.

Fixed Satellite Service (FSS). At the initial stage of development, the FSS has developed in the direction of creating a system of main connection with the use of large earth station antennas with a mirror diameter of about 12..30 m. At present, there are about 50 FSS systems. Examples mention of the SCS "Molniya-3", "Raduga", "Horizon" and the international system of Intelsat and Eutelsat. Development of FSS is on the direction of increasing the life of the AES, increasing the accuracy of the AES on the orbit retention, development and improvement of multibeam antennas, as well as the ability to work on antenna earth station with a small diameter (m 1,2..2,4) (VSAT system).

The mobile-satellite service (MSS). Due to the international nature of transport for its management there is an international system of global satellite communication, for example, the Inmarsat system for marine satellite communications, which entered into force in 1982. Functionally, it includes geostationary satellites above the Atlantic, Indian and Pacific Oceans; shore stations on different continents and an extensive network of ship stations of different standards. Currently, the Inmarsat system is used by about 15,000 vessels. As part of the Inmarsat organization solves the problem of creating a system of aeronautical satellite communications.

Advances in space technology in recent years, as well as advances in microelectronics, the emergence of efficient algorithms for parametric companding speech signals, the development of the inter-satellite laser communication lines have aroused great interest in the use of light low-flying AES for MSS. Maintaining a large (tens of units) on LAO satellite groups to ensure continuity of communications is economically feasible due to the relatively low cost of the satellite on LAO and the ability to create small-sized systems with subscriber stations having an isotropic antenna.

There are two types of SCS with LAO. In the simplest of these packets of information are transmitted via AES relay immediately or with a delay of flight time on the track. The second type of system provides a continuous connection. Zones of radio visibility of individual satellites are combined into a single information space.

An example of how the system is operates is an international project Iridium, led by Motorola. The system is based on 66 light (weight 689 kg) AES, equally spaced at 6 polar orbits (11 AES in each orbit) height of 780 km, the plane of which are spaced at 30 °, but at the same phase of motion. Each AES is connected to four neighbors. The repeater operates on the multi-beam antenna with a number of rays 48, which enables to arrange in the system 2100 simultaneously active beams, i.e. create a cellular coverage area on the Earth's surface.

The system received multiple access time-frequency division multiplexing, for inter-satellite links and gateways provides bandwidth «K» 19..29 GHz subscriber lines for "Earth-AES" and "AES-to-Earth" - the use of two bands in the range frequency «L» 1610..1626,5 MHz. Iridium system will be able to cover up to 1.5 million subscribers. When a subscriber located in a coverage area of the cellular communication system is served by the system. When a subscriber leaves the coverage area of the cellular system, it is automatically switched to the service system SCS Iridium.

Broadcasting Satellite Service (BSS). BSS implements one of the main directions of development of telecommunications - personalization, i.e. TV programs is made directly to the individual receivers of subscribers. ITU approved the International Plan of satellite broadcasting in the range of 12 GHz (HTB-12). The plans are fixed points standing the AES in geostationary orbit, the numbers of frequency channels, and the parameters of onboard transmission equipment. For satellites CIS highlighted five points state: 23 °, 44 °, 74 °, 110 ° and 140 ° east longitude. It should be noted that because of the historical development of the existing technical it means that for the direct TV it also used a range of 11 GHz allocated to the FSS. [18]

By 1992, the HTB-12 was used in the world of more than 80 satellites, including TV-SAT-1, TV-SAT-2, TDF-1, TDF-2, TELE-X and others.

For a broad introduction of HTB needed multiprogramme satellites with dozens of programs in order to purchase a comparatively expensive receiving equipment user (audience) could dramatically increase their TV choice. In this context, it is relevant in the field of digital compression of television images, allows to send the same frequency trunk to 6..10 programs simultaneously.

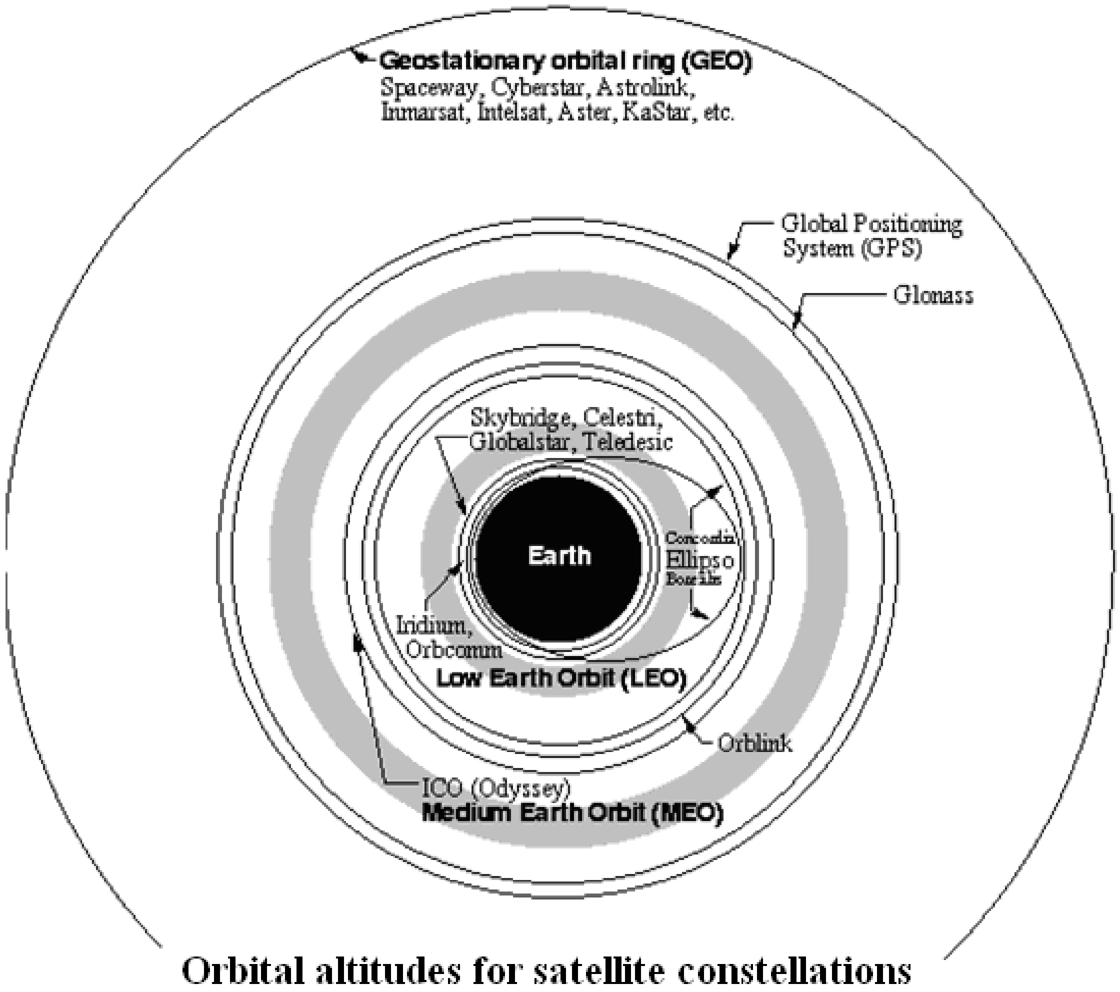


Figure 4.3 - The orbital altitude of the satellite constellations

Figure 4.3 shows the orbit: GO, MO, HBO and AES orbit satellite navigation systems: GPS (6 circular orbit at an altitude of about 20,000 km, an inclination of 55 °, with circulation period of 12 o'clock 24 satellites) and GLONASS (3 circular orbital altitude of 19100 km, inclination of 64,8 °, a period of 11 hours 15 minutes 44 seconds and 24 satellites).

Darkened color in the figure marked the radiation belts of the Earth's orbit is not arranged as belt adversely affect performance solar AES.

4.3 Inmarsat satellite communications system

Inmarsat - the first and the time-tested system for mobile satellite communications (it was created more than 25 years). Now the third generation of this system is operating. Four geostationary satellites provide coverage across the globe with the exception of the poles. The call from the terminal Inmarsat hits the satellite, which pulls it to the ground station (LES). LES is responsible for the call forwarding of telephone networks and the Internet. If there is area where there is an increased activity of subscribers, the satellite allocates some extra rays to work with the region. [19]

In addition to the standard telephone system, the system support equipment to track the location of the subscriber. The terminals of the Inmarsat-C standard are used for text messaging, as well as for monitoring of mobile objects (ships, cars, airplanes). The system is used to ensure the safety of navigation (GMDSS) and for air traffic control.

4.4 Globalstar satellite communications system

Globalstar - a global digital personal communications system based on the use of low-orbit satellites. In developing the Globalstar system was used experience in creating cellular communication systems with CDMA of QUALCOMM, Inc company. The set of services Globalstar system includes voice, data, fax, signaling personal radio (paging messages), and the coordinates of moving objects [20].

Globalstar system consists of three main segments: a space (spacecraft), ground and user.

According to the draft space segment consists of 48 AES and 4 main reserve located on 8 orbits - 6 major AES on each. Orbits - inclined, circular with an inclination to the equator - 52 °, which narrows the width of the service area of the system. Circulation period of the AES in orbit is 113 minutes. The height of the orbit is 1414 km. The high altitude of the orbit causes, on the one hand, greater coverage area of each AES and longer life of spacecraft (7.5 years), on the other hand - more delay and attenuation of the signal, the more expensive the satellite is in orbit.

The space segment is structured to provide the best service to users at mid-latitudes. It was in the mid-latitudes are available for at least two spacecraft. The width of the entire service area is limited to 70 ° north and south latitude. Therefore, in Antarctica, the North Pole, in some areas of the Northern Sea Route using the Globalstar system is impossible.

Globalstar AES is a repeater with frequency conversion, performs signal reception within the service area, conversion and transmission to the ground station. All processing operations of calls switching them signal conversion and separation channels are produced on the ground, where the implementation of these functions is less expensive; equipment is available for maintenance and can be upgraded over time.

The ground segment of the satellite mobile communications (SSMC) Globalstar consists of an earth station interface, command and control centers constellation (Satellite Operations Control Center) and ground-based (Ground Operations Control Center). The control center and control the orbital grouping based on telemetry data monitors the current status of the AES and the parameters of their orbits, if necessary, issue the commands. Center management and control of land resources is responsible for planning and resource allocation system, the control of its operation. The centers are located in the United States, and linked with other earth stations in the system using a special data network GDN (Globalstar Data Network).

When communicating mobile terminal the Globalstar first checks the opportunity to work in a terrestrial cellular network, and only if connection cannot establish via satellite. The signal from the user terminal (phone) is transmitted via satellite to a ground station near gateway that connects it to the desired party of regular telephone network, a cellular network or a subscriber of Globalstar. The operating principle of the system is shown in Figure 4.4. The maximum signal delay is not exceeding of 150 ms and the connection time - 5 seconds. World roaming will allow the subscriber to call on the same phone number, regardless of their geographical location.

The Globalstar system uses noise-like signal (NLS) and a combination of multiple access techniques, code (CDMA) and frequency division multiplexing (FDMA). This solves a number of problems and, above all, the problem of frequency reuses and improve throughput. In contrast to the narrow-band signals, strict requirements to the level of isolation between the beams in multibeam antenna the BS signals can significantly reduce the requirements for the junction between the beams. As a result, one can use the same frequencies and different wavelengths. At the same time it can be reduced requirements for electromagnetic compatibility with other systems operating in the same frequency band on a primary base. Another advantage of the BS signal is anti-interference capability in the form of reflected signals by adding them to the main signal in a multichannel receiver Globalstar.

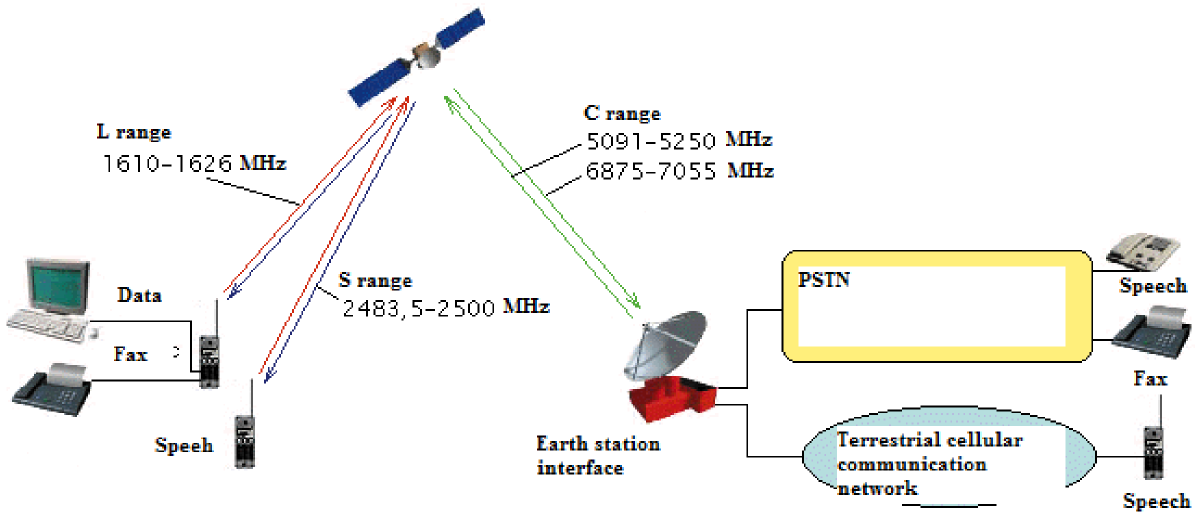


Figure 4.4 - the Globalstar system

Frequency reuse provides due to CDMA registration voice activity and use multibeam antenna whereby each AES is capable of simultaneous retransmission of about two thousands of telephone channels.

The total bandwidth allocated to the communication is 16.5 MHz in the L- and S-bands. In this band placed 13 frequency channels. The bandwidth of each channel is 1.25 MHz.

Within each frequency channel separation is performed by signal waveforms, i.e. line Walsh sequence. Total used for communication used 127- CDMA channels (Walsh sequences).

The system uses the following channels:

- A pilot channel. Transmission speed 1,2 Mbit / s. Modulation - QPSK;
- Sync. In the sync channel data stream is transmitted at 1200 bit / s. It contains the following information: the current time, the identification code of the SCS, the spacecraft ephemeris, paging channel schedule;
- Paging channel. Via transferred technological information needed to establish the connection (frequency identification code of the user, the local phone number);
- Direct information channel. The channel is for information transmission network subscribers of Globalstar. All subscribers use the same system and the same sequence, but with different (unique to each user) timing offset;
- Access channel. The channel is designed to transmit an interrogation packet length of 60 ms. Transmission rate in the access channel - 4,8 Kbit / s.

4.5 Thuraya Satellite Communications System

European Telecommunications Standards Institute (ETSI) and the US Telecommunications Industry Association (TIA) have jointly developed two sets of radio interface specifications for regional mobile communication systems based on geostationary satellites (Geostationary Mobile Satellite Systems, GMSS). Both these sets of standards are based on GSM [21].

These sets of specifications were named Geo Mobile Radio-1 (GMR-1) and Geo Mobile Radio-2 (GMR-2). As established on the basis of the specifications of the system using compact dual-mode (GSM / GMR) terminals, allowing roaming between terrestrial implement GSM-networks and satellite networks based on user preferences or geographical coverage of satellite networks.

GMR-1 air interface designed for the satellite system Thuraya, and GMR-2 air interface - for the Asian Cellular System (Asia Cellular System, ACeS) and Garuda 1 satellite.

Strong similarities on upper layer protocol systems GMR with GSM terrestrial systems allows integration into new systems standard of GSM service with maximum use of elements of the network infrastructure GSM, as a mobile switching center (MSC), movement registers (VLR), service centers of short message (SMSC) et al. The development Strategy GMR also provides the possibility of the evolution of the satellite system to the UMTS.

The specification GMR-1 introduced a number of methods to increase the efficiency of the voice channel via GSM, including improved modulation and improved speech codec with a low transmission rate. GSM standard supports eight full-rate speech channels per 200 kHz or 40 such channels on 1 MHz, and the GMR-1 - 256 speech channels on 1 MHz.

Space Segment Thuraya-1 has a reflector of L-band - 250-300 narrow beams (spot beam), digital beam-forming system (which provides dynamic coverage of the territory and its optimization in relation to changes in traffic) and more power. It provides the ability to connect two mobile terminals through a single satellite.

One point source of narrow beams is a satellite mobile communication, which allows synchronizing all of the control channels. It is very important to select and switch the narrow beams. Control signals cells in GSM-networks have different sources and asynchronous, that is taken into account in the design and protocol control channels GSM. To speed up and improve the accuracy of the choice of narrow beams, as well as to improve the effectiveness of a control channel in the GMR-1 uses a synchronization channel. Fast channel switching of GMR-1 is provided by the fact that they are always in sync.

Since the protocol architecture of GMR-1 is closely tied to GSM, GSM protocol improvements can be used in GMR-1. The most important step in the evolution of GSM is the inclusion in the standard of services based on packet switching protocol GPRS, EGPRS and protocols of 3rd generation.

GMR-1 system ensures fast positioning as the own funds and with the use of GPS. Features of GPS positioning reduce time from 90 s to 5 s or less.

Control questions:

1) Characterize the construction of networks of satellite communication systems.

2) What is the difference between low, mid and high orbital and communication systems?

3) What are the frequency bands used for satellite communication systems?

4) What is the main cause of losses in satellite communication systems?

5) What are the satellite communications systems do you know?

CHAPTER 5

5 Multiple access methods

5.1 Methods of multiple access signals and diversity

One of the main problems of building wireless systems is a solution to the problem of many users access to a limited resource medium. There are several basic methods for multiple accesses (also called sealing methods or multiplexing) based on the separation between the stations of parameters such as space, time, frequency and code. The aim of multiple accesses is allocate to each communication channel space, time, frequency or code with minimum interference and maximum use of the characteristics of the transmission medium [22].

Multiple access space division based on the division of signals in space, where each wireless device may transmit data only within a certain area (spatial domain) to any other device which is prohibited to transmit their messages. The easiest way to spatial separation is limitation of power transmitters.

Until recently, this method was considered to be ineffective - as long as a commercial development of the system, providing a sufficiently accurate localization zones of the actions of individual transmitters. With the advent of the equipment (and related standards), which provides an adaptive transmitter power restructuring subscriber and base stations, as well as systems based on tunable antenna radiation pattern, this method is widely used. A typical example of this system is a cellular telephone system with digital beamforming and etc.

In multiple access schemes with frequency division (Frequency Division Multiplexing - FDM), each device operates at certain frequency, whereby multiple devices can transmit data in the same area. This is one of the most known methods, anyhow used in most modern wireless communication systems. A typical example schemes FDMA - operation of several radio stations in the same area, but at different frequencies. However, their operating frequencies must be separated by a protective frequency interval, eliminates interference. This scheme, although many devices can be used in a certain area, in itself leads to unnecessary waste of scarce frequency resources is usually because it requires assigning a separate frequency for each wireless device.

Multiple access time division (Time Division Multiplexing - TDM) is more flexible. In this scheme, the channels allocated to the time, i.e. each transmitter broadcasts a signal at the same frequency, but in different time intervals (typically looped) under strict synchronization transmission process.

Such TDMA scheme is very convenient because the time slots may be dynamically reallocated between network devices. Devices with high traffic are assigned longer intervals than devices with less traffic.

However, the method of temporary seals cannot be used in purely analogue networks, even if the analog input data (e.g., speech), it requires them to capture and decomposition into packages. The rate for a specific package, as a rule, considerably exceeds the rate of transmission of the original digitized data. A typical example of the use of time division multiplexing (wired networks) is a method of transmission of telephone traffic through E1. At each nodal exchange analog telephone channel data stream is converted to a 64 Kbit / s (8 bits x 8 KHz sampling frequency samples). Fragments of 8 bits of the 32 channels (30 telephones and 2 services) form a loop. The duration of each cycle is 125 ms, respectively, the data rate - (32 x 8 bits) / 125 ms 18 Kbit / s (i.e. 2048000 bits / s). This stream is broadcast on the main channels and restored (de-multiplexed) on the receiving end.

The main disadvantage of systems with time division is a momentary loss of information at disrupting the synchronization channel, for example, due to strong interference, accidental or deliberate. However, the successful experience of the operation of such well-known TDMA systems such as cellular telephone networks of GSM standard, evidence of sufficient reliability of the mechanism of temporary seals.

Another type of multiple accesses is a code division multiplexing (Code Division Multiplexing - CDM). Initially, due to the complexity of implementation, the scheme has been used for military purposes, but over time has firmly taken its place in civilian systems. The name of a CDMA based mechanism for channel separation (CDMA - CDM Access) even called standard cellular telephony IS-95a, as well as a number of standards of the third generation of mobile communication systems (cdma2000, WCDMA, etc.). In this scheme all transmitters transmitted signals at the same frequency but with different base codes.

The principle of a code seal illustrates a situation where a lot of people in a room talking different languages. In addition, each person understands only one specific language. For each question in an incomprehensible language, it will be perceived as meaningless noise, devoid of useful information. And against the backdrop of the noise, he will perceive the flow of information in the language that he can understand.

In the CDMA scheme, each transmitter replaces every bit of the original data stream on CDM-symbol - code sequence length of 11, 16, 32, 64, etc. bits (called chips). The code sequence unique for each transmitter, wherein they are selected so that the correlation between any two CDM- code has a minimum (and, in some cases, to the autocorrelation CDM-code with a phase shift was also minimal). Typically, if substitutions in 1 source data stream using a CDM-code, 0 is used to replace the same code but inverted.

The receiver knows the CDM-code transmitter whose signals must accept. He constantly receives all the signals, digitizes them. Then, in a special device (correlator) performs convolution operation (multiply-accumulate) of the input digitized signal with a known to him CDM-code and its inverse. In a simplified form, it looks like a dot-product operation input vector and the vector with CDM-code. If the signal at the correlator output exceeds a preset threshold level, the receiver considers that adopted 1 or 0. In order to increase the probability of reception of the transmitter it may repeat sending each bit several times. At the same time signals of other transmitters with other CDM-code receiver perceives as additive noise. Moreover, due to the high redundancy (each bit is replaced by dozens of chips), the received signal can be compared with the integrated noise power. CDM-similarity signals at random (Gaussian) noise achieve using CDM-code generated by the pseudo-random sequences. Such code sequences known as noise-like, respectively, of the modulated signals - noise-like signals (NLS). It is obvious that the transmission through the NLS expanded range of the original message many times. Therefore, this method is called the method of spread spectrum by direct sequence (DSSS - Direct Sequence Spread Spectrum).

The strongest side of the seal is increased security and secrecy of data transmission: not knowing the code cannot get a signal, and in some cases detect its presence. In addition, the code space is incomparably more significant in comparison with the frequency compression scheme that allows without too much trouble to assign each transmitter its own individual code. The basic problem of the code seal until recently was the complexity of the technical implementation of the receivers and the need for precise synchronization of the transmitter and receiver for the guaranteed receipt of package.

Note that the seal code division - a synthetic technique, i.e. it is based on frequency or time compression techniques. In the most "pure" form of code compaction method is realized in the case of DSSS. In addition, they are known and used methods of spreading through the frequency and time jumps (or FHSS - Frequency Hoping Spread Spectrum and THSS - Time Hoping Spread Spectrum). In the case of spread spectrum frequency hopping means (yet it is called by the operating frequency of the pseudo-random adjustment - VRDP) in a given frequency band F simultaneously running multiple transmitters, each in a narrow band, many times at F. Central frequency of each transmitter during operation varies by discretely law, asked for a unique code sequence. The receiver knows the code sequence and tunable reception synchronously with the transmitter. The code sequences are selected so as to minimize the probability of simultaneous operation of two transmitters. This provides some protection against eavesdropping and interference. This method in some cases is quite effective and is used in particular in so popular today WNI technology as Bluetooth.

If the method of frequency hopping is a frequency division multiplexing method with the change of the frequency band, the method is similar to temporary surges temporary seal, only moments start broadcasting transmitter packages are not strictly periodic, but vary according to a pseudorandom. Typically, a code sequence determines the deviation of the start of the next broadcast packet from a predetermined period. Such a mechanism, in particular, is implemented in ultra wide communication systems with a spectral band of Time Domain.

Another important derivative method of code and frequency division is multiplexing mechanism through orthogonal carriers (OFDM - Orthogonal Frequency Division Multiplexing). Its essence: all available frequency bands is divided into a lot of sub-carriers (from a few hundred to a thousand). One communication channel (receiver and transmitter) is prescribed for the transfer of several carriers, selected from the entire set of particular law. The transfer is carried out simultaneously on all subcarriers, i.e. at each transmitter the outgoing data stream is divided into N subflows, wherein N - number of subcarriers assigned to the transmitter. Subcarrier allocation during operation can be dynamically changed, which makes this mechanism is less flexible than the method of time division multiplexing. Until recently, the spread OFDM technology held back the complexity of its hardware implementation. Today, however, with the development of semiconductor technology, it is no longer an obstacle. As a result, OFDM technique is becoming more widespread, particularly useful in popular standards of communication systems such as IEEE 802.11 a / g and DVB, and is also one of the main mechanisms of WVI regional broadband standard IEEE 802.16-2004.

Generally described scheme in wireless networks are used in combination with each other. For example, in GSM mobile networks are used simultaneously seals of SDM scheme, TDMA and FDMA, in systems of the IEEE 802.16 technologies are effectively combined OFDM, CDMA, FDMA / TDMA and SDM.

The above mechanism is a way of sharing a common resource on the transmission channels. However, these channels have yet to assign specific devices. Consider a few of the most popular schemes of distribution channel resources on the basis of TDMA technology (similar arrangements are possible with other methods of sealing).

The simplest algorithm for sealing TDMA scheme is a fixed timing between different devices. Distribution deals with the base station (central device), which reports to each subscriber unit transmission start time. Such a scheme is an ideal scheme for wireless networks, which have a fixed bandwidth. However, it is not optimal in case of irregular transfer, during the silence interval apparatus it cannot be used by another terminal. Therefore, the number of subscriber stations (or allowable transmission rate) essentially and substantially limited.

The opposite of this scheme is the mechanism for random access or classical scheme Aloha. The data transmission by the mobile device is not being used by an algorithm that would allow avoid collisions (two transmitters operate simultaneously at one time at a single frequency). This means that any device can transmit data at any time and there is no guarantee that the data will be successfully delivered to the recipient. This circuit is one of the earliest mechanisms for access for wireless communication systems. It was developed in the 70s in the University of Hawaii and used in ALOHANET network for wireless connection of several stations (university buildings, located on different islands of the Hawaiian archipelago). This scheme works well in networks with weak load, i.e. networks that have a small number of devices or transmit a small amount of information per unit time. The maximum system capacity is achieved at 18% load due to intensity of the Poisson distribution packet generation devices.

Improvement of the basic scheme was Aloha multiple access technique to the detection of a carrier (Carrier Sense Multiple Access - CSMA). The detection of the carrier frequency only means that the channel is listening by devices. If it is busy, i.e. another device is transmitting data, the transmitter proceeds to the standby mode until the time when the channel becomes free. This method can significantly improve the system capacity. As in the random access method, in this scheme does not require a central unit, i.e. each device decides to transmit independently. Since actual access to the environment receives that station, which was the first to transfer, this mechanism is called competitive access.

There are several versions of the CSMA scheme. If use an unstable CSMA scheme the channel listens to the station, and if the channel is free, it immediately begins the transfer. If the channel is busy, the station before re-definition of the state of the channel waits for a random interval, and then listens to the channel again. If the channel is clear, the terminal transmits data. The ρ-persistent of CSMA schemes nodes also define the state of the channel, but the data is transmitted with probability of ρ. The apparatus may delay transmission until the next time slot with probability (1 - ρ), i.e. the performed additional separation medium access. The l-persistent CSMA systems of all the stations that need to transmit data at the same time gain access to the media as soon as it is released.

Another variation of this method is CSMA / CA (CA - Collision Avoidance, conflict prevention), used in the wireless LAN standard IEEE 802.11. Here, after determining the channel idle timeout is randomly selected in a certain time interval. The specification HIPERLAN 1 uses a similar scheme: without priority multiple accesses with exclusion (Elimination Yield - Non-Preemptive Multiple Access, EY - NPMA).

Driving with digital detection (DSMA Digital Sense Multiple Access) uses similar to the CSMA / CA principle. This method is called multiple access detection suppression (Inhibit Sense Multiple Access - ISMA). The difference is that the channel occupancy determined not by listening of channel, but the base station by sending a packet in which the determined channel status. In this scheme, the base station must be synchronized with the transmitter so that the transmitter does not transmit data during the transmission of the channel status. If the channel is busy, the station is waiting for a random amount of time for transmission. As the number of stations can simultaneously transmit data, the central station sends a confirmation of receipt of the data packet.

In modern WNI typically use a combination of the mechanisms of central slot assignment methods and competitive access. In fact, the performance of these systems occurs in two stages. The first step is the reservation of resources (slots) for future transmission. At this stage all stations are making request (trying to make request) of their needs in channel resources. The second step is the direct transfer of data in a designated time interval. In these schemes it uses the central terminal with which synchronization is performed and the transmission is reserved. Typically, redundancy mechanisms results in longer delays in obtaining a package with a weak boot, but it provides a higher bandwidth.

An example of such a mechanism is a *multiple access scheme with the distribution of on-demand (Demand Assigned Multiple Access DAMA)*, also known as the Aloha scheme redundant. It is particularly useful in satellite communication systems. During a certain time interval, divided into mini-slots, all stations are trying to reserve for themselves the future time slots for data transmission.

However, due to conflicts on a backup stage, some stations cannot reserve channel resources. If the station is able to reserve a time interval, hence no other station cannot transmit at this time. Thus, the base station collects all successful queries (the rest are ignored), and sends back a list of specifying access rights to the subsequent time slots. This list is subject to all of the stations. DAMA scheme refers to a scheme with a clear redundancy when each slot is reserved for the transmission explicitly.

Redundant TDMA scheme differs from the previous scheme, because the reservation step is not based on concurrency, and the usual fixed TDMA scheme. Each device is assigned to a temporary mini-slot during which it reports, whether to transmit data. Therefore, at the beginning of each cycle, the base station transmits a packet divided into N intervals, each of which indicates that the channel is reserved or not. Followed by (N · k) for these intervals. This method ensures that each channel of the station is reserve with a certain bandwidth. Other stations can send data over intervals that no one has reserved, but on the principles of competitive access, and there is no guarantee of packet delivery.

Scheme with redundant of packets (PRMA - Packet Reservation Multiple Access) is an example with hidden redundancy as implicitly reserved intervals. The central unit at the beginning of each cycle sends out a list of timings. The very same reservation is made for a different scheme. Imagine that need to transfer data to any device, but there is not reserved time slot. This device regularly receives a list with the reserved slots. For example, in the resulting list shows that the third, fifth and eighth slots are reserved, i.e. free. The device randomly decides in which range user can try to transfer the data. For example, the device transmits a fifth interval, if the transfer is successful, the device receives this confirmation. The base station reserves the channel for the new device, and includes it in its list. If a request has not reached the base station, the device should try again to send the data in one of the empty slots.

5.2 Multiple accesses based on code division multiplexing (CDMA) system and a direct spread spectrum rearrangement operating frequency

5.2.1 CDMA: principles of operation.

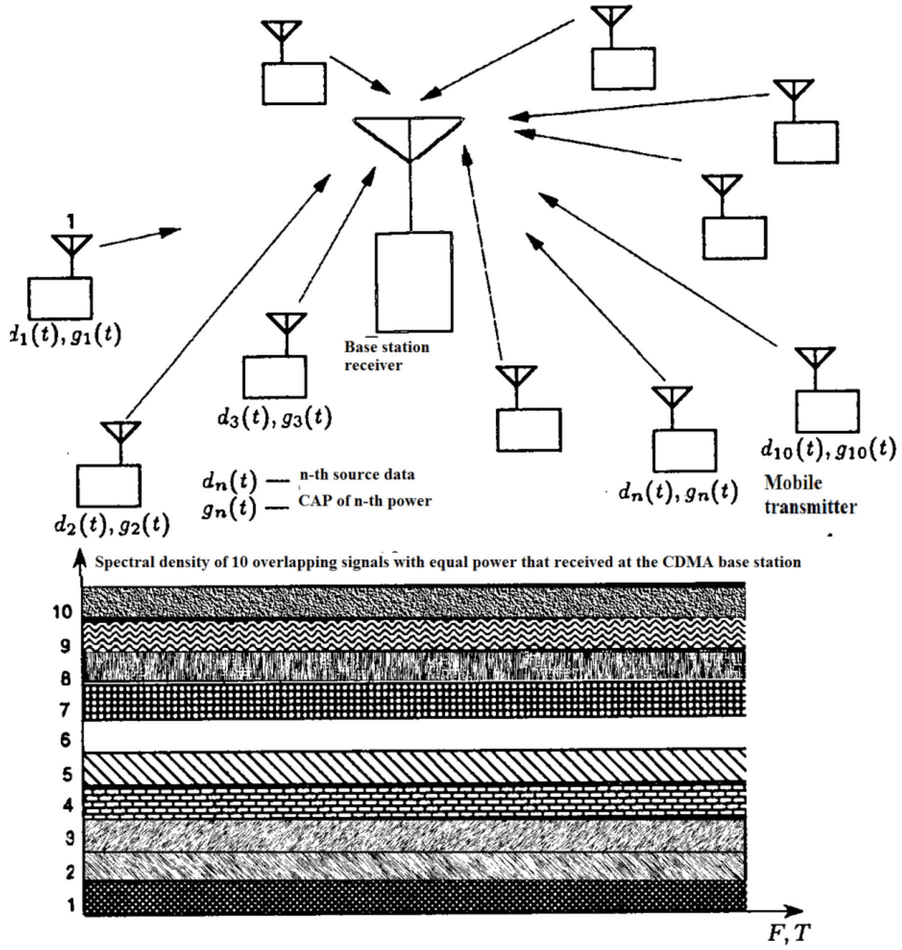


Figure 5.1 – Using of sharing spectrum in CDMA

Multiple access systems based on code division multiple access systems are a development of the direct-spread with a pseudo-random sequences, and spread-spectrum systems by tuning the operating frequency. In a CDMA system, each user is allocated a separate, different from the other PS. If these PS are mutually uncorrelated, then within one cell to the K independent subscribers can send messages simultaneously occupying the same RF bandwidth. At the receiver, signal processing is carried out correlation (despreading), resulting in the recovery of transmitted messages di (t) = 1 ... K. The figure 5.1 shows the concept of spectrum sharing in a CDMA system with K = 10 carriers. If assume that K = 10 mobile transmitters transmit simultaneously, the receiver input of the base station will be present 10 signals overlapping by time and frequency [22].

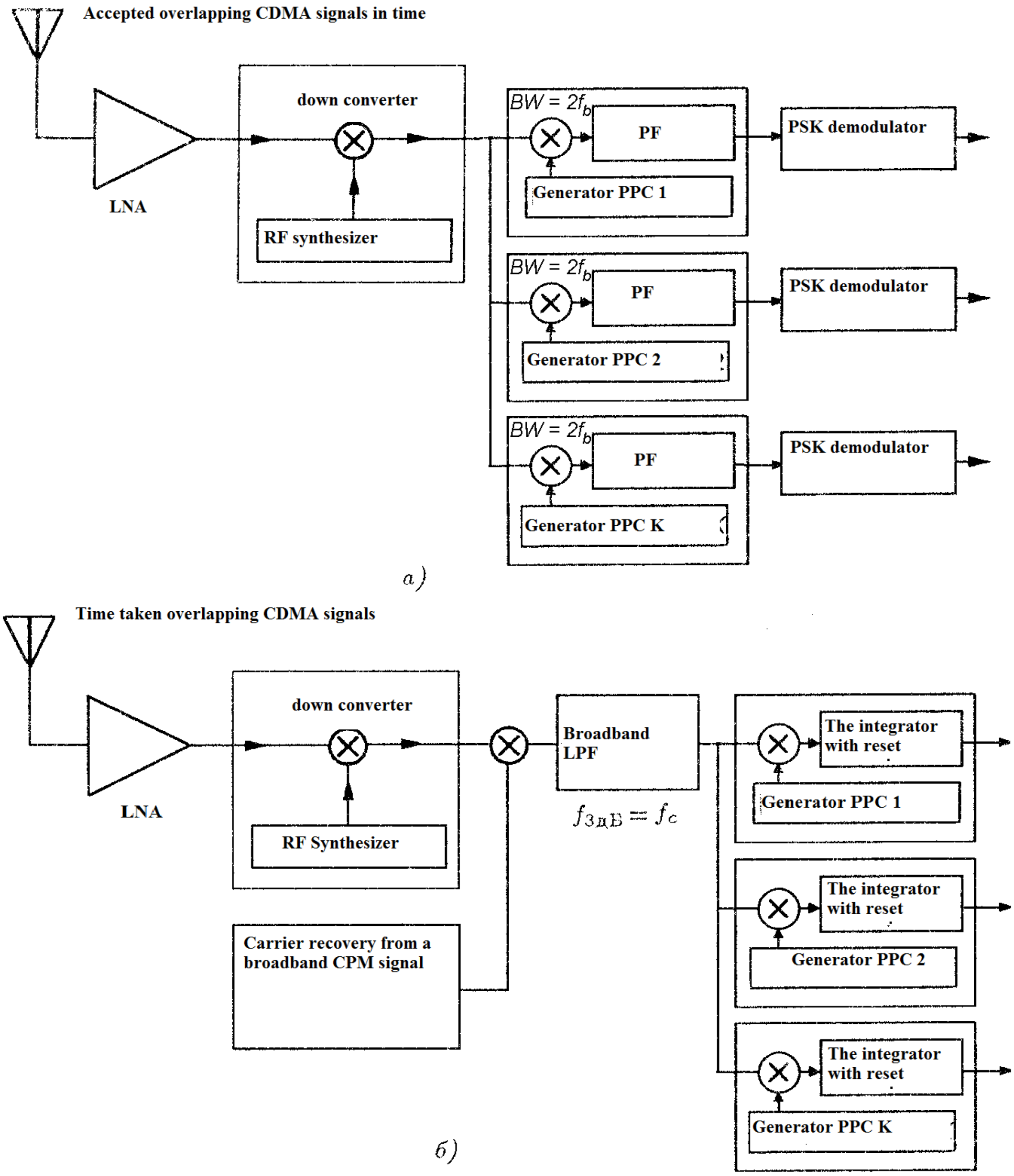
The same can be said for the mobile station receiver. If the power of the received signals considered equal to Ps and only one useful signal interferes with the other nine CDMA signals of equal power, the signal to noise ratio (C / I) nA RF input of the receiver will be equal to 1/9 or (C / JT) = -9 54 dB. This negative value of the signal / noise caused intersystem interference generated by the other nine-carrier direct spread simultaneously occupy the same frequency band as the desired signal carrier. As a result of the correlation processing (despreading) is a negative ratio carrier / interference (C / I) over a broad band of frequencies is transformed into a positive value of the signal / noise (S / I) in a narrow band baseband. The signal / noise ratio in the baseband should be high enough to guarantee the achievement of relatively low values of Re. The value of the signal / noise (S / I) in the baseband signal selected by several dB higher than the signal / noise ratio (S / N).

During the same time interval K users simultaneously transmit signals with the direct spreading occupy the same radio band with a center frequency fo and have random phase φi, statistically independent from phases of other users. Each mobile transmitter has a unique PS of spreading gi (t). Assuming the existence of an ideal adaptive adjustment of the power, at the input of the base station there are K radio signals that is present with equal power Hs [24].

Each user sends a message to about the same speed, and the frequency of the characters fb PS supported approximately constant. At the base station receiver input is present the total RF signal defined by the expression:

$$v(t) = \sum_{i=1}^{K} \sqrt{2P_s}\, g_i(t) d_i(t) \cos(\omega_0 t + \theta_i)\,. \tag{5.1}$$

The base station receiver must perform dispreading of signals and demodulating of K independent signals with direct spreading. For this purpose uses K correlation, as shown in Figure 5.2. In essence, the CDMA receiver comprising a set of correlators and presented on Figure 5.2 and is an expanded version of the receiver. In this embodiment, despreading is carried out at an intermediate frequency (IF). Another version of the receiver is shown on a Figure 5.2 b.



a - correlation processing is performed first, and then narrow-band demodulation;

b - wideband demodulation is performed first, and then despreading the signal.

Figure 5.2- The construction of CDMA receivers

Summary of the RF signal is converted in frequency down to a convenient intermediate frequency of, for example, 70 MHz, and is demodulated by a common broadband coherent demodulator. The bandwidth of the low pass filter of the demodulator is chosen sufficiently broad and consistent with the symbol rate f_o.

The following equations are valid for both embodiments of the receiver shown in Figure 5.2. The output of the demodulator of the receiver signal is shown in Figure 5.2 a, with the inclusion of low pass filter integrator, built into PSK demodulator is determined by the following expressions:

$$v' = \sum_{i=1}^{K} \sqrt{2P_s}\, g_1(t) g_i(t) d_i(t) \cos(\theta_i - \theta_1), \qquad (5.2)$$

$$v' = \sqrt{P_s}\, d_1(t) + \sum_{i=1}^{K} \sqrt{2P_s}\, g_1(t) g_i(t) d_i(t) \cos(\theta_i - \theta_1). \qquad (5.3)$$

These expressions are similar to the expression defining the output of the receiver to direct spread baseband frequencies, except for the additional (K - 1) interference components:

$$G_J(f) \approx (K-1)\frac{P_c}{4f_0}, \quad |f| \le f_b. \qquad (5.4)$$

If take the total interference power equal to

$$P_J = (K-1)P_s, \qquad (5.5)$$

The error probability P_e when exposed to "self-interference" K-1 produced simultaneously received signals with equal power will be determined by the expression:

$$P_e = \frac{1}{2} erfc\left(\sqrt{2\frac{1}{K-1}\frac{f_0}{f_b}}\right), \qquad (5.6)$$

Where f_b – transmission speed;

f_0 – symbol rate.

From the results it follows that for a given value of P_e for a fixed number of users K need to carefully match the baud rate f_b and the frequency of the symbol PS f_0.

As for the expression (5.6), it is necessary to note the following assumptions have been made in its derivation:

a) The received signals from the direct spread have equal power and formed using uncorrelated PS. Equal power suggests an ideal adaptive power control.

b) Consider the impact of just-interference and do not consider the impact of thermal noise.

5.2.2 Problems of interference from closely spaced and remote users in systems with direct spread.

In systems with direct spreading all communications channels (traffic channels) within the same cell at the same time share the same radio frequency band, i.e. radio channel. Neighboring cells may use either the same or adjacent frequency channels. Some of the mobile object may be positioned close to the base station, and - the other far away. Strong signal received by the base station from nearby mobile unit, will mask the weak signal received from the remote mobile unit. For example, assume that all 10 moving objects shown in Figure 5.1, transmit signals to one and the same RF power Ps = +30 dBm, the propagation loss of radio waves from a remote mobile unit 10 constitute a number of 95 dB, and a similar loss from nearby Object number 4 make up only 35 dB. In this case, the power of the signal received at the base station of the mobile object number 4 is equal Rpr4 = + 30 dBm - 35 dBm = -5 dBm and the received signal power of remote mobile unit number will be equal to 10 Rpr10 = 30 dBm - 95 dBm = -65 dBm. Thus, in-band noise power generated by nearby objects will be 60 dB higher than the received power from the remote mobile unit. Interference of this kind is a serious problem in the design and use of CDMA systems.

Equation (5.4) establishes a mathematical relationship between the frequency of the symbols f_0, transfer rate, and a predetermined value of f_b and given value P_e for K simultaneous users. In the derivation of this expression it was assumed that all signals received at the base station have the same capacity. The requirement for equal capacities substantially maximizes capacity of CDMA systems.

5.2.3 The adaptive power control in CDMA spread spectrum systems.

Power management can reduce the level of "near-far" interference. Perfect power control scheme provides equal power of all signals received at the base station moving objects that are located in the cell, regardless of the displacements, the propagation loss of radio waves and the location of the mobile object.

The straight line in a CDMA system is a communication link between the base station and the receiver of the movable object. Reverse link - the communication link between the mobile unit and the base station receiver. In the case of open-loop transmit power control (TxRS) transmitted analog or digital pilot signals in a straight line. The measured level of the received pilot signal enables the mobile unit to estimate the propagation loss of radio waves from the base station transmitter to the receiver of the movable object. The evaluation of losses on the movable object generated transmit power control signal and sets the required transmitter power. This procedure is repeated with the required duty cycle, and thus achieved an adaptive control with open loop. It is assumed that the propagation loss in the forward and reverse radio links are the same. However, control with open-loop may not always provide sufficient accuracy and quality. The best performance has a scheme with closed loop control TxRS (see. Figure 5.3, 5.4, b).

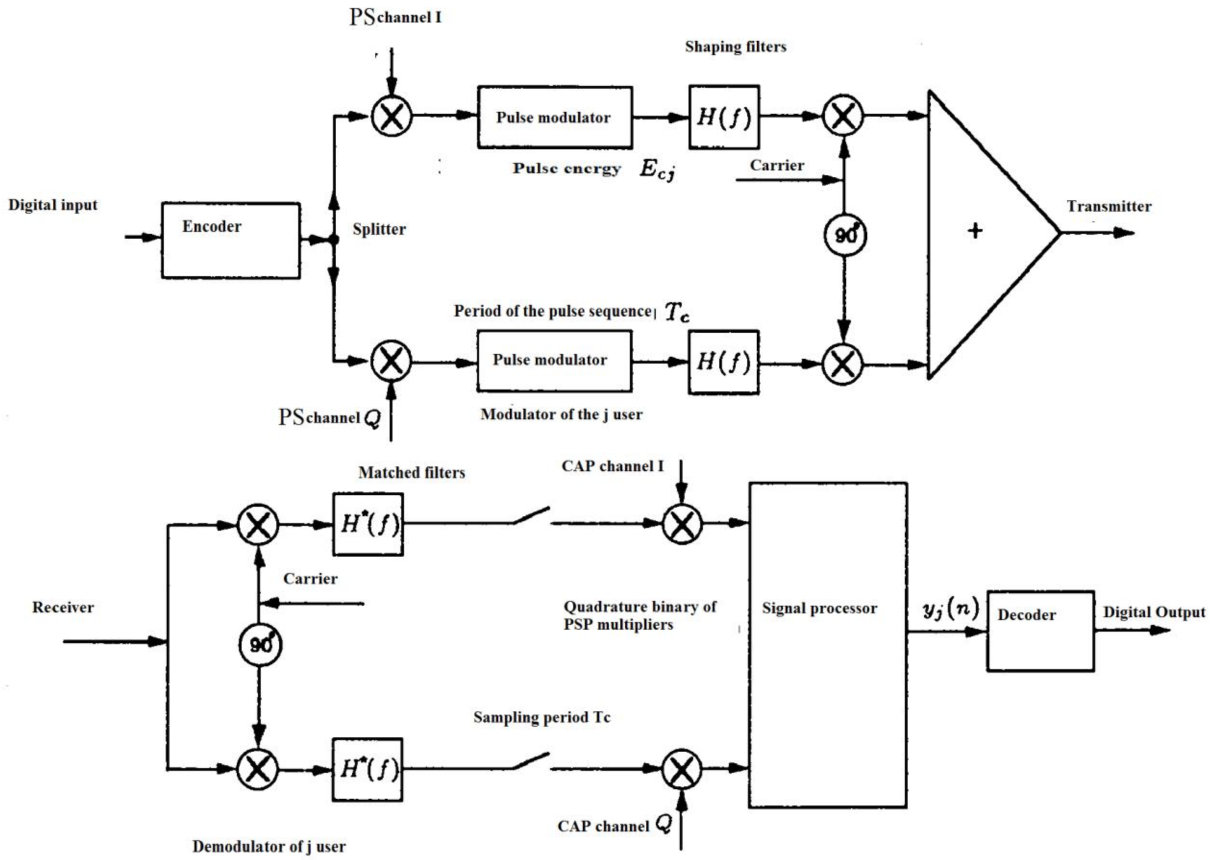


Figure 5.3- Block diagram of a CDMA cellular system communication IS-95 standard

Here, adaptive power control is performed in the following sequence:

a) In the base station receiver is made (using reverse radio link 1) Evaluation of RF power, received from the mobile unit (see Figure 5.4);

b) From the base station (straight line 2) on the mobile unit transmits the command control to ensure that the installation of the required transmit power level of the mobile object (see Figure 5.4).

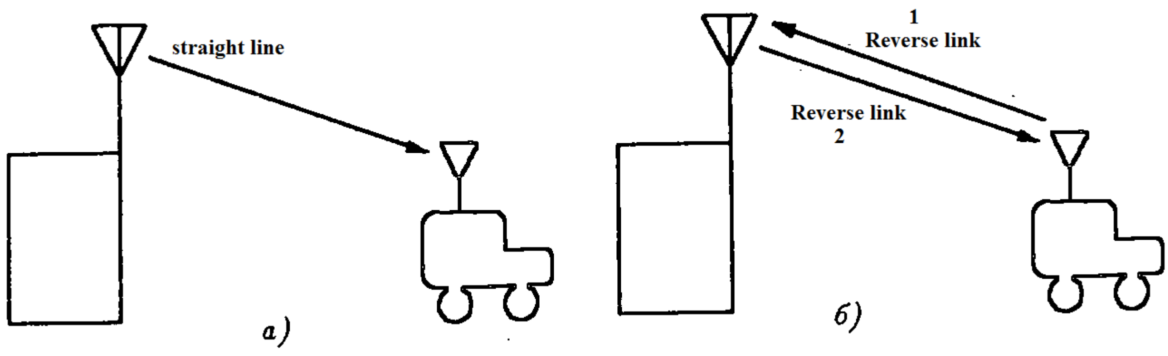


Figure 5.4- Transmit power control using an open (a) and closed (b) loop

The real accuracy power control with a TxRC closed loop is 1.5 dB. Ideally, it should be equal to 0 dB. This means that all the signals transmitted from different moving objects should be taken with the same power, i.e. the difference between their levels is 0 dB. This allows to solve the problem of a subject close and remote users and to optimize (maximize) the capacity of CDMA cellular systems.

Control questions:

1) What are all the methods of separation and briefly describe them.

2) What is the difference FDMA, TDMA, CDMA?

3) Expand functioning principles many station access based on code division multiple access.

4) What are the main types of interference, and briefly describe them.

5) Tell us about the PRMA, DSMA, CSDA schemes.

CHAPTER 6

6 Optical systems

6.1 Principles of construction of optical communication systems

Optical range. Electromagnetic oscillations have a small range of optical wavelengths in comparison with radio waves, so they measure the following units: micrometer (1 micron = 10^{-6} meters), nanometers (1 nm = 10^{-9} m). In this chapter, micrometers mainly used, and the oscillation frequency in hertz, defined by the formula $\nu = 3 \bullet 10^{14} / \lambda$, where λ is measured in microns.

Optical range is called the land of the electromagnetic spectrum, corresponding to wavelengths of 0.01 ... 100 micron and a frequency of $3{\cdot}10^{12}$... $3{\cdot}10^{16}$ Hz. From the side of shorter wavelengths it is adjacent to the X-ray range, and from longer - to radio frequencies. Often optical range is divided into three sub-bands: ultraviolet wavelengths from 0.01 ... to 0.38 microns, visible wavelengths from 0.38 ... to 0.74 micron and infrared wavelengths from 0.74 micron ... to 100 micron [25].

It is considered to be that for the purposes of communication are promising wave length 0.3 ... 30 micron. Currently, however, used a tiny fraction of the optical range, corresponding to the narrow lanes in mostly near the following wavelengths: 0.53, 0.63, 0.8 ... 0.9 microns, 1.06 microns, 1.3 ... 1, 5 microns and 10.6 microns. The reason is, first of all, the high technical parameters (radiation power, efficiency, bandwidth modulation, lifetime, etc.) light sources (lasers, light-emitting diodes), and secondly - the presence of the respective bandwidths ("transparency windows") in used in environments in which distributed optical radiation (atmosphere, quartz glass, and others.).

Advantages and disadvantages of optical range in terms of communication. In the optical range possible in principle to the creation of the OCS with a huge capacity, this is due to the extremely high frequency of the optical carrier. So, in the wake of 1 mm relative frequency band of only 1% corresponds to the transmitted frequency band $3{\cdot}10^{12}$ Hz, which is equal to the entire radio spectrum band, starting with a wavelength of 0.1 mm. Practical implementation of this feature is associated with the creation of the respective devices modulation and demodulation of light. It has now been band near 10^{9} Hz.

Another important advantage is the possibility of creating small optical antennas with great gain. This is because in the case of coherent radiation gain is inversely proportional to the square of the wavelength. Therefore, the optical antenna with an aperture diameter of 10 cm on a 1 micron wave achieves a gain of about 107 dB. To obtain such a gain in the radio in the wake of 3 cm would be required antenna diameter of about 3 km. It is the dignity of the optical band plays a first role in communications in space over long distances.

In the optical range is possible in principle to transfer the signals in the frequency range up to several GHz of optical fibers without an intermediate relay to a distance of several hundred kilometers.

In the optical range it is much easier than in the radio, to solve the problem of electromagnetic compatibility means of information transmission due to sharp direction of the optical antennas, weak "population" range and most of its width.

An important advantage is the possibility of miniaturization of all elements of the OCS, including the antenna.

In addition, the OCS is inherent serious shortcomings. Thus, the above-noted possibility of implementing high gain antenna leads to the serious problem of guidance on correspondent and support in the process of communication, due to the extremely small beam width (with the diameter of the aperture of 10 cm and a wavelength of 1 micron, it can have a value of about 3 ", the accuracy of the guidance and support must be better than 1 "). In the case of moving objects, such as in communication in space, ensuring the required accuracy causes considerable difficulties. Currently it was achieved accuracy of about 3 ... 5 ".

Another problem encountered with regard to the optical range - providing highly reliable lines, lines that are partially or completely in the atmosphere due to the strong growth of the loss of light due to rain and atmospheric pollution. For example, in a dense fog the attenuation per unit length can reach 100 dB / km. In fact, this factor significantly restricts the use of OCS for communication in connection with the atmosphere and space objects through the atmosphere.

A serious drawback is the difficulty in the practical implementation of heterodyne reception in optics due to the strong sensitivity to fluctuations in the arrival direction of the signal light wave and violations of its spatial coherence due to random heterogeneities of a medium. For these reasons, the specified type of reception is now almost does not apply. In the radio the situation is reversed: it is applied almost exclusively heterodyne reception.

Finally, it should be noted that serious difficulties is the implementation phase in the optical transmission techniques due to lack of narrowband and frequency stability of the used radiation.

6.2 Classification of optical communication systems

Optical communications, as, indeed, and the radio can be divided to the ground, space and ground-space. Ground has relation between places on Earth's surface. Space-ground communication - is the relationship between places on Earth and in outer space, that is, between the earth station and spacecraft (satellite, ship, station). Space optical communication is carried out between places in outer space. It can be carried out between the satellites, spaceships, stations, etc.

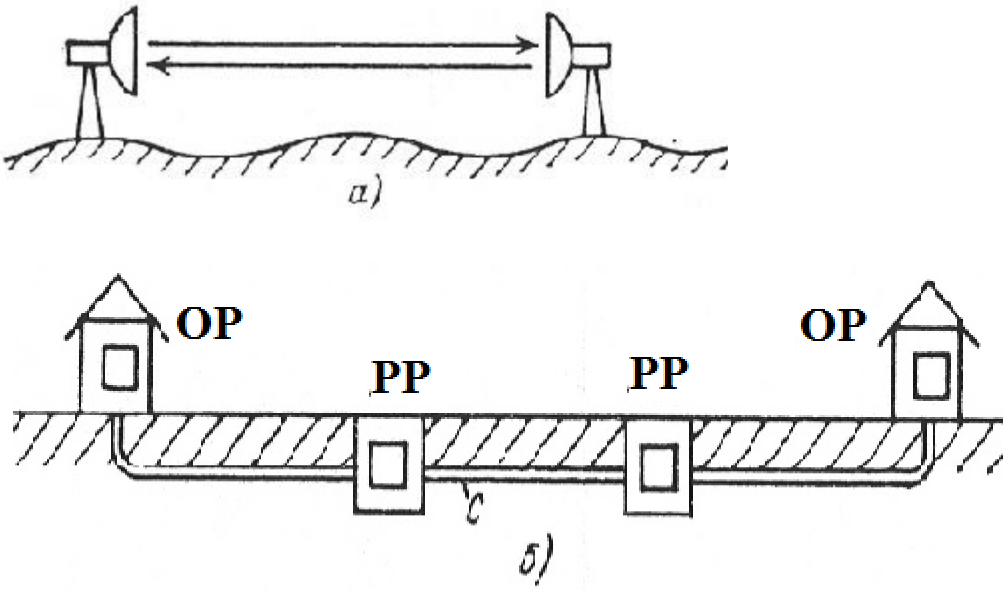
The ground connection can be carried out using the following types of OCS: OCS atmospheric (see Figure 6.1, a), fiber optics OCS (see Figure 6.1, b) and satellite OCS (see Figure 6.1 in). The first type of OCS is characterized in that the medium of light is the atmosphere. These systems are not widespread due to strong exposure due to atmospheric precipitation and contamination. They are usually used for the mobile service single telephone connection over short distances (0.1 ... 1 km) on large construction sites, mines, etc.

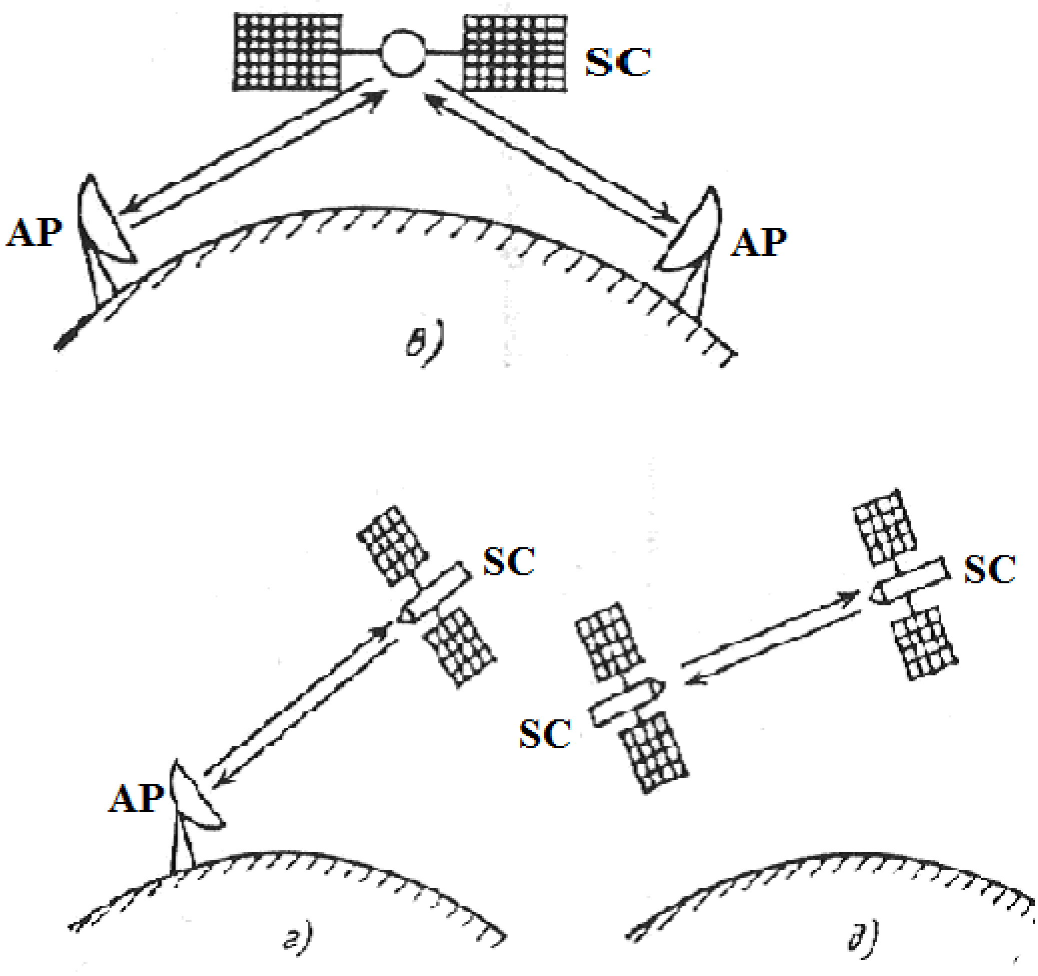
The light-guiding OCS environment of light is a "closed environment" rail system.

Despite a number of important advantages (small Loop loss, lack of dispersion distortions of the transmitted signals, protection from the effects of rain, etc..) Luchevidnye OCS not widely used because of the difficulties laying beam guide and maintain normal conditions of light transmission. In this regard, currently the main type of OCS light guide is optical fiber, in which a guide system uses optical fibers, which is typically quartz glass fine thread diameter of about 0.1 mm. Thus, the OCS fiber light propagation medium is silica glass.

The OCS satellite is providing a ground connection (see. Figure 6.1 in), and ground-space OCS (see. Figure 6.1 g) propagation of light takes place partly in the Earth's atmosphere, which substantially reduces the reliability of the connection between the ES and the spacecraft. Therefore, this type of system has not yet received the distribution. To reduce the influence of the atmosphere is expected to post further earth stations high in the mountains above the clouds that are difficult operation of such stations.

In the space OCS (see. Figure 6.1, d) the light propagates in free space, which allows achieving extremely high quality transmission. OCS of this type have been developing and very promising due to the immense energy gain of the optical antenna and compact equipment. The main difficulty in the development of these systems is providing extremely high precision alignment of optical antennas (unit arc seconds).





a - the atmospheric, b - light guide, в - satellite, г - ground-space, д - space; OP - end point, PP - intermediate point, AP - earth station, SC – spacecraft

Figure 6.1- Types of optical communication systems

6.3 Features of construction of optical communication systems

Atmospheric OCS noted that this type of OCS not spread as a means of commercial communications as a result of the strong influence of atmospheric precipitation on reliability. In thick fog light attenuation is so significant that the relationship is practically impossible, even at a distance of hundreds of meters. Another factor aggravating the reliability is the turbulence of the atmosphere, leading to the random fluctuations of the amplitude, phase, polarization and direction of propagation of the light wave. The difficulty of the highly reliable of OCS in the atmosphere over long distances has been confirmed by numerous experimental studies. Atmospheric optical communication is considered to be forward-looking and may be used for operational communications on large construction sites, mines, with moving objects in a complex environment in terms of electromagnetic compatibility: in sea and river ports, railway stations and etc.

[28]. Usually it is a single-channel, and in the absence of strong precipitation can be carried out at a distance of about 1 km.

The main requirements for equipment such communication systems are compact and easy entry into the bond and its maintenance, low weight, power consumption and low cost. Therefore, in the equipment most commonly used transceiver antenna lens with an aperture of less than 10 cm, less expensive than mirror and having a large field angle. Antenna pointing is carried out manually or motor driven with an optical viewfinder. For convenience, sometimes pointing the beam is expanded to a few degrees with the help of the diverging lens, which stands after the laser, or by defocusing the antenna.

The light sources are used low-power gas lasers a mixture of helium and neon (λ = 0,63 m) or semiconductor lasers based on gallium arsenide (λ = 0,8 ... 0,9 mm) with a capacity of radiation in a continuous mode 2 .. . 5 mW. Helium-neon laser produces visible light that simplifies the process of antenna pointing and entering into relationship. The semiconductor laser emits in the infrared region, but has a higher efficiency and smaller size.

If necessary, due to the long distances and at high precipitation expedient carbon dioxide laser λ = 10,6 micron, the radiation is attenuated in the atmosphere to a lesser extent (see. Figure 8.2).

In the transmitters with atmospheric OCS used most often direct modulation of the light intensity by changing the pump current of the laser. In the case of gas lasers transmission is usually on a subcarrier (20 ... 50 kHz) modulated in amplitude or frequency of the primary telephone signal. It may also be applied using the light modulation external electro optic modulator. In the case of semiconductor lasers it is the pulse-frequency modulation (PFM) due to the nonlinearity of their characteristics.

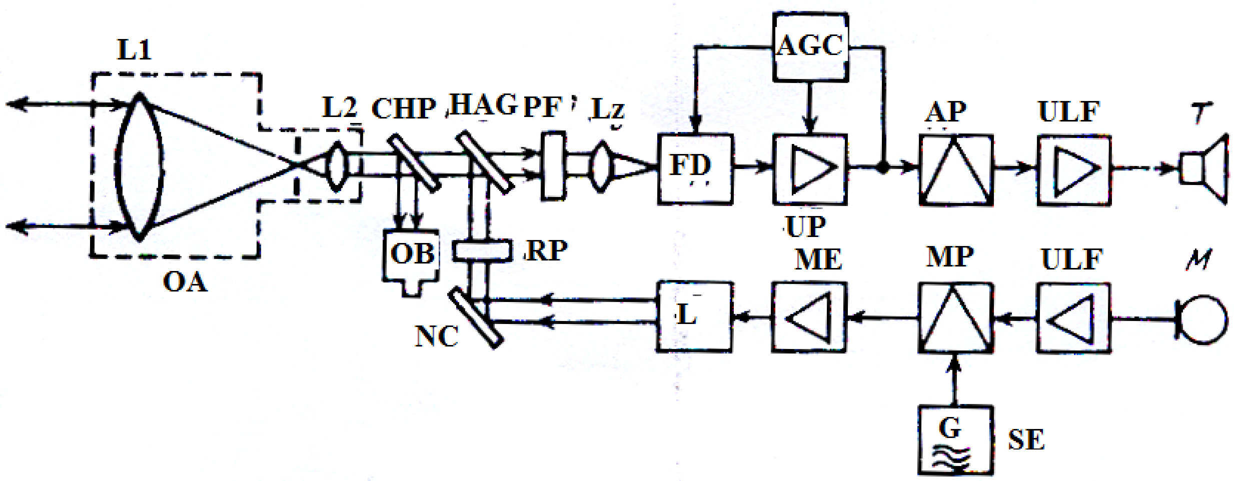


Figure 8.2 - Block diagram of the transmitting equipment Atmospheric Environment for telephony on subcarrier

The atmospheric OCS uses the atmospheric optical receivers' direct detection of a photomultiplier or a photodiode as a photo detector. Heterodyne receivers are not applicable, because of the higher cost, the need for a second laser system with AFC and reduce the efficiency of the fluctuations due to the angle of arrival of the signal light waves caused by atmospheric turbulence.

A typical block diagram of a transceiver with a combined atmospheric OCS with lens antenna and transmission to the subcarrier. Primary telephone signal is supplied to the subcarrier modulator (SM) (under modulator), the other input of which simultaneously receives the signal from the subcarrier generator (SG). The modulated subcarrier is amplified in a modulation amplifier (MA) and enters the laser providing pump current control. With the help of a semitransparent mirror (SM) radiation is introduced into the optical antenna. In order to expand the beam serves a BE element (beam expander).

The received signal passes through the optical filter (OF) for attenuating the external noise (background) is input to the photodetector PD. A dedicated sub-carrier signal is amplified selective subcarrier amplifier (SA) and demodulated subcarrier demodulator (SP), the output of which the primary phone signal is amplified and fed to the phone. Automatic gain control (AGC) covers not only the subcarrier power, and, in the case of a photomultiplier, photodetector (regulated by the current flowing through the voltage divider).

By using a semiconductor laser and a PFM the scheme remains the same, but is replaced by subcarrier generator pulse generator, the following 8 kHz, and the modulator and demodulator of sub PFM modulator and demodulator.

Space OCS. Nowadays, two cases are present the greatest interest: the connection of low and of high-altitude satellites to geo-stationary and the link between geostationary satellites. This satellite, which move in orbits other than the geostationary, usually given to the role of information-gathering stations and geostationary - accumulation and transfer data to earth stations. Due to the strong influence of the atmosphere on the propagation of waves of optical range on the Earth track - AES preferably communicate at radio frequencies. However, not excluded and optical communications channels.

In the first case the length of the link is about 40 000 km, and the second can reach 70 000 km. The overlap considerably less knowledge-distances requires the use of powerful optical transmitter and extremely narrow beam antennas. In connection with this problem are especially acute guidance antennas during the search and tracking.

Another important feature of the space optical communication is the need to transmit digital information at very high speeds (up to 1 Gbit/s and higher). It is believed that the use of OCS space becomes justified when the data transmission rate of 100 Mbit/s.

When the connection between low-flying and geostationary satellites there is a significant shift in the frequency of light due to the Doppler effect and it reaches approximately ± 700 MHz.

In addition, the link opens in space such opportunities, which are not on Earth. Firstly, due to the absence of the atmosphere it can be effectively utilized heterodyne receivers. Secondly, with regard to the satellites of high-altitude with sun lighting, as well as the link between geostationary satellites can use the sun as a source of optical pumping laser transmitters. Third, in the space due to the absence of a material medium the light is propagated with minimal attenuation, no effects such as fading, phase fluctuations, changes in the direction of propagation, the change in polarization, the dispersion of the phase velocity, and etc., which greatly facilitates the solution to the problem of optical communication .

In the space operating communication systems used, as noted, digital communication methods with direct modulation of the light amplitude, intensity or polarization. The combination of these modulation methods is using in order to increase the transmission rate by half.

During the using amplitude modulation of the binary symbols of the digital signal (zeros and ones) are usually transmitted by the position-width modulation (Discrete PWM) in which each of them corresponds to a definite position within the clock pulse interval. If it is using polarization modulation the symbols correspond to the two types of circular polarization: the polarization of the left or right rotation. In both cases, each clock period is transmitted only one bit of information. With the combination of these two types of modulation in each clock period is transmitted two bits of information as may be used in two different pulse position and two polarization values. In fact, this corresponds to a transition from binary code to the code with a base of four.

OCS space for equipment meet the following basic requirements: small dimensions and weight, high reliability, long life, low power consumption, minimal entry into the connection, the transfer of digital information at high speed and high reliability.

In connection with these requirements and the requirements of communication range in the OCS space used exclusively reflector antennas with aspheric mirrors and large aperture (typically 25 ... 35 cm). For small axial size and weight they can achieve extremely high gain. However, a further increase in the size of the aperture is limited by excessively high requirements for guidance accuracy in the search process and maintenance. Even under the above amounts required accuracy better than ± 1 mcrad ≈ ± 0,2 ".

The light sources used solid-state and gas lasers. Semiconductor lasers do not provide the required radiation power and have a greater beam divergence (pro-poor spatial coherence of the light output).

The most promising solid-state laser that meet the requirements listed above shall be deemed YAG doped with neodymium (λ = 1,06 microns, without doubling the frequency and λ = 0,53 micron - with a doubling), with the highest efficiency (1 - 2%) including solid-state lasers, and provides the required radiation power (units - tens of watts and continuous mode). Furthermore, the laser has small dimensions, long life, and is suitable for pumping sunlight. Since required to transmit information at high speed, it is convenient to mode locking, in which the laser produces a periodic sequence of pulses. Experimentally achieved pulse repetition frequency of 0.5 GHz. Using an external optical modulator this sequence is pulse position modulated or polarization. With the combination of both types of modulation data transmission speed is 1 Gbit / s.

By relatively broad emission bands and high-frequency stabilization problems, solid state lasers cannot be used in combination with the heterodyne receivers. The equipment of OCS space with neodymium laser receivers are used for direct detection, which is used as a photodetector is usually a photomultiplier. An important advantage of the receiver of direct detection is that it is not sensitive to the frequency shift of the signal due to the Doppler effect, which, as noted, is very significant.

From gas lasers the most appropriate space for the OCS is a laser ultra-high pressure carbon dioxide (λ = 10,6 micron), having a small size, high efficiency (20%), which provides the required radiation power and long service life. When using longer wavelength light (10.6 instead of 1.06 micron or 0.53 micron) is significantly reduced antenna gain (while maintaining the same aperture), but will also benefit from - the weaker the influence of exposure to the atmosphere during transmission through the Earth - AES.

Modulation of the light may in this case be carried out both by means of an external optical modulator, and by placing the control element (for example, the electro optical crystal) within the laser resonator. Moreover, experiments have shown that as attainable data transmission rate of about 1 Gbit/s

Carbon dioxide laser equipment in the OCS space can be used as a receiver of direct detection and heterodyne. In both cases a photo detector is used as a cooled photodiode or photo resistor of telurita cadmium mercury. For cooling device can be used micro cryogenic liquid nitrogen or metal plate, focused on the dark part of the sky, protected from solar radiation.

Note the advantage of using heterodyne receiver - effective filtering of background radiation of the Sun, Earth, planets, bright stars due to the spatial and frequency selectivity. When using a narrow antenna directivity pattern in the receiving mode spatial selectivity not essential. The frequency selectivity is equivalent in effect to the use of the input optical filter with a bandwidth equal to the intermediate frequency band path heterodyne receiver. However, crucial in all cases is the relative weakening of the noise caused by background radiation by increasing the power of the laser oscillator. With this heterodyne receiver can operate successfully in the direct solar radiation to its input.

The big drawback is the need to compensate for the Doppler shift in the frequency heterodyne receiver. Due to significant changes in the frequency limits, we have to do in two phases in the receiver, which significantly complicates the device.

The final choice of the type of laser and type of optical receiver must be carried out with all the requirements to space OCS and its specific use in conjunction with other means of communication.

The most difficult problem with the creation of the OCS space, is the problem of automatic communication between moving stations, remote of tens of thousands of kilometers, and maintain it for a long period of time. To this end, the composition of plants provides a set of special tools for data discovery and tracking.

To perform these operations in the station provides a rough pointing of the antenna with a flat mirror on gimbals, accurate pointing using a system of mirrors moved by a piezo elements, which control voltage is applied, the motion compensation image of transmitting station by means of coarse and fine guidance and receiving tracking error signals (angular misalignment), required for the operation of the servo system in the maintenance mode.

There are two main ways of obtaining angular error signals: in the information channel (on the information signal) and a separate channel targeting (for information signal or a signal beacon laser operating at a different wavelength of light).

6.4 Atmospheric laser communication

The main reason for the demand for wireless technology, optical communication is huge potential to transfer large amounts of data at high speeds in the infrared wavelength range far beyond of the accepted range of radio frequencies (up to 400 GHz), thus substantially reducing administrative costs. Among the world-renowned developers and operators of telecommunications networks in order to adopt a wireless optical technology - Sprint, Nextel, Verizon (in the last Bell Atlantic), VimpelCom, Motorola, Siemens [26].

Optical communication is done by transmitting information using electromagnetic waves in the optical range. In the 60-es of XX century it was created by lasers and the opportunity to build broadband optical communication systems. The first atmospheric communication line (ACL) in Moscow began in the late 60s: the telephone line has been started between the building of Moscow State University on Lenin Hills and Zubovskaya stretching over an area of 5 km. The quality of the transmitted signal fully complies with the standards. In those same years experiments with ACL held in Leningrad, Gorky, Tbilisi and Yerevan. In general, the tests were successful, but at that time, experts believed that the bad weather conditions make laser communication unreliable, and it was recognized as unpromising. Using signals from a continuous (analog) modulation used in those years, led to a normalized attenuation of the optical signal due to the influence of the atmosphere.

Modern ACL widespread in many countries of the world began in 1998, when they were created inexpensive semiconductor lasers with a capacity of 100 mW or more, and the use of digital signal processing, thus avoiding non-normalized signal attenuation and perform retransmission of the packet of information when an error occurs.

The benefits of wireless links are obvious: efficiency (no need to dig trenches for laying of cables and ground rent); lower operating costs; high capacity and quality of digital communication; rapid deployment and reconfiguration of the network; easy to overcome obstacles - railways, rivers, mountains, etc.

Wireless radio communication frequency is limited congestion and lack of frequency range, insufficient reserve, and susceptibility to interference, including deliberate and adjacent channels, increased power consumption. In addition, for radio communication it is required a long coordination and registration with the appointment of frequencies Gossvyaznadzor authorities of the Republic of Kazakhstan, the rent for the channel, mandatory certification of radio equipment the State Commission for Radio Frequencies. The use of laser means eliminates this complex issue. This is because, firstly, the laser radiation frequency communication systems beyond the range in which the necessary alignment, secondly, the lack of practical possibilities of detection and identification as a means of information exchange.

6.4.1 Main properties of laser systems:

- Practically absolute security against unauthorized access channel and, as a result, a high level of performance and noise immunity by allowing the concentration of the energy signal from a fraction of the angular corners minutes (space laser communication systems) to tens of degrees (full communication systems in premises);

- High information channel capacity (up to tens of Gbit/s);

- The lack of strongly pronounced unmasking attributes (mainly by electromagnetic radiation) and the possibility of additional masking allow to hide not only transmit information, but the fact of the information exchange.

In addition, many experts say the biological safety of these systems as well as the average power density in laser systems for various purposes several times lower irradiance produced by the Sun, as well as the simplicity of the principles of their construction and functioning, relatively low cost compared to traditional means of information transfer similar purpose [27].

6.4.2 Summary

Thus, the connection by laser beam through the atmosphere has now become real. It provides transmission of large amounts of data with high reliability at distances up to 5 km, and the most simple and efficient solution for the "last mile."

Systems of ACL can be used not only for "last mile" of communication channels, but also as inserts in optical fiber lines in separate areas impassable; Communication in the mountains, airports, between the individual buildings of the same organization (administration, shopping centers, industrial facilities, campuses, hospital complexes, construction sites and etc.); creating at spaced local area networks; when creating communication between switching centers and base stations of cellular networks; for operational laying lines with limited installation time.

At the same time, there is a need for laser communications since it become rapidly evolving in information technologies. Dramatically there is an increase in the number of subscribers that require the provision of such telecommunication services as the Internet, IP-telephony, cable TV with a large number of channels, computer networks, and etc.

Therefore, in recent years there is a growing interest in this type of communication.

Control questions:

1) List the advantages and disadvantages of optical communication band.
2) How can we classify the optical communication system?
3) What is the range of electromagnetic radiation considered to be optically?
4) What do you know about the atmospheric laser communication?
5) Where applicable atmospheric laser communication?

CHAPTER 7

7 Technical concept of building systems BS

This chapter describes the principles and propagation models as applied to cellular systems, personal communications systems (PCS), and land mobile radio systems of general use (PLMR). For typical cellular and PCS systems of indirect sight (NLOS) multipath random track is characterized by three main factors - fading due to multipath, screening and path loss. The chapter discusses the causes and the real value of the Doppler scattering (time selective fading) and temporal dispersion (frequency selective fading). It describes the physical nature of a number of mathematical models of distribution and appropriate modeling tools (hardware and software). Major highlighted the cellular systems with the engineering concepts and design principles that can be taking into account the characteristics of radio wave propagation and network optimization. Give the final formula for the calculation of the maximum length of coverage area.

7.1 Propagation in the mobile communication

A typical model of land mobile radio systems, for example, PCS, or transmission line cellular system includes high altitude antenna (or multiple antennas) of the base station with respect to enforcement in a short section of the spread line of sight (LOS) [28].

There are also lots of tracks with a transformation (i.e. indirect visibility - NLOS) and one or more mobile antennas installed in a car or (a more general case) sensor in the mobile transceiver station or worn. In most cases, there is a part-section of radio wave propagation in the line of sight between the antenna of the base station, or access point antennas and mobile stations for natural and artificial obstacles (see. Figures 7.1 and 7.2). Under these conditions, the radio circuit can be modeled as randomly varying propagation path. In the illustrated example (see figure 7.1) antenna of the base station is located at a height of 70 m, i.e. on the roof of the tallest building. Direct LOS track the spread of free space (does) lies between the antenna base and the first building. Because of its impact on the direct route is brought do attenuation. Located in remote upland reflect signals. The reflected signals are delayed at reception may have a capacity comparable to the capacity of weak signals direct path.

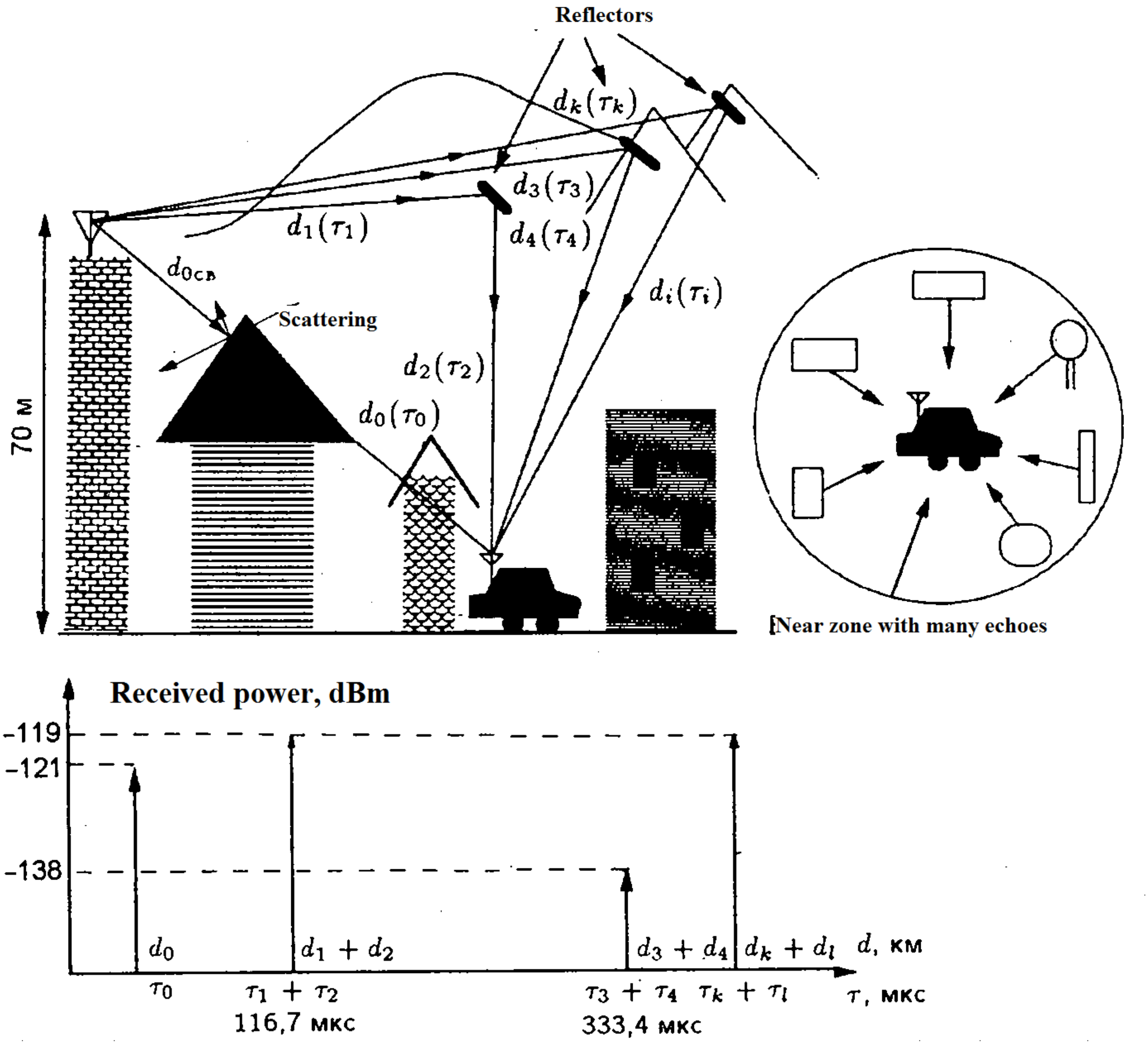


Figure 7.1 Radio wave propagation environment for land mobile radio system direct (LOS) and indirect (NLOS) visibility

In many cases it may be more than one propagation path, and this situation is called multipath. The propagation path varies with the movement of the moving object, the underlying hardware or movement of surrounding objects and the environment. In Figure 7.2 the antenna height of the base station (access point) of approximately 3 m; the height of the antenna of the mobile station, on the desktop, about 1 m. Office space is partially divided by partitions. Central laboratory, warehouse and industrial area are insulated walls and in some place the metal sheets.

Even the smallest, slowest movement results in a change in time of multipath conditions and, consequently, in modifying the received signal. Suppose, for example, that the subscriber of the cellular system in the vehicle in a parking near an autobahn

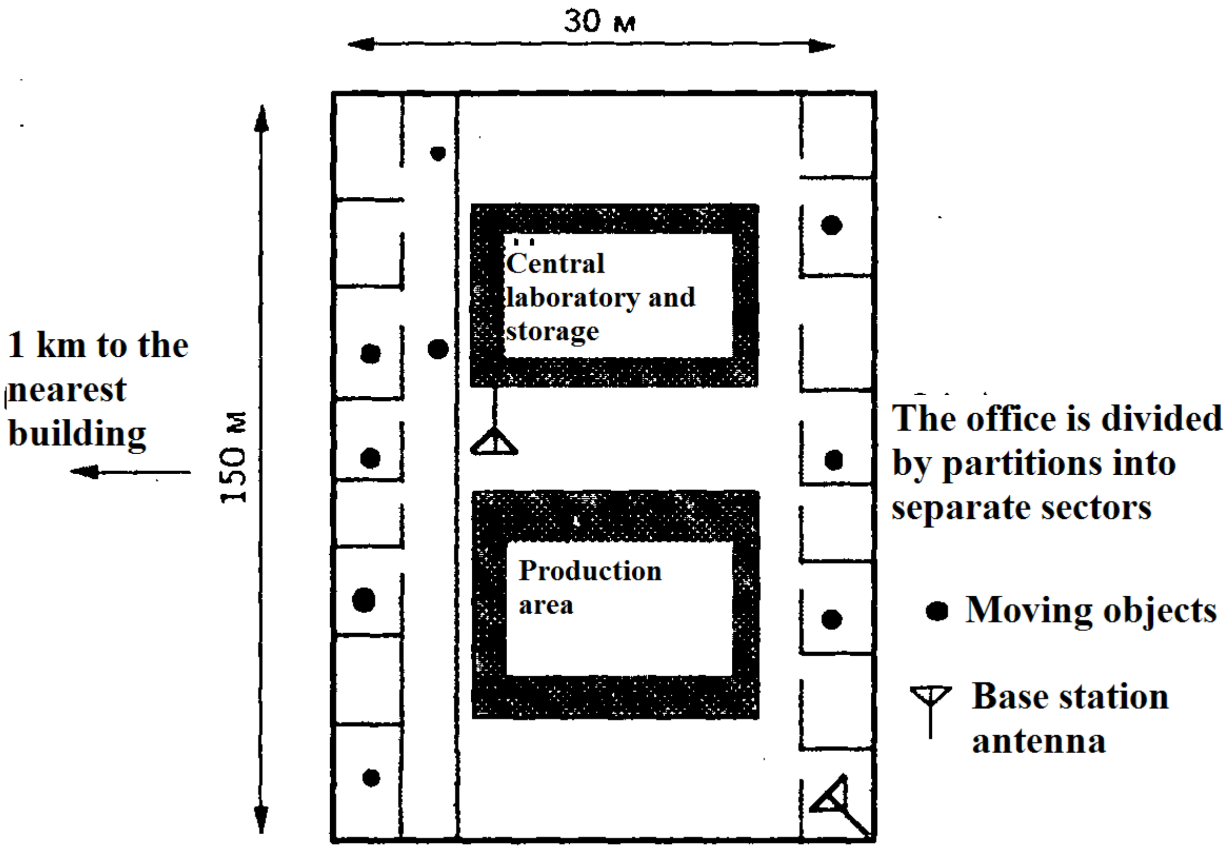


Figure 7.2 - Propagation environment indoors for microcells with covering radius r = 1 km or nanocell with coverage 1m≤r≤50m

Although subscriber relatively stationary part of the environment is moving at a speed of 100 km / h. Cars on the freeway becoming "reflectors" radio. If, during transmission or reception, the user also moves (e.g., at 100 km / h), the parameters randomly reflected signals are changed with higher speed. The rate of change of signal level is often described Doppler scattering.

Propagation in such circumstances is characterized by three partly separate effects, known as fading due to multipath propagation, shadowing (or shielding) and propagation loss. Fading due to multipath are described through the fading envelope (do not depend on the frequency of changes in amplitude), Doppler scattering (selective over time, or time-varying, random phase noise) and the scattering time (time-varying propagation length of the reflected signals cause temporary changes themselves signals). Scattering time leads to frequency selective fading. These phenomena are illustrated in Figure 7.3 and discussed further.

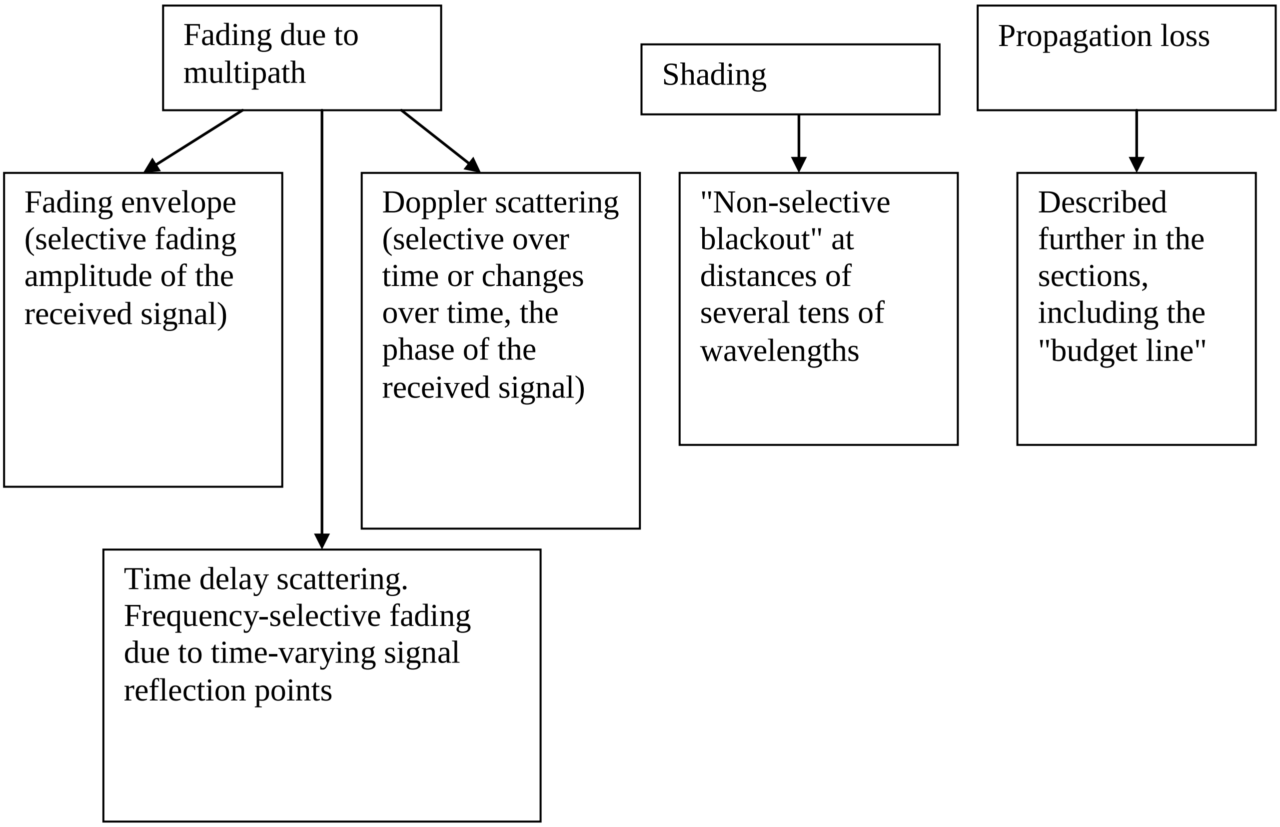


Figure 7.3 - The phenomena of fading due to multipath, shadowing and losses Propagation

7.1.1 Fading envelope.

To illustrate the basic properties of the fading envelope, let us turn to Figure 7.4. It is assumed that the base station transmits the signal $S_T(t)$ with PM and constant envelope:

$$s_T(t) = Ae^{j[\varpi t+\psi_s(t)]}, \qquad (7.1)$$

where A — Constanta;

ω — corner radiofrequency (CR);

$\psi_s(t)$ — modulating the phase and frequency of the carrier signal information, also known as a baseband signal.

Varies in time "propagation medium» p (t) can be represented as:

$$p(t) = r(t)e^{j\psi_r(t)}, \qquad (7.2)$$

where $r(t)$ — time-varying envelope;

$\psi_r(t)$ — time-varying random phase propagation environment.

Random propagation environment envelope r (t) can be divided into long-term, or averaged, fading component m (t) and a short-term component, due to fast fading due to multipath ro (t), which is reflected by the formula:

$$r(t) = m(t)r_0(t), \tag{7.3}$$

where $r_0(t)$ - it has an average value of 1.

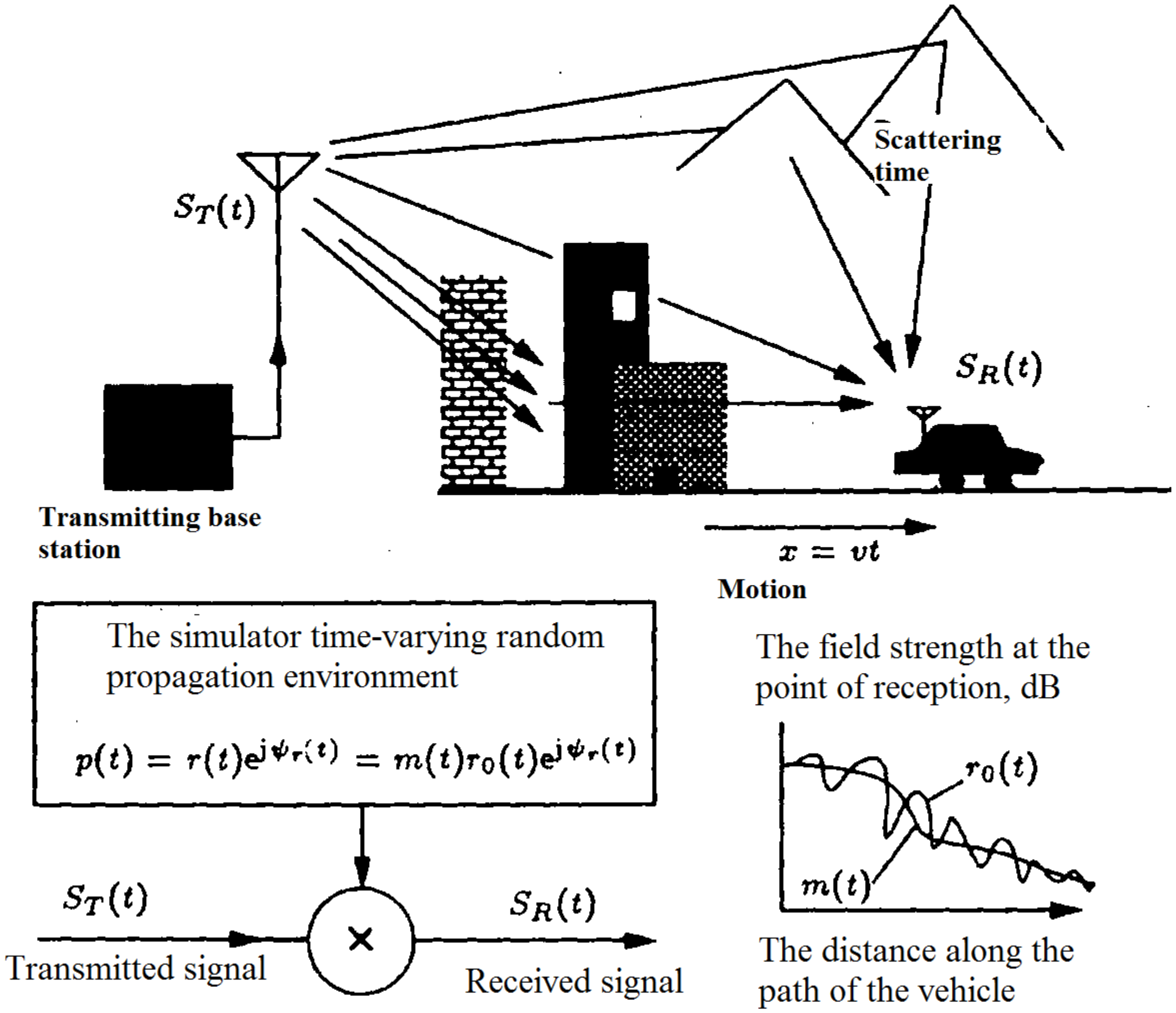


Figure 7.4 - fading phenomenon - illustration of changing the time in the envelope fading channel

If the base station and mobile units are stationary, but the environment is moving (which is almost always the case, as even the slightest and most slow movement leads to a time-varying reflections in the NLOS), then it can be used the expression (7.3), where the time t - a random variable. If the mobile unit is moving with velocity v, m / s or km / h, the length of the propagation path between the base station and the mobile unit is equal to

$$x=vt. \quad (7.4)$$

In this case, the expression (7.3) can be written as the

$$r(x)=m(x)r_o(x). \quad (7.5)$$

The transmitted signal St (t) with constant envelope is multiplied by the time-varying random "transfer function" propagation environment p (t). Thus, we have a model multiplicative fading. Note that we use the additive model, for example, the model of additive white Gaussian noise for fixed channels which are found in the systems of geostationary satellites, or coaxial cable systems.

When the receiver, transmitter or the environment is even slightly moved the efficient movement is more than a few hundredths of a wavelength. For example, in wireless communication systems range from 2 GHz the wavelength

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8 \, м/с}{2 \cdot 10^9 \, Гц} = 15 \text{ cm.}$$

Thus, if the receiver is moved at a distance of 1.5 cm, it is shifted by 1.5 / 15 = 0.1 wavelength. Moving to a distance of more than a few hundredths of a wavelength it can lead to fluctuations of the envelope. This situation is illustrated in Figure 7.4.

The envelope of the received signal has a fluctuating Rayleigh distribution when the number of incident plane waves with a random direction of the parish is large enough, and among them there is no clearly dominant component of the track line of sight (LOS). Rayleigh distribution is the most frequently used functions of distribution channels for land mobile communication systems, including external (outdoor), land mobile and internal (indoor) use radio communications. Many experimental results show that the Rayleigh distribution is sufficiently accurate mathematical model. Fading 20 dB or more as compared with the deep root mean square envelope signal occur within approximately 1% of the time; fading 30 dB or more - for 0.1% of the time; 40 dB or more - only 0.01% of the time. The probabilities of occurrence, duration and extent of the fading envelope have a significant impact on the performance of both digital and analog mobile radio systems.

7.1.2 Doppler scattering: random variation and phase coherence time.

It has been previously shown that the envelope changes over time due to random fading random phase change are accompanied. These phase changes cause the appearance of noise due to the random frequency modulation (FM). The width of the random FM noise spectrum at baseband frequency is equal to approximately twice the maximum Doppler scattering, or twice the maximum Doppler frequency.

The maximum Doppler frequency

$$f_d = v / \lambda \tag{7.6}$$

and

$$\lambda = c / f \quad . \tag{7.7}$$

In this way,

$$f_d = \frac{v}{\lambda} = \frac{v}{c/f} = \frac{vf}{c} \quad , \tag{7.8}$$

where $c = 3 \cdot 10^8$ м/с— speed of light;

v — moving speed of the mobile object based on the velocity of the environment, m / s;

λ — the wavelength of the radio signal, m;

f — radio frequency, Hz.

Doppler scattering is determined by the width of the spectrum of the received carrier, when in a multipath channel carrying transmitted only sinusoidal carrier. If the carrier is transmitted at a frequency fo, is due to the Doppler scattering fd we accept "smeared" the signal spectrum with spectral components between the frequencies fo – fd and fo + fd. This effect, known as selective fading over time, can be interpreted as the effect of the decorrelation time of the channel with random fading due to multipath propagation.

C_T coherence time is usually defined as the time interval over which the correlation coefficient values envelope not less than 0.9. This parameter is inversely proportional to the maximum Doppler frequency and is defined:

$$C_T = \frac{1}{f_d} \quad . \tag{7.9}$$

7.1.3 Scattering time: physical cause and overall presentation.

The physical cause of the scattering time τ illustrated in Figure 7.1. The signal propagation path within the line of sight (LOS) d_o, having the time of distribution τ_o, severely weakened by tall buildings. Assume that the power of the attenuated signal on a LOS line equal to 121 dBm. The mobile unit also receives reflected signals when passing highway track d_1+d_2, track $d_3 + d_4$, track $d_k + d_l$ and many other routes that are not shown in Figure 7.1. If it is assumed that the power of the signal received from the track with a total length d_1+d_2, equal to -119 dBm, have now roughly equal to the direct path signal (LOS runs from weakening) and the track LOS with multipath. In this illustrative example, if d_1+d_2= 36 km and d_o = 1km, there is a delay on the road, or scattering time that is equal to:

$$\tau = \frac{d_1 - d_2 - d_0}{c} = \frac{36\,km - 1\,km}{3 \cdot 10^8\,m/s} = 116{,}7$$

microsecond

The most commonly used real systems specifications are mean square value scattering time and the maximum value of the scattering time.

The effect of the temporary presence of scattering is manifested in the frequency-selective fading. This effect can lead to a strong distortion of the shape of the demodulated signal and impose limitations on such a characteristic high-speed digital radio systems as the probability of bit error (BER).

The coherence bandwidth is the frequency spacing C_B within which the values of the envelope correlation coefficient of not less than 0.9. This parameter is inversely proportional to the mean root square value (rms) of the scattering time and is defined as:

$$C_B = \frac{1}{\tau_{rms}} \quad . \tag{7.10}$$

7.1.4 Shading and propagation loss.

Early it shows that the fading on the track can be divided into a long-time, or averaged, fading and short or fast, fading due to multipath. After the fast fading due to multipath are eliminated by averaging the interval of several hundreds of wavelengths remains nonselective shading. The cause of the shading characteristics are basically the terrain along the propagation path of radio land mobile systems. This phenomenon causes the slow changes in the average values of the parameters of Rayleigh fading. Although there is no shading appropriate mathematical model, the distribution that best fits the experimental data in a typical urban area, declared a log normal distribution with a variance of 5 to 12 dB. Propagation loss - is the mean value of the log-normal shadowing, which is also known as the average for the area (area average).

7.2 Fundamentals of gain antennas for mobile objects

To facilitate the understanding of the calculation of energy losses during propagation on tracks straight (LOS) and non-line (NLOS), the received signal power and budget line, will present the basics and gain omni directional antennas for mobile objects.

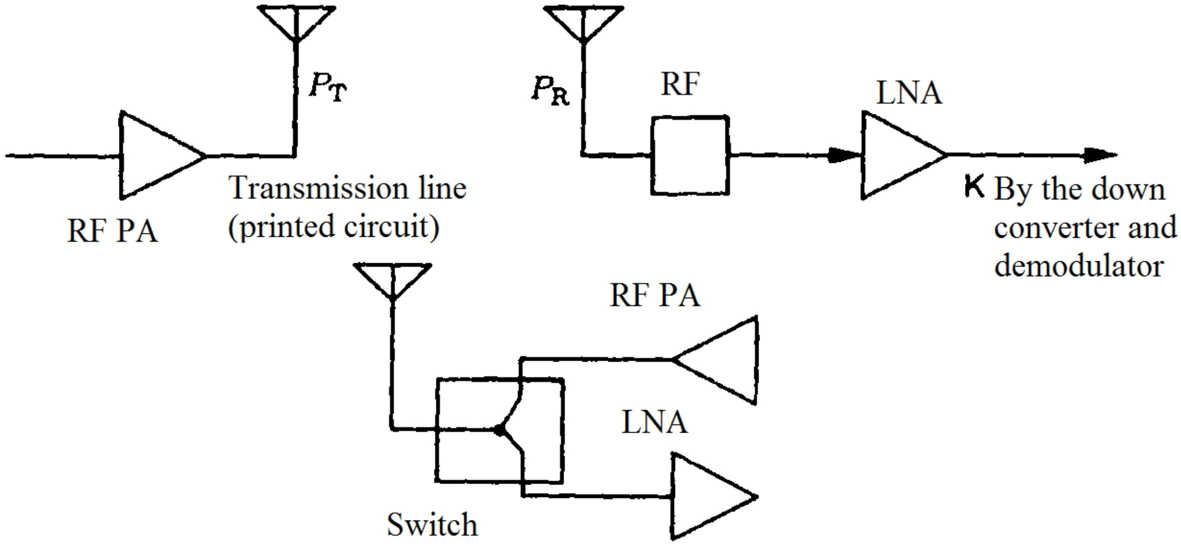


Figure 7.5 - Elements of the transceiver: transmit RF power amplifier (PA), transmitting antenna, receiving antenna, an RF section and a low noise amplifier (LNA); switch is used to provide redundancy or diversity mode

Suppose that the sender sends a RF amplifier power Pm W isotropic transmission antenna, as shown in Figures 7.5 and 7.6. Power density ρ, W / m2 or outgoing electromagnetic energy flux, measured at a distance r from the antenna is determined by the formula:

$$\rho = \frac{P_T}{4\pi r^2}\,. \qquad (7.11)$$

Directional antenna concentrates radiated power in a particular direction. The orientation of this antenna is defined as

$$D = \frac{\textit{Power density at a distance r in the direction of maximum radiation}}{\textit{Average power density at a distance r}} \qquad (7.12)$$

To use this definition of the antenna, it requires knowing the power actually radiated by the antenna. This power differs from the power at the corresponding points of the transmitter and receiver due to losses in the antenna itself.

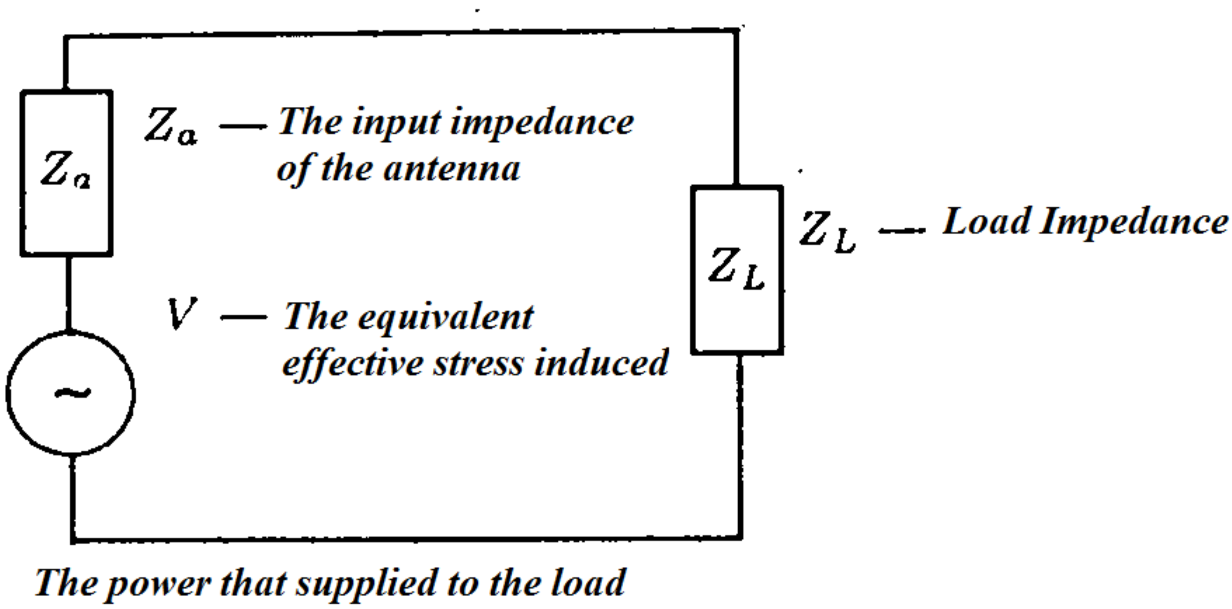


Figure 7.6 - Equivalent circuit antenna

The receiving antenna with an effective aperture of A and B at a distance *r* from an omnidirectional transmitting antenna receives power P_R, W is given by:

$$P_R = \rho A = \frac{P_T A}{4\pi r^2} . \qquad (7.13)$$

The antenna gain G associated with the antenna aperture and wavelength λ, m, radio signal

$$G=4\pi A/\lambda^2, \qquad (7.14)$$

where

$$\lambda=c/f. \qquad (7.15)$$

An ideal omnidirectional antennas G = 1; hence, from (7.14) we have:

$$A=\lambda^2/4\pi. \qquad (7.16)$$

7.3 Propagation characteristics

7.3.1 The formula for propagation loss in free space.

From (7.11) - (7.16) it is possible to obtain a formula for calculating the transmission loss in free space (or propagation loss) for omnidirectional transmission and receiving antennas with unity gain (G = 1), spaced at a distance of *r* meters. This formula has the form

$$\frac{P_R}{P_T} = \left(\frac{\lambda}{4\pi r}\right)^2 = \left(\frac{c}{4\pi r f}\right)^2 . \qquad (7.17)$$

For two antennas spaced apart by *r* m, with a gain of the transmitting antenna

$$G_T = 4\pi A/\lambda^2 \qquad (7.18)$$

and the gain of the receiving antenna

$$G_R = 4\pi A/\lambda^2, \qquad (7.19)$$

formula for propagation loss in free space assumes the form:

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi r}\right)^2 . \qquad (7.20)$$

From (7.20) we obtain the expression for the propagation loss (L_f, dB):

$$L_f = 10\lg\frac{P_R}{P_T} = 10\lg G_T + 10\lg G_R + 10\lg\left(\frac{\lambda}{4\pi r}\right)^2 =$$

$$= 10\lg G_T + 10\lg G_R + 20\lg\left(\frac{c/f}{4\pi r}\right), \qquad (7.21)$$

$$L_f[\partial Б] = 10\lg G_T + 10\lg G_R - 20\lg f - 20\lg r + 147.56 \text{ dB} \qquad (7.22)$$

For isotropic transmitting and receiving antennas with a gain of 1 (i.e. ideal omnidirectional antennas), and in the absence of obstacles within the line of sight (LOS) basic transmission loss is calculated by the formula:

$$L_B \text{ [dB]} = +27{,}56 - 20\lg f \text{ [MHz]} - 20\lg r \text{ [m]}. \qquad (7.23)$$

or the formula:

$$L_b \text{ [dB]} = -32{,}44 - 20\lg f \text{ [MHz]} - 20\lg r \text{ [km]}. \qquad (7.24)$$

From these relations for basic propagation loss in the line of sight (LOS), it follows that the received power decreases (relative to the transmitted power) by 6 dB for each doubling of the distance and twice the value of each radio frequency.

From (7.11) shows that the unit power is radiated watts per meter squared (W / m2). Typically, transmitted and received power expressed in watts (W) or decibels relative to 1 milliwatt (dBmW or dBm), whereas the propagation loss - in decibels (dB). Determine the ratio and conversion factors for these frequently used items.

Assume that use one - or two vibration receiving antenna. The induced voltage V, V / m is associated with a field strength E as follows:

$$V = \frac{E\lambda}{\pi} \quad . \tag{7.25}$$

Maximum power PR W / m2, delivered to the load impedance RL, the system output is equal to the agreed

$$P_R = \frac{V^2}{4R_L} \, . \tag{7.26}$$

It is assumed that an equivalent antenna induced voltage is V. The input impedance Za of the antenna is equal to the load impedance ZL, and RL - load resistance ZL, as shown in Figure 7.6. Thus, the received power may be expressed in Watts per square meter.

From the following expressions can be obtained

$$P_R = \frac{V^2}{4R_L} = \frac{(E\lambda/\pi)^2}{4R_L} = \frac{E^2\lambda^2}{4\pi^2 R_L} \, . \tag{7.27}$$

Determine the capacity of the PR, expressed in decibels relative to 1 W

$$P_R[\text{dBW}] = 10\lg E^2\left[B^2\right] + 10\lg\left(\frac{\lambda}{\pi}\right)^2[\text{dB}] + 10\lg\frac{1}{4R_L}R_L\left[\frac{1}{\text{Ohm}}\right] .$$

For standard load resistance RL = 50 Ohms have 10 lg [l / (4 · RL)] = -23 dB;

in this way:

$$P_R\,[\text{dBm}]=10\lg E^2[\text{mkW}^2]-10\lg(10^6)^2+10\lg(\lambda/\pi)^2-23\text{ dB}.$$

The formula for the power of PR, expressed in decibels relative to 1 mW of power, has the form:

$$P_R\,[\text{dBm}] = 10\,\text{Ig}E^2\,[\text{mkW}^2] +10\,\text{Ig}\,1000 -10\lg(10^6)^2 +10\lg(\lambda/\pi)^2- 23\text{ dB};$$

$$P_R\,[\text{dBm}] = E[\text{dBm}]- 113\text{dBm}+ 10\lg(\lambda/\pi)^2 \quad . \tag{7.28}$$

Or, turning to radio frequency f using the relation $\lambda = c/f$, get:

$$P_R[\text{dBm}]=E[\text{dBm}] – 113\text{dBm} + 10\lg(3\cdot10^8/f\pi)^2 \;;$$
$$P_R[\text{dBm}]=E[\text{dBm}] + 46{,}6\text{ dBm} - 20\lg f\ [\text{Hz}];$$
$$P_R[\text{dBm}]=E[\text{dBm}] + 46{,}6\text{ dBm} - 120\text{ dB} - 20\lg f\ [\text{MHz}];$$

$$P_R[\text{dBm}]=E[\text{dBm}] – 73,4 - 20 \lg f. \qquad (7.29)$$

Example: The relations between the moderate field intensity at the reception, expressed in decibels relative to 1 microV, and the received power expressed in decibels relative to 1 mW, for a wireless communication system operating at the radio frequency of f = 1,9 GHz

Solution example: From (37) we have:

$$P_R\,[\text{dBm}] = E\,[\text{dBm}] - 73,4 - 20\ \text{Ig f}\ [\text{MHz}] = \\ E\,[\text{dBm}] - 73,4 - 65,57 = E\,[\text{dBm}] - 139\ \text{dB}. \qquad (7.30)$$

7.3.2 Propagation loss for systems of indirect sight (NLOS) and line of sight (LOS).

Most cellular land mobile systems and PCS systems operate under conditions of radio wave propagation in the absence of direct line of sight (NLOS), as shown in Figures 7.1 and 7.2. From (7.24) it follows that the line of sight (LOS) received power decreases as 1 / r2 as the distance r between the antennas. In other words, the average propagation losses increase in proportion of degree n of the distance. The exponent n to systems line of sight without any obstacles in the propagation path of radio waves is equal to 2 (n = 2).

On the basis of experimental data has been developed and is used by most engineers' sufficiently general model for estimating losses in the propagation of radio waves in the absence of direct visibility. This model is described by the following expression:

$$L(d) \sim L_B(d/d_o)^{-n} \qquad (7.31)$$

and indicates that the average propagation loss (L) increase in proportion to a power of the distance. In the formula, the symbol ~ means - in proportion to, and use the following notation:

n — exponent, $3,5 \le n \le 5$;

d — distance between the transmitting and receiving antennas;

d_o — the reference distance and the length of the segment runs to the first obstacle (area free space propagation);

L_B - propagation loss on the LOS road for do, m, (formula (7.23) and (7.24));

L — total loss (propagation loss) combined route consisting of sections of NLOS and LOS.

The exponent n indicates how fast the propagation loss increases with increasing distance.

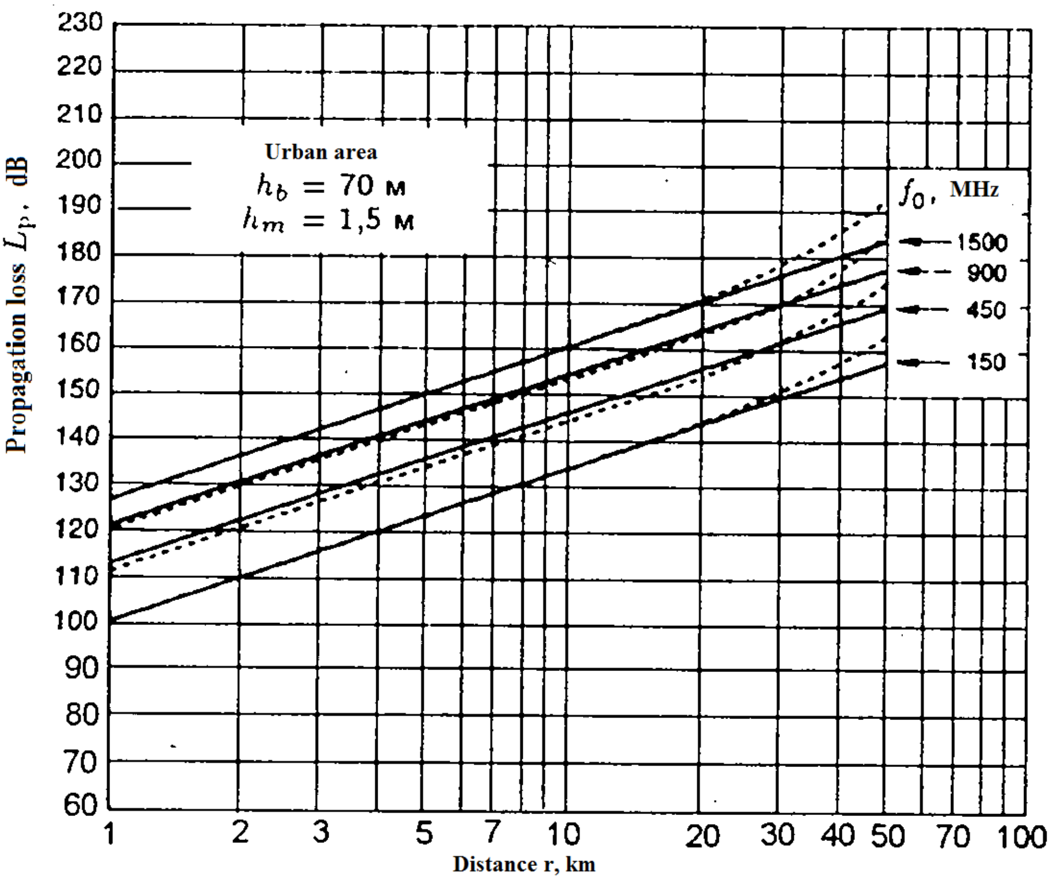
The reference distance d_o suggest that, within it, i.e. between the antenna and the point d_o, there is radio propagation (smooth) in free space. In practice, the values d_o (the length of the route segment, where there is a free space propagation) inside buildings are generally in the range 1 ... 3 m

Absolute average propagation loss L (d), expressed in decibels, defined as the propagation loss from the transmitter to the point on the reference distance L (d_o) plus additional propagation losses described by expression (7.31). In this way

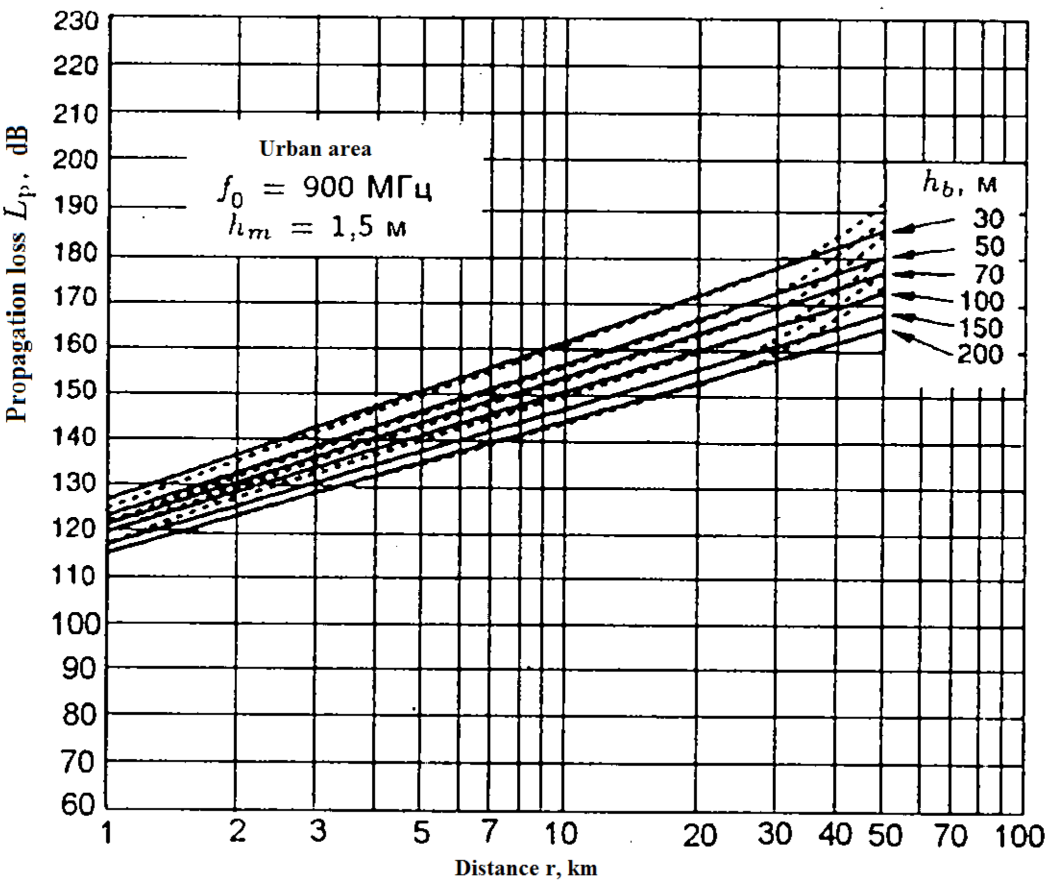
$$L(d)=L(d_o) - 10n \lg (d/d_o). \tag{7.32}$$

The experimental results (see Figure 7.7) shows that for a typical cellular mobile communications systems outside buildings with no direct line of sight (NLOS) $3,5 \le n \le 5$, and for use within the building $2 \le n \le 4$.

Figure 7.8 illustrates the additional experimental results regarding the average propagation loss at frequencies of 900 MHz and 1.75 GHZ.



a)



б)

Figure 7.7 - Propagation loss

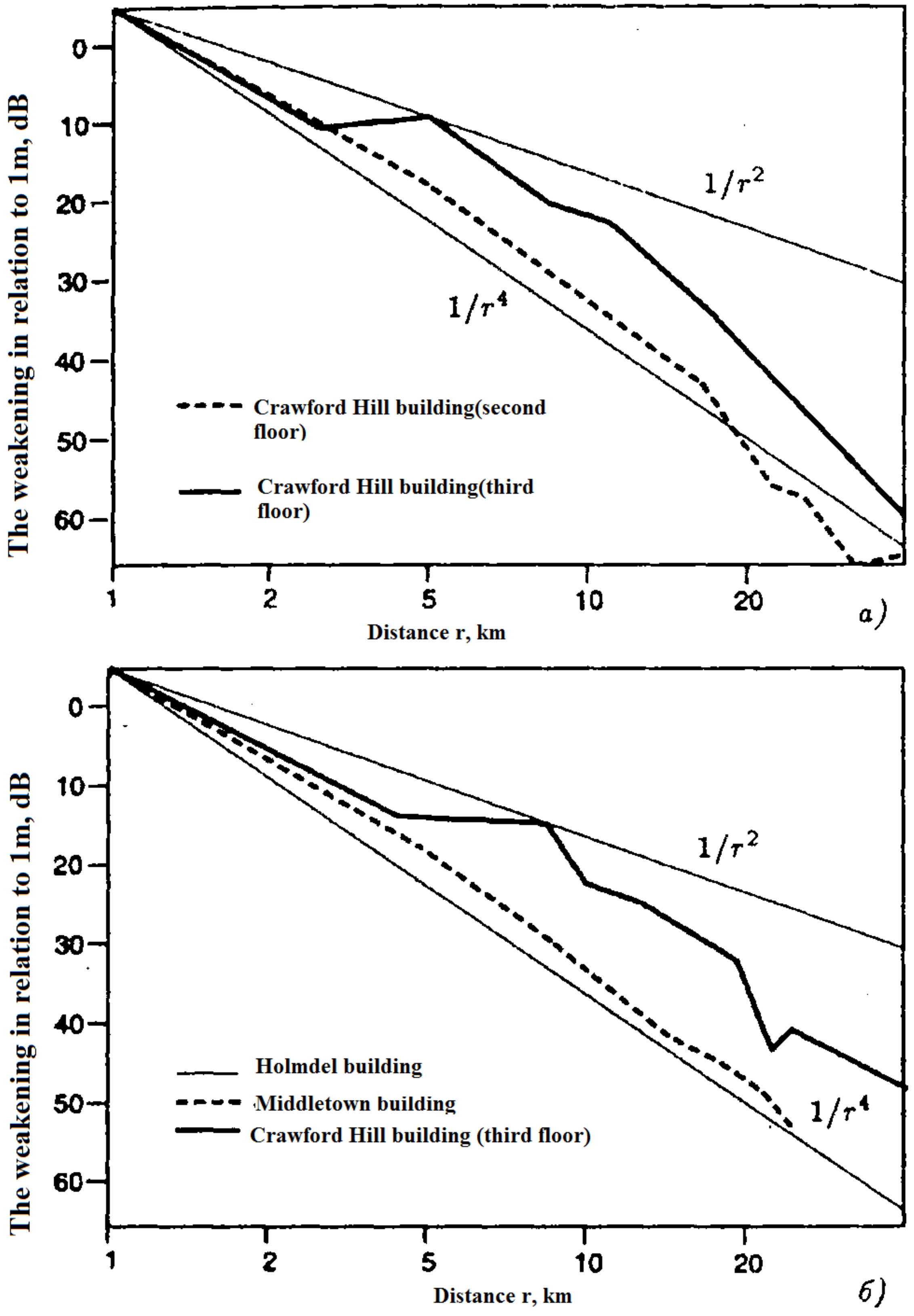


Figure 7.8 - Measurements of attenuation due to the propagation at frequencies 900 MHz (a) and 1.8 GHz (b) for the mobile PCS in range from 1 to 30 m

7.3.2.1 Maximum coverage area (d_{max})

The formula for the communication range, or the maximum distance at which the service can be carried out for propagation in free space within the line of sight, is derived from the ratio (7.19):

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2 . \quad (7.33)$$

In this case, assume that

$$P_R = Pr_{min} \ .$$

It represents the minimum carrier power, which leads to an acceptable, or "threshold" value of the bit error rate. For voice communications as "acceptable, or threshold characteristics" is often taken BER = $3 \cdot 10^{-2}$ transmission without coding and pre-processing. From (7.32) conclude that for the radio communication systems-of-sight (LOS):

$$d_{max} = \sqrt{\frac{P_T G_T G_R}{P_{R\,min}}} \frac{\lambda}{4\pi} = \sqrt{\frac{P_T G_T G_R}{P_{R\,min}}} \frac{c}{f} \frac{1}{4\pi} , \quad (7.34)$$

where d_{max} is expressed in meters.

For more general propagation conditions in the absence of direct line of sight (NLOS) assume that there is a reference distance, or "dead-end" range, which is characterized by the spread of the free space between the transmitter antenna and the nearest obstacle. As shown in Figure 7.1, the initial portion of the radio waves does go under the line of sight (LOS), and then radio waves are scattered and distributed in NLOS conditions.

The maximum distance and range, for a combined LOS and NLOS transmission path is obtained from the equation:

$$P_R = P_T G_T G_R L_{TOT} , \quad (7.35)$$

Where L_{TOT} is the propagation loss for the combined highway LOS and NLOS.

$$L_{TOT} = L_{d0} L_{NLOS} , \quad (7.36)$$

L_{TOT} has two losses components: on the property line of sight (Ld_0 or $Ld_{ОСВ}$) and in the area NLOS (L_{NLOS}). Loss of sight in the area designated as Ld_0, to indicate that the radio waves propagate in LOS conditions only on the distance d_o, the rest of the distance d is necessary to distribute in NLOS conditions. Usually $d - d_o \approx d$, since d_o much less than d. From the previous formulas have:

$$L_{TOT}(d) = \left(\frac{\lambda}{4\pi d_0}\right)^2 \times \left(\frac{d_0}{d}\right)^n . \qquad (7.37)$$

Note that this formula is almost identical to the formula (7.31). There are several designations changed to get a more convenient formula for the communication range.

The expression for the communication range (maximum distance d_{max}) is derived as follows:

$$P_R = P_T G_T G_R L_d , \qquad (7.38)$$

$$L_d = L(d_0)L(NLOS) = \left(\frac{\lambda}{4\pi d_0}\right)^2 \left(\frac{d_0}{d}\right)^n , \qquad (7.39)$$

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d_0}\right)^2 \left(\frac{d_0}{d}\right)^n , \qquad (7.40)$$

$$d^n = \left[\frac{P_T G_T G_R \left(\frac{\lambda}{4\pi d_0}\right)^2}{P_R}\right] d_0^n , \qquad (7.41)$$

$$d = \left[\frac{P_T G_T G_R \left(\frac{\lambda}{4\pi d_0}\right)^2}{P_R}\right]^{1/n} d_0 . \qquad (7.42)$$

7.3.2.2 Determination of system gain (G_S).

The gain of the system is a useful indicator for assessing the characteristics of the system, as it combines many parameters of interest to the designers of radio systems. In its simplest form is applicable only to the apparatus, the gain of the system - it is the difference between the transmitter output power and receiver sensitivity threshold. Receiver sensitivity threshold - the minimum received power required to achieve an acceptable level of performance, such as maximum bit error probability (BER). The gain of the system must exceed or at least equal to the sum of the gain and external to the equipment losses. Mathematically, this is expressed as follows:

$$G_S = P_T - C_{\min} \geq F_M + |L_P| + |L_F| + |L_B| - G_T - G_R, \qquad (7.43)$$

where G_S — system gain in dB;

P_T - Output transmitter power taking into account losses in the antenna splitter and other losses of the antenna connection, dBm;

$C_{\min} = Pr_{\min}$ — the received power of the carrier dB for minimum value of the reception quality index.

Typically $C_{\min}$, dBm maximum value is determined for BER. For the telephone lines of mobile systems according to several standards adopted as a threshold BER = $3 \cdot 10^{-2}$. For data channels in such systems as a threshold may be BER = 10^{-6}. $C_{\min}$ is also called threshold sensitivity; $Pr_{\min} = C_{\min}$, as defined above; L_p - propagation loss between isotropic radiator in the line or in the free space:

$$L_p = -92{,}4 - 20\lg d - 20\lg f, \qquad (7.44)$$

Where d – length of the route, km;

f - carrier frequency, HHz;

L_F - losses in the antenna feeder;

L_B - loss due to branching, i.e. complete loss of the filter and the circulator when the transmitter and receivers are connected to the same line;

G_T, G_R - antenna gains of the transmitter and the receiver relative to an isotropic radiator (although the gain of the antenna depends on the frequency, for simplicity, usually refers to the value corresponding to the center frequency of the range that is reported in the manufacturer's catalog);

F_M - margin for fading on the radio in a system without diversity required to ensure communication reliability index, dB.

Expression (7.44) is similar to (7.23) and (7.24), but this is determined by the radio frequency in gigahertz.

7.3.2.3 The empirical formula for the propagation loss.

To predict the average propagation loss using empirical models based on extensive field measurements. The track runs from the base station antenna to the antenna of the mobile object. The experimental curves for propagation loss are obtained by measuring the power level of the received signal (RF carrier) and subtracting from the power of the transmitted signal. For example, if we have an omnidirectional antenna with a gain of 1, the transmitted power is + 30 dBm, and at some point the received carrier power P_R = - 105 dBm, while the propagation loss

$$L_p = P_T - P_R = +30 \text{ dBm} - (-105 \text{ dBm}) = 135 \text{ dBm}. \qquad (7.45)$$

Since P_T and P_R are expressed in the same units, the loss L_p may be expressed in decibels.

Numerous measurements made by Okumura, have provided the empirical formula for the average propagation loss L_p, dB, in the case of isotropic (ideal omnidirectional), with a gain of 1, base station antennas and the mobile unit. This formula is known as well as a method of predicting Okomury has the form:

$$L_p = \begin{cases} A + B\lg(r) & \text{for urban areas} \\ A + B\lg(r) - C & \text{for a residential suburb} \\ A + B\lg(r) - D & \text{for open areas} \end{cases} \qquad (7.46)$$

Where r - the distance between a base and mobile station, km.

The radio frequency carrier f_o, MHz, base station antenna height h_b, m, and the mobile station antenna height h_m, m; values A, B, C and D are expressed respectively as follows:

$$A = A(f_0, h_b, h_m) = 69.55 + 26.16 \cdot \log(f_0) - 13.82 \cdot \log(h_b) - a(h_m),$$

$$B = B(h_b) = 44.9 - 6.55 \cdot \log(h_b) \qquad (7.47)$$

$$C = C(f_0) = 2 \cdot \left[\log\left(\frac{f_0}{28}\right)\right]^2 + 5.4,$$

$$D = D(f_0) = 4.78 \cdot [\log(f_0)]^2 - 19.33 \cdot \log(f_0) + 40.94,$$

where $a(h_m)=[1,1\cdot\lg(f_0)-0,7]\cdot h_m-[1,56\cdot\lg(f_0)-0,8]$ – for medium-sized and small cities;

$a(h_m)=3,2[\lg(11,75\cdot h_m)]^2 -4,97$ – for big cities.

Formula (55) can be used if the following conditions are performed:

– f_o: from 150 to 1500 MHz;

– h_b: from 30 to 200 m; the expansion of the range is possible (from 1,5 to 400 m);

– h_m: from 1 to 10 m;

– r: from 1 to 20 km; the expansion of the range is possible (from 2m to 80 km).

Figure 7.7 shows the propagation loss L_p, dB, in the urban area, wherein the carrier frequency fo and a base station antenna height h_b are variable parameters. The results, shown in solid lines, prepared by the empirical formula, and the dotted lines - Okomury prediction method. These numerical results indicate that the maximum error is only approximately 1 dB at distances from 1 to 20 kilometers. The results of experimental measurements of the attenuation of radio wave propagation for PCS with a small service area (within the range of 1 to 30 m) is obtained on the basis of AT & T, are illustrated in Figure 7.8. Comparison of experimental data with calculations by (7.46) and (7.47) shows that these formulas can also be used for systems operating at a distance of 3 m.

7.4 Model radio fading caused by multipath propagation

Earlier describes the basic concepts and given a physical representation of the radio propagation paths on mobile direct and indirect visibility. There is a mathematical model of the transmission of an unmodulated sinusoidal carrier for a variety of random propagation paths between a fixed base station and a moving receiver. This theoretical model is useful for further analysis of the distribution of the envelope fades carrier (signal strength), frequency and duration of emission signal fading. These parameters and their representations are required in dealing with certain aspects of the design lines and communication systems (such as the choice of methods for correcting errors and access). For example, the duration and frequency of emissions fading allows the connection between the bit error rate (BER) and the probability of error in the word (WER).

Assuming that the velocity v of the movable object is sufficiently small compared to the product central carrier frequency f_0 wavelength of carrier λ, i.e. $v \ll f_0 \cdot \lambda$, accepted freezes carrier *c(t)* can be represented as:

$$c(t) = \sum_{n=1}^{N} c_n(t) = \mathrm{Re}\left[\sum_{n=1}^{N} z_n(t) e^{j2\pi f_0 t}\right], \qquad (7.48)$$

where $C_n(t)$ — elementary wave;

Re[*] — the real part [·],

$z_n(t)$ — complex random function, which simulates *c(t)*, generated by random changes in the parameters of propagation paths due to the movement of the movable object.

Provided that N is sufficiently large and that all | $z_n(t)$ | equal, according to the central limit theorem, the function can be represented as a narrowband Gaussian process:

$$c(t) = \mathrm{Re}\left[\bar{z}(t) e^{j2\pi f_0 t}\right], \qquad (7.49)$$

where *z(t)* — an integrated low-frequency stationary Gaussian random process with the following properties:

$$\langle \bar{z}(t) \rangle = 0$$
$$\frac{1}{2}\langle \bar{z}(t) z^*(t-\tau) \rangle = \psi_z(\tau) \quad . \qquad (7.50)$$
$$\frac{1}{2}\langle z(t) z(t-\tau) \rangle = 0$$

In terms $\psi_z(\tau)$ — autocorrelation function *z(t)*, which is given by:

$$\psi_z(\tau) = \int_{-\infty}^{\infty} W_z(f) e^{j2\pi f\tau} df \ , \qquad (7.51)$$

where $W_z(f)$ — the spectral density of the process *z*(t)*;
(•)* — complex conjugate.

In a typical mobile-radio system under consideration has an antenna with an omnidirectional radiation pattern in the horizontal plane, and the angle of arrival of each elementary wave has a uniform distribution. The spectral density of the unmodulated carrier is defining shown in Figure 7.9.

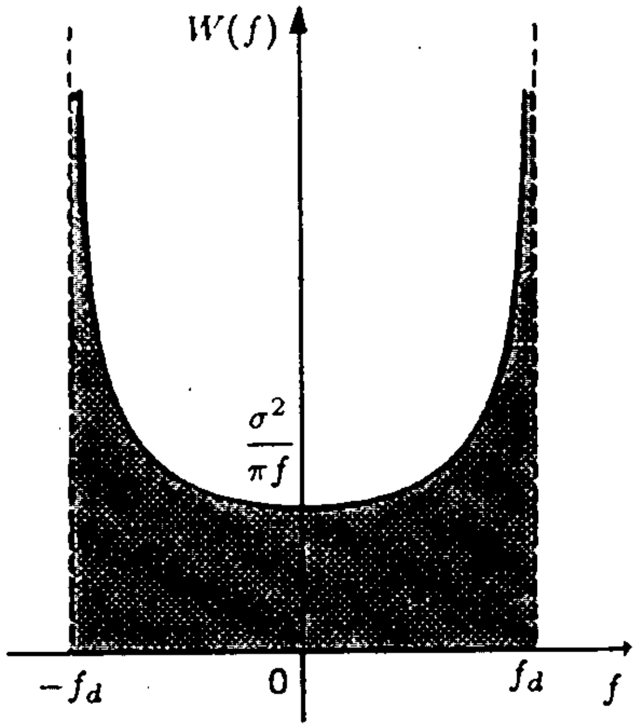


Figure 7.9 - The theoretical spectral density of the driving sine wave (unmodulated carrier)

Thus, we obtain an expression for $\psi_z(\tau)$:

$$\psi_Z(\tau) = \sigma^2 J_0(2\pi f_D \tau) , \qquad (7.52)$$

where $J_0(\bullet)$ - Bessel function of the first kind of zero order;
$f_D = v/\lambda$ - the maximum Doppler frequency.

For land mobile radio systems there are several types of spectral density of the signal fades, which are based on the results obtained above.

From these relations it follows that fading due to multipath can be treated as a multiplicative complex stationary Gaussian process, which is characterized by functions $W_Z(f)$ and $\psi_Z(\tau)$. This fundamental property is used in the development of simulators fading in the design of communication systems with mobile objects.

Control questions:

1) What is "breaking", "fading", "interference" of electromagnetic waves?
2) What is the difference between the diffraction and dispersion?
3) What is the difference between fast and slow fading waves?
4) What is the difference between selective fading and the amplitude?
5) Write the basic formulas propagation loss LOS and NLOS system visibility.

CHAPTER 8

8 Spread Spectrum Systems

8.1 The benefits of spread spectrum

The term "spread spectrum" has been used in numerous military and commercial communication systems. In spread spectrum systems, each carrier signal messages requires considerably wider radio frequency band as compared with a conventional modulated signal. The wider bandwidth allows to get some useful properties and characteristics that are difficult to reach by other means. Spread spectrum is a technique of forming a spread spectrum signal using the additional modulation step, providing not only the extension of the signal spectrum, but its weakening effect on other signals. Additional modulation is not related to the transmitted message. Broadband systems are used due to the following potential benefits:

a) increased noise immunity;

b) providing opportunities for code division multiple access based on it in systems using the CDMA technology;

c) energy stealth thanks to the low spectral density;

d) high resolution when measuring distance;

d) secure communications;

f) ability to withstand the effects of jamming;

i) increased capacity and spectral efficiency in certain cellular systems, personal communications;

a) gradual reduction of communication quality by increasing the number of users at the same time occupying the same RF channel;

l) implementation of low cost;

m) the availability of modern electronic components (integrated circuits).

In accordance with the architecture and modulation types used by the spread spectrum system can be divided into the following groups:

1) System with direct spread spectrum-based pseudo-random sequences (PRS), including the CDMA system.

2) Systems with the restructuring of the operating frequency (a "jump" frequency), including CDMA systems with slow and fast restructuring of the operating frequency.

3) multiple access spread spectrum carrier sense (CSMA).

4) Systems with the restructuring of the temporal position of the signals.

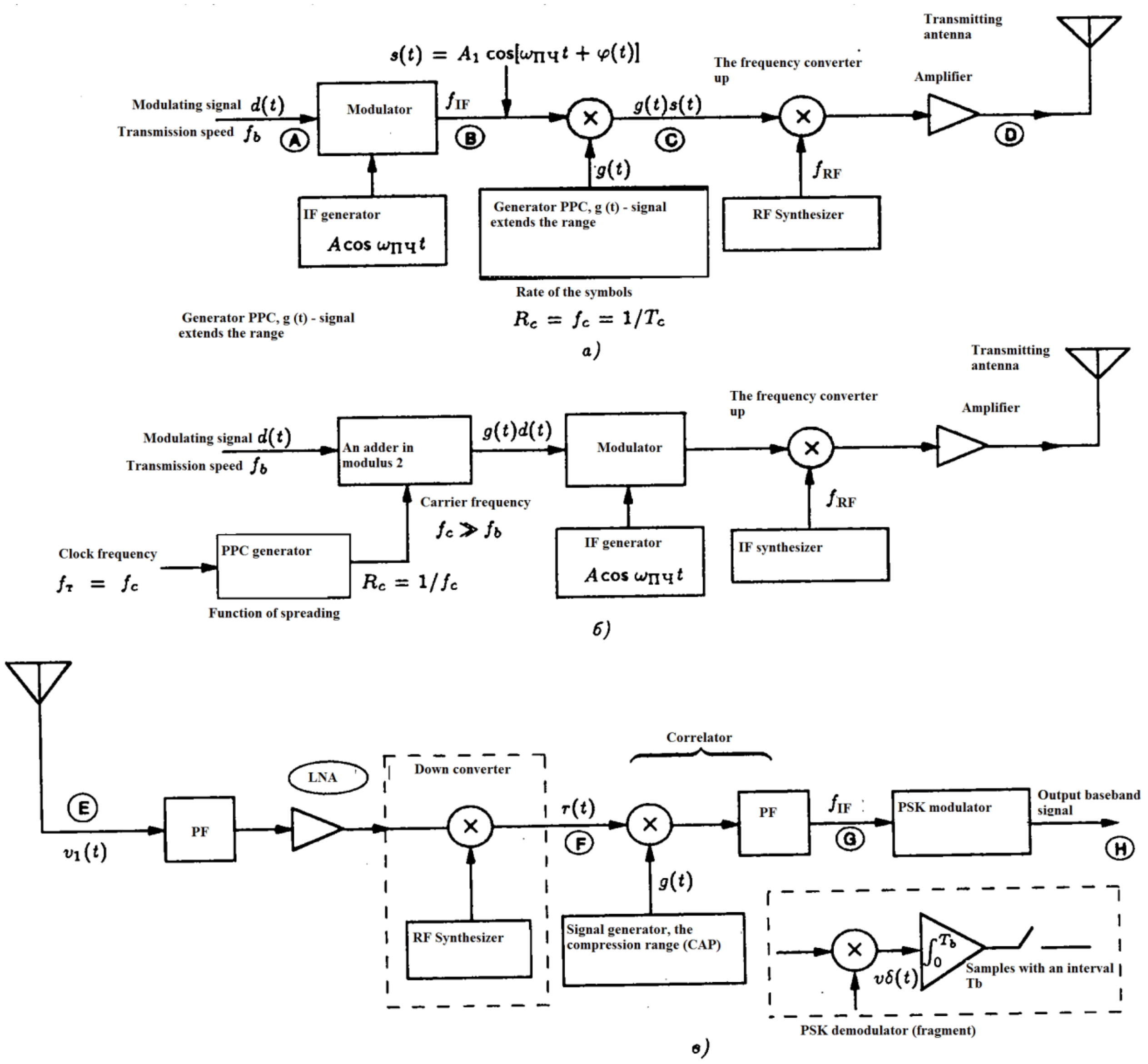
5) Systems with linear frequency modulation signals (chip modulation).

6) System with mixed spreading methods.

In mobile radio systems employing direct spreading adjustment operating frequency and range of the control carrier. These techniques are discussed in more detail below [29].

8.2 Basic concepts Spread Spectrum Systems

8.2.1 Direct expansion of the range with the help of pseudo-random sequences.



a - transmitter signals with QPSK and subsequent spreading, b - spread spectrum transmitter in baseband, c – receiver.

Figure 8.1- Block diagram of Direct Spread

$$s(t) = \sqrt{2P_S}\, d(t) \cos \omega_{ПЧ} t, \qquad (8.1)$$

where *d(t)* — unfiltered two-level signal that have two states: +1 and -1;

$\omega_{пч}$ — intermediate frequency;

P_s — power of signal.

As a signal spreading g(t) signal is used pseudo-random sequence (PRS) with the symbol rate $f_o = 1/T_c$ [30].

As a result, re-modulating formed PSK spread spectrum signal

$$v(t) = g(t)s(t)\sqrt{2P_S}\,g(t)d(t)\cos\omega_0 t\ . \qquad (8.2)$$

This intermediate frequency signal is then transferred up to the desired frequency synthesizer via radio frequency (RF). Here ω_0 is either intermediate ω_{IF} or radio frequency ω_{RF}.

Within one cell mobile radio systems, as a rule, there are several subscribers simultaneously using telephone, each of which uses the same carrier frequency *fRF* and occupies the same bandwidth B_{RF}

The process of generating signals in a spread spectrum multiple access system takes place in two stages: the modulation and spectral spreading (or secondary modulation by the pseudo-random sequence). The secondary modulation by means of an ideal operation of multiplication of *g(t)s(t)*. With this multiplication is formed an amplitude modulated two-way carrier signal. The first and second modulators can be interchanged without changing the characteristics of the potential system

The signal *g(t)s(t)* spread spectrum is converted up to the desired radio frequency. Although the conversion rate is up or down for most systems it is almost a necessary process, though this step is not determinative. Hence assume that the signal *g(t)s(t)* is transmitted and received at an intermediate frequency, eliminating from consideration subsystem transformation frequency up and down.

Thus, the receiver input receives the sum of M independent spread spectrum signals occupying the same RF bandwidth:

$$r(t) = \sum_{i=1}^{M} g_i(t)s_i(t) + I(t) + n(t), \qquad (8.3)$$

Where M — the number of simultaneously transmitting (active) users;

$g_i(t)$ — CAP of i-th pair of transmitter-receiver;

$s_i(t)$ — modulated signal;

$I(t)$ — interference (intentional or site);

$n(t)$ — AWGN.

At the receiver, the user to whom the message is intended, there is a timing synchronized signal *gi(t),* and compresses the spectrum representing the replica of the transmitter signal corresponding to the SRP. Obtained after dispreading of narrowband PSK signal is demodulated. To study the fundamentals of building a spread spectrum systems assume that it is using binary phase-shift keying

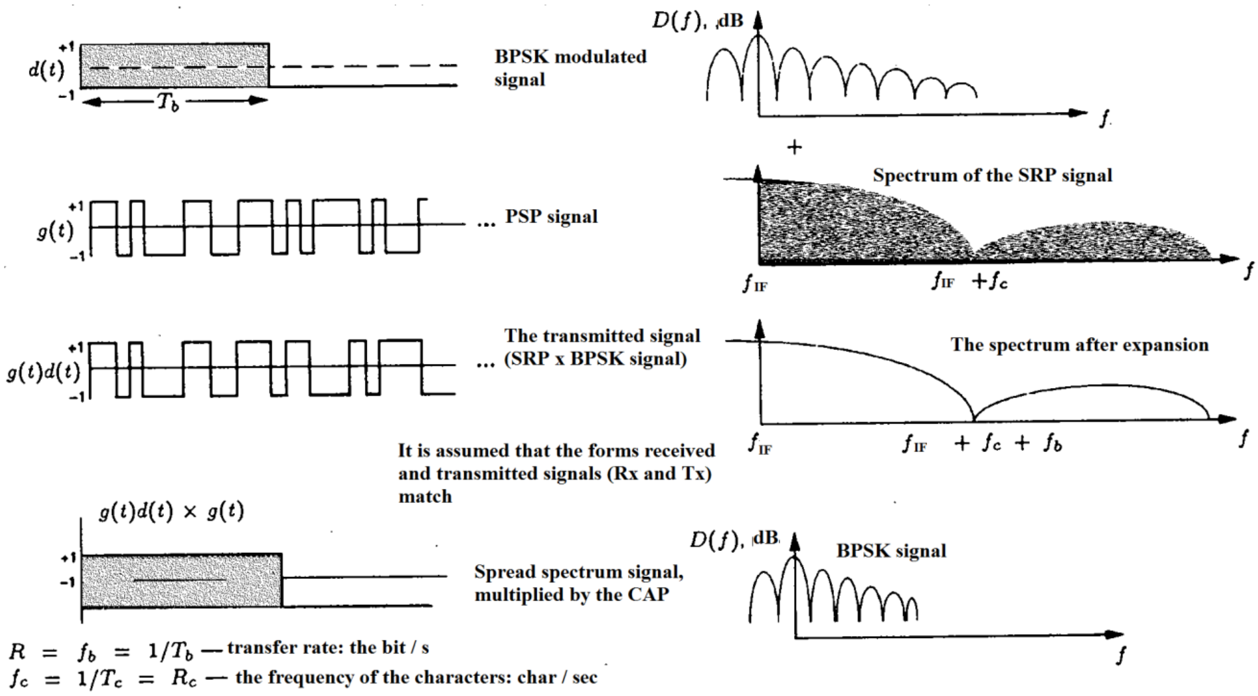


Figure 8.2 - Time and spectral chart the expansion of the spectrum

If an ensemble of correlated signals CAP is selected therefore after despreading operation is preserved only the modulated useful signal. All other signals are being uncorrelated retain broadband and have a spectral width greater than the cut off filter bandwidth of the demodulator. Figures 8.1 and 8.2 are shown simplified temporal and spectral diagrams qualitatively illustrating the processes of expansion and contraction of the spectrum signals. In particular, they lack the carrier signal.

Winning at the correlation processing Gp or just processing gain - a factor that shows how many times the signal / noise ratio *(S/N)* or the signal to noise ratio *(S/I)* at the output is increased compared with the corresponding values in the input. For example, if *(S/N)*in or *(S/N)*in at point F in Figure 8.1, a is 5 dB after despreading the desired signal using a matched with him reference signal SRP ratio *(S/N)out* in point G is equal to 27 dB, the processing gain is 22 dB.

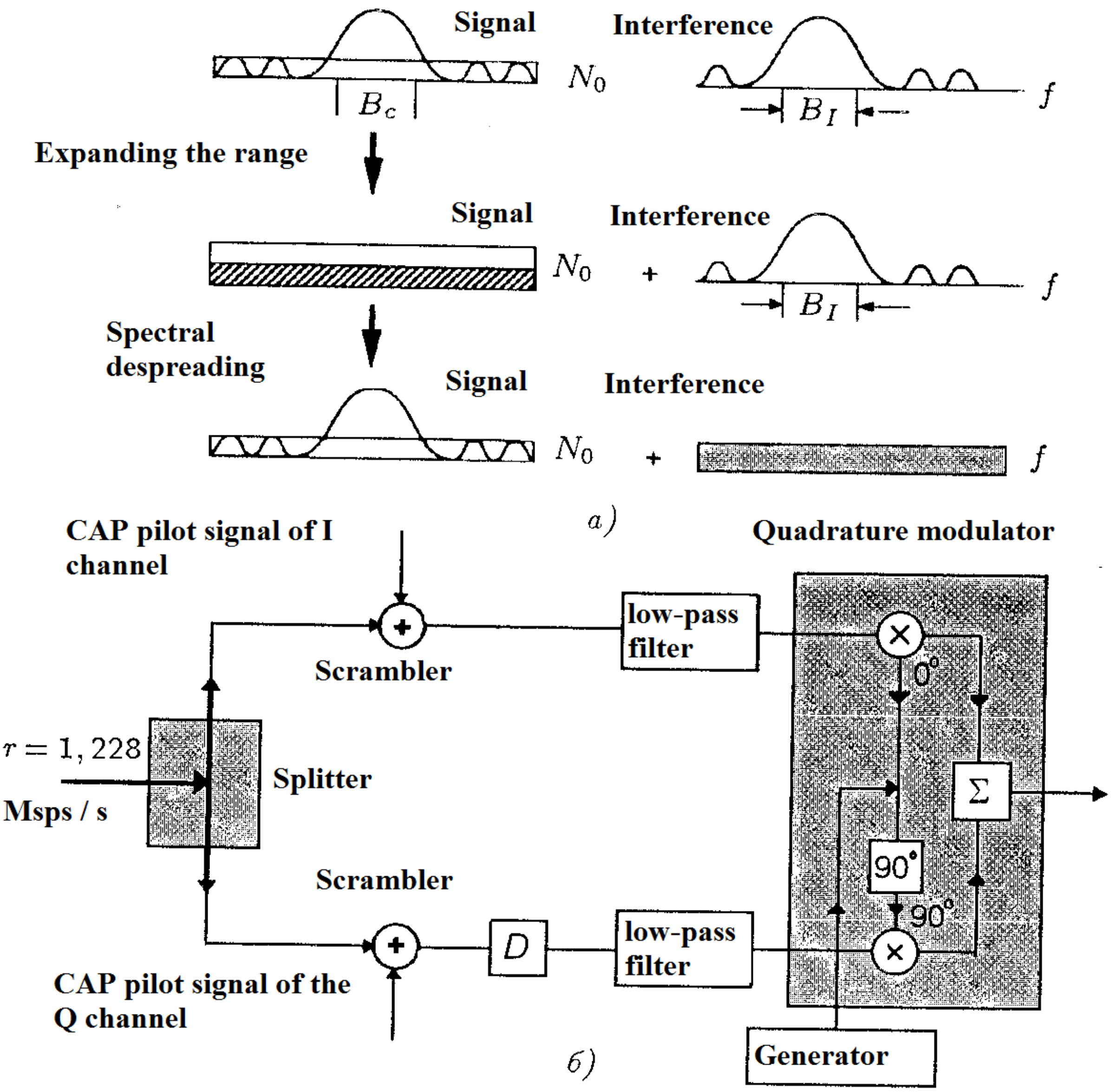


Figure 8.3 - Illustration of expansion and contraction of the spectrum

Thus, the processing gain G_p can be determined as follows:

$$G_p = (S/N)_{вых}/(S/N)_{вх}\ . \qquad (8.4)$$

Available processing gain is often estimated by the relation

$$G_p = \frac{BW_{РЧ}}{BW_{МОД}} = \frac{BW_{РЧ}}{R_{ИНФ}} = \frac{BW_{РЧ}}{f_b}, \qquad (8.5)$$

where BW_{hf} — RF strip width;
BW_{mod} — the bandwidth of the modulating signal.

The bandwidth of the baseband signal is $R_{inf} = f_b$, i.e. the transmission rate of the modulating signal when its spectrum efficiency is 1 bit / (s • Hz).

M_j interference immunity factor takes into account the value of the required signal / noise ratio $(S/N)_{out}$ and possible energy losses in the implementation of the system (L_{sys}) and is defined as follows:

$$M_j = G_p - [L_{cucm} + (S/N)_0]. \tag{8.6}$$

Example. Suppose that in a CDMA system with a direct spread spectrum data transmission rate f_b = 10 Kbit / s, and the frequency of binary symbols PS used for spreading is f_o = 10 Mbit / s. Determine the coefficient of interference resistance M_j, if necessary relation signal / noise *(S/N)out* output when the error probability P_b = 10-6 is equal to 12 dB.

According to (8.5) the processing gain

$$G_p = \frac{BW_{PЧ}}{R_{ИНФ}} = \frac{20\,\text{MHz}}{10\,\text{Kbit/s}} = 2000 \text{ or } 33\,\text{dB}$$

Here, the width of the RF bands was determined by the zeros of the first QPSK signal spectrum, so the repetition frequency of binary symbols f_o = 10 Mbit / s, it is 20 MHz. Such a simplified definition of the width of the RF band is often used in the analysis of simple spread spectrum systems. If the energy losses in the implementation of the system, due to non-ideal formation processes, tracking and demodulation take equal L_{sist} = 2 dB, the interference immunity factor:

$$M_j = G_p - [L_{cucm} + (S/N)_0] = 33\,\text{dB} - [2\,\text{dB} + 12\,\text{dB}] = 19\,\text{dB}$$

8.2.2 Expanding the range of frequency by tuning program.

The concept of spread spectrum systems by software adjustment of the working frequency is very similar to the concept of systems with direct spreading. Block diagrams of the transmitting and receiving sides of the system shown in Figure 8.4. Here PS generator binary synthesizer controls the frequency with which a transition ("hopping") from one frequency to another of the plurality of available frequencies. Thus, there is the effect of spreading achieved by the pseudo-random frequency hopping carrier, the value of which is selected from the available frequencies f_1,..., f_N, where N may reach values of a few thousand or more. If the speed adjustment messages (speed change of frequency) exceeds the rate of transmission of messages that have a set of frequency-agile. If tuning speed less than the speed of transmission of messages so that the range adjustment is transferred a few bits, then we have a system with slow frequency hopping. [31]

If Δf - frequency interval between adjacent discrete frequencies and N - total number of available frequencies, i.e. frequency channels, the processing gain in the frequency hopping:

$$G_p = \frac{BW_{RF}}{BW_{Inf}} = \frac{N\Delta f}{\Delta f} = N \qquad (8.7)$$

The most commonly used methods of spreading (direct expansion or frequency hopping), must have the PS by which solved the problem of expansion / contraction of the spectrum and synchronization. Various PS and their properties are discussed further.

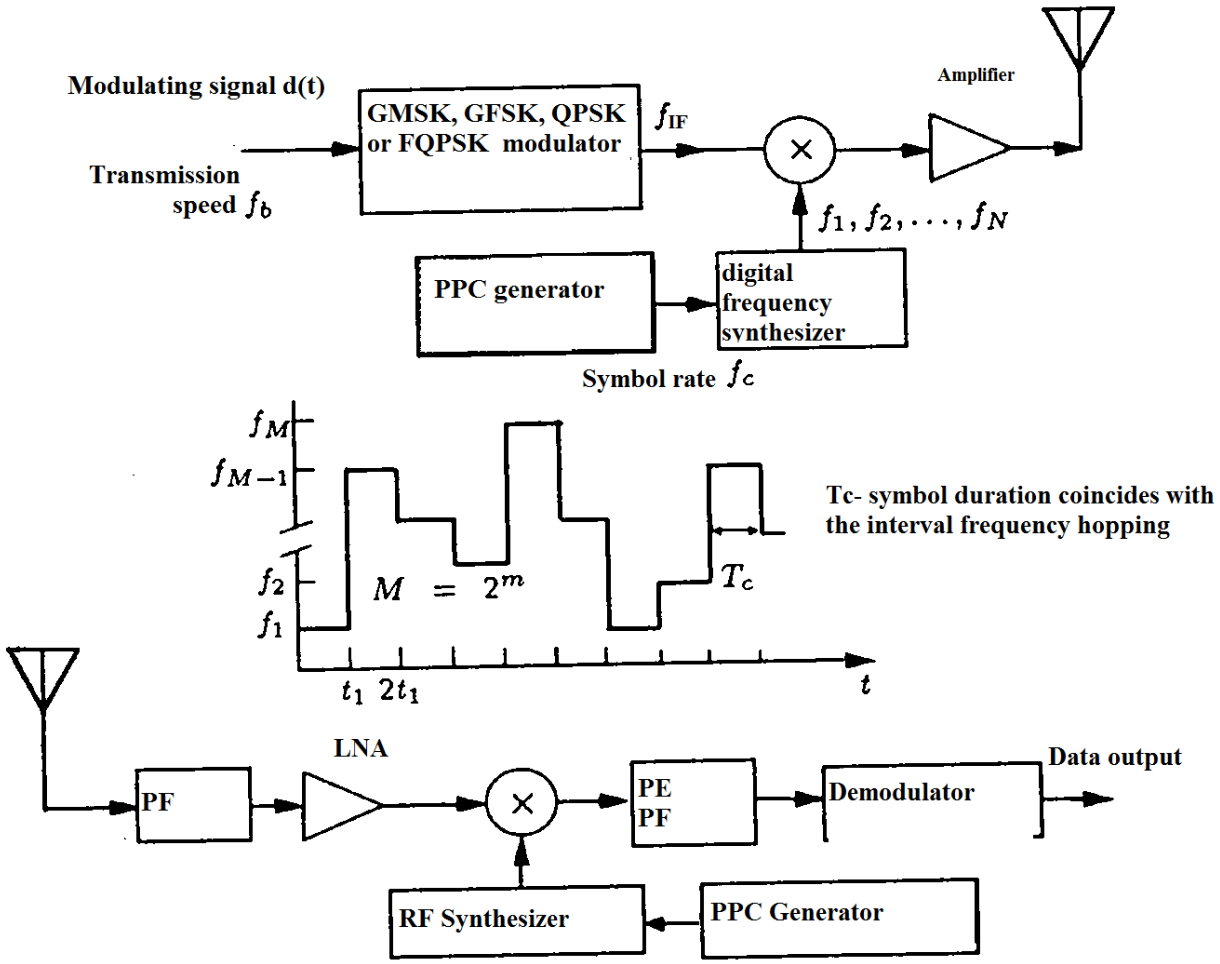


Figure 8.4-Block diagram of the transmitter and receiver of a spread spectrum by frequency hopping

8.3 The pseudo-random sequence

8.3.1 Definitions and Requirements.

In digital radio communication systems or personal, used in CDMA and expansion of the range, using pseudo-random sequences to solve the following tasks:

a) Spread spectrum modulated signal in order to increase the bandwidth for transmission.

b) separation of signals of different users using the transmission same band in multiple access.

To solve these problems, the sequence should have special correlation properties.

The autocorrelation function $R_a(\tau)$ generally defined by the integral:

$$R_a(\tau) = \int_{-\infty}^{\infty} f(t) f(t-\tau) d\tau \quad . \tag{8.8}$$

It is a measure of the correspondence between the signal *f(t)* and its replica shifted in time by τ.

Interrelation functions $R_{vz}(\tau)$ is a measure of the respective two different signals *f*(t) and *g(t)* when a time shift τ is determined on the integral

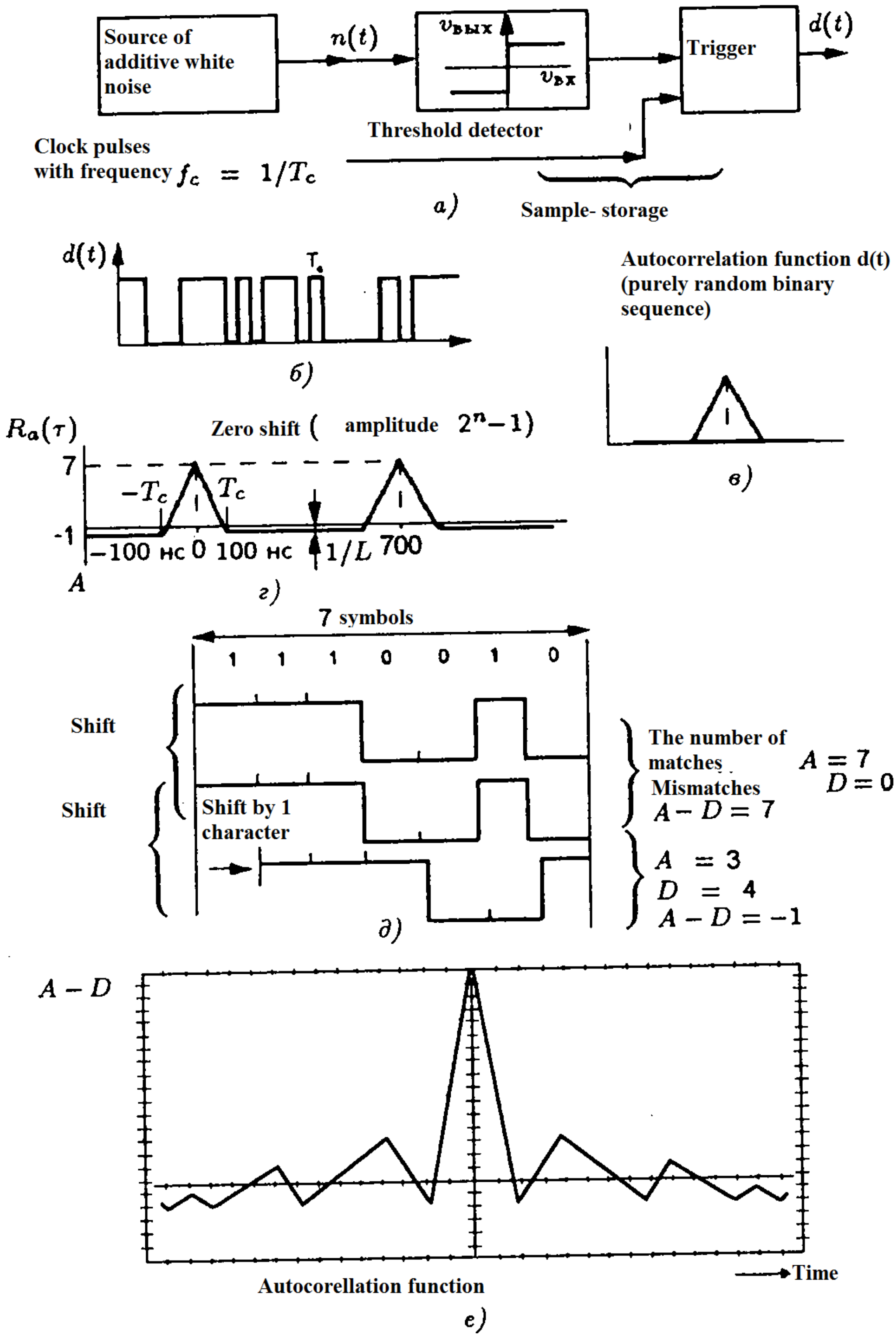
$$R_{B3}(\tau) = \int_{-\infty}^{\infty} f(t) g(t-\tau) d\tau \quad . \tag{8.9}$$

In known radio systems as the spreading signal used binary digital PS. Auto and interrelation functions of these sequences in the discrete shifts, multiple symbol duration in the region of interest is calculated by counting the number of matches (A) and mismatches (D) for character at a time (bitmap) comparison (see Figure 8.5, e).

For spreading and uniform load transmission band spectral density of a single sequence should be uniform, as in the AWGN. Such a sequence can be obtained by the circuit shown in Figure 8.5, and wherein the noise-like digital pattern sequence is formed by restricting the analog signal AWGN combined with the operation of "sampling-storage". The sampling frequency (rate) is equal to the frequency of the symbol: $f_o = 1/T_c$. The autocorrelation function of the signal random sequence is shown in Figure 8.5, b.

The presence of a single narrow emission autocorrelation function at τ = 0 is a very important feature and simplifies the synchronization of the receiver. If the sequence length N symbols are repeated periodically, it turns pseudonoise or pseudorandom sequence. For pseudo-random sequence autocorrelation function is periodic (see Figure 8.5 g).

The second and more difficult problem solved by the PS in a CDMA system with many users, is the separation of signals of different users using the same transmission band. PS signal serves as a signal "key" for each user and allows the receiver to allocate it intended signal. Therefore, the full ensemble of the PS should be chosen such that the cross-correlation between any two sequences was fairly small. This helps to minimize the level of adjacent channel interference (ACI). Theoretically, a value of zero cross-correlation is ensembles orthogonal spread spectrum signals (for example, the basis functions of the Fourier series and the Walsh function).



a - synchronous random sequence generator; б - timing chart of a random sequence; в - autocorrelation function; г - autocorrelation function of a short sequence length of 7 characters; д - the number of matches and anticoincidence; е - calculated as the difference of the autocorrelation function.

Figure 8.5 - The autocorrelation properties of a random sequence

However, in real radio communication systems it is required to provide ease of formation of the coherent PS bandwidth for transmitting and receiving sides. Among the most well-known and well-studied PS are maximal length sequences (m-sequences). They are very attractive for spread spectrum systems, aimed at a single user, and are widely used in military applications. From the point of view of the requirements-correlation properties required in CDMA systems, cellular or personal communications more interesting are the Gold sequences, Kasami and Walsh. In some cases, they are combined with τ-sequences. The following discusses some of the sequences and their basic properties.

8.3.2 m-sequence.

Consider first linear maximal length codes or sequences with a maximum length shift register (τ-sequence), which play an important role in digital systems, spread spectrum systems and systems for measuring distance. Figure 8.6 shows the hardware implementation of τ-sequence generator and a corresponding correlator, or matched filter data used in the receiver. The generator comprises a chain of serially connected D-triggers, the outputs Q of which are connected to the inputs of subsequent D triggers, except for the first trigger input Do.

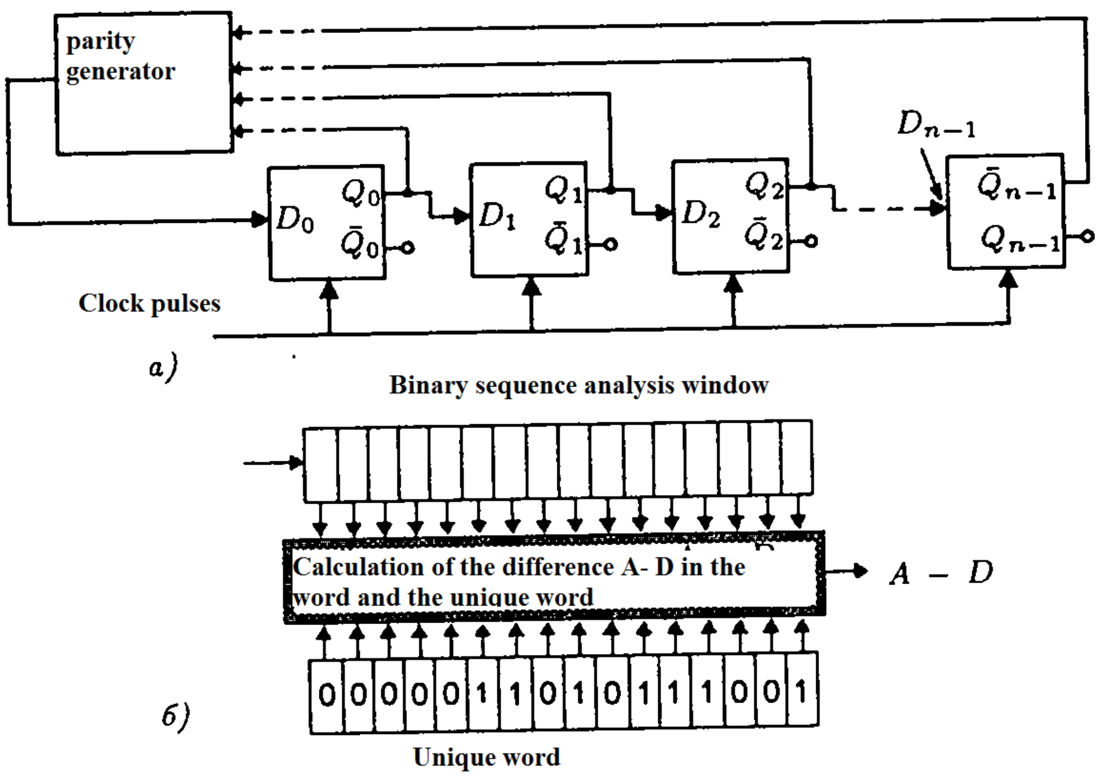


Figure 8.6 - PS oscillator circuit (a) and the corresponding correlator - filter matched data (b)

Some of the Q outputs are not connected to the trigger generator parity bits, as noted by dashed lines in figure. The total number of triggers n and the number of triggers coupled to parity generator, respectively, define the length and properties of formed PS. At the output of parity generator logic 0 is formed in the presence of an even number of logic 0 input and the logic 1 in the presence of an odd number of logical 1 at the inputs. For linear codes the maximum length can always find a how to connect the outputs of triggers to the parity generator, which formed a sequence of maximum length of period:

$$L = 2n - 1 \text{ symbols,} \tag{8.10}$$

where *n* — number of trigger.

T a b l e 8.1- length L and S number PS maximum length m for a given number of bits (triggers) of the shift register n

The number of bits (flip-flops) n	The sequence length, L = 2n -1	Number of m-sequences C	D0 to P = 2n -1 in scheme
3	7	2	Q1 ⊕ Q2
4	15	2	Q2 ⊕ Q3
5	31	6	Q3 ⊕ Q4
6	63	6	Q4 ⊕ Q5
7	127	18	Q5 ⊕ Q6
8	255	16	Q1 ⊕ Q2 ⊕ Q3 ⊕ Q7
9	511	48	Q4 ⊕ Q8
10	1023	60	Q6 ⊕ Q9
11	2047	176	Q8 ⊕ Q10
12	4095	144	Q1 ⊕ Q9 ⊕ Q10 ⊕ Q11
13	8191	630	Q0 ⊕ Q10 ⊕ Q11 ⊕ Q12
14	16383	756	Q1 ⊕ Q11 ⊕ Q12 ⊕ Q13
15	32767	1800	Q13 ⊕ Q14

Table 8.1 shows the logic connections to the inputs of triggers output a parity bit generator in the circuit of Figure 8.6, but for values of n from 3 to 15. The length of the resulting m-sequences may be from 7 to 32767 bits. Also in the table shows one of the possible options for connecting the output of triggers of the shift register with the parity bit generator. There are other options that lead to different m-sequences with low cross-correlation. The upper limit for the number of different m-sequence is determined by the expression:

$$S \le (L - 1)/n. \tag{8.11}$$

The values of S are given in Table 8.1. In one period of the m-sequence contains 2*n*-1 - 1 zeros and 2*n*-1 units.

If the original m-sequence consisting of the symbols (0,1), substitution of symbols 0 to 1 and 1 to -1 and receive a sequence of symbols (-1, + 1), a periodic autocorrelation function is given by:

$$R_a(\tau) = L = \begin{cases} 2^n - 1, & \tau = 0; \\ -1, & \tau \neq 0 \end{cases}$$

And is the best in the sense that there is no any other binary sequence with a minimum value of the autocorrelation function for $\tau \neq 0$. This property of m-sequences is important in their use as sinhropreambul to provide symbol and frame synchronization.

Since m-sequence is a periodic sequence, it cannot be considered accidental. But it can still be determined by the statistical properties of the series of ones and zeros. Indeed, in each period, half of the series has a length of 1, a quarter of the series - a length of 2, the eighth of the series - the length of 3 and etc.

Example. Create a table and construct the autocorrelation function of the m-sequence of length 23 - 16 = 7 characters, assuming that the frequency of the symbol is f_o = 10 Msps. / S and the reference sequence has a structure 1110010

Solution. As a result of counting the number of matches A and mismatches D of reference sequence and its cyclic shifts on one character to obtain the following data listed in Table 8.2

T a b l e 8.2 - Result calculation example

Shift number	Sequence	Number of matches (A)	Number of mismatches (D)	A-D
0	1110010	7	0	7
1	0111001	3	4	-1
2	1011100	3	4	-1
3	0101110	3	4	-1
4	0010111	3	4	-1
5	1001011	3	4	-1
6	1100101	3	4	-1

The resulting autocorrelation function of the signal m-sequence is shown in Figure 8.5 g. Note that the values of the autocorrelation function for all shifts except 0, 7, 14 and etc., are equal to -1. For these numbers, shifts the value of the autocorrelation function maximum and equal to 7.

The maximum value of the autocorrelation function is called the maximum emission of the autocorrelation function. This spike is used to code or framing. For intermediate values of time shift lying between 0 and +1 or -1, the autocorrelation function is linearly decreasing. Therefore, the autocorrelation function of the m-sequence has a triangular shape as shown in Figure 8.5.

Two or more independent signals can be simultaneously transmitted in the same band, and then successfully allocated when their code sequences are cyclic shifts m-sequences by more than one character. In range measurement systems can be provided within the measurement accuracy of the duration of one symbol, when used as a marker in the emission maximum of the autocorrelation function.

8.3.3 Sequence of Gold.

Compared with conventional m-sequences, the Gold sequence is more attractive for a CDMA system with many users. These systems require a significantly larger number of sequences with good correlation properties between them.

This method consists of mod 2 addition of two different m-sequences, clocked one clock generator (see figure 8.6). The most important point in the formation of Gold sequences with "good" correlation properties is that they can only be used by special pair of m-sequences called preferred.

Since both m-sequences have the same length L and the single clocked generator, the Gold sequence is formed by a length L, but is not a maximal length sequence. Let n - number of bits in the shift register m-sequence generator, then the length Gold sequence $L = 2n - 1$.

Calculate the number of different Gold sequences generated using two m-sequence generators for different initial conditions. Recall that for any new cyclic shift of the initial conditions of the m-sequence generators, a new Gold sequence.

Since each m-sequence has a length L, then the number of the various shifts between them is also equal to L. Therefore, the Gold sequence generator based on two different m-sequences may form $L = 2n — 1$ Gold sequences. By selecting the appropriate pair of m-sequences can receive ensemble Gold sequences with "good" correlation properties.

8.4 Characteristics of Direct Spread system

One advantage of spread spectrum systems is the ability to withstand the effects of interference that other systems can completely disrupt communication. This section discusses the characteristics of systems with direct spread in conditions of relatively narrow-band interference and heat, i.e. AWGN.

8.4.1 Spreading property with respect to thermal noise.

Referring to the circuit shown in Figures 8.1 and 8.2, and note that the expansion of the range of the signal provided by the second modulator using spread spectrum signal $g(t)$ in the form of a cap with a symbol rate $R_c = f_0 = 1/T_c$. Spread spectrum signal does not depend on signal communication with a repetition rate of information symbols $f_b = 1/T_b$

Consider the simplest case of QPSK without filtering when the change of the signal states of +1 and -1 occurs at a rate of $f_b = 1/T_b$. Changing the states +1 and -1 signal SRP occurs at a rate $f_0 = 1/T_c$ (see Figure 8.2). If consider a spread spectrum system in general, it can be seen that the transmitted message signal $d(t)$ is multiplied twice in the signal expansion / contraction range of $g(t)$ in the form of the SRP. Since $g2(t) = 1$, then the influence of the signal $d(t)$ does not appear in the output signal of despreading receiver. Thermal noise AWGN or entered in the receiver portion of the communication channel subsystems, low-noise amplifier (LNA) and down converter. AWGN is inherently broadband, and has approximately a Gaussian probability density function. Noise band LNA and down converter is usually exceeds the bandwidth of the spread spectrum signal.

The despreading process is performed on the multiplication noise dither signal, whereby a change of polarity of the noise realization in the nominally random times that are multiples of the duration of $T_c = 1/f_0$ PPC symbols. Polarity reversal has no effect on the spectral density function and a probability density distribution AWGN. Therefore, the P_e system for spread spectrum under the effect of AWGN saved same as in the system without spreading the appropriate choice of modulation / demodulation: $P_e = f(E_b/N_o)$. For example, $P_e = f(E_b/N_o)$ for a spread spectrum system and coherent demodulation of BPSK signals is given by:

$$P_e = (1/2) erfc\left(\sqrt{E_b/N_0}\right), \tag{8.12}$$

where $E_b = CT_b$ — specific energy consumption, the average received signal energy per bit message;

C — the average power of the received carrier;

N_o — spectral noise density, i.e. the noise power per 1 Hz bandwidth;

$T_b = 1/f_b$ — the duration of the message bit;

f_b — transmission rate, bit / s.

Similar conclusions can be drawn regarding the equivalence of the characteristics of the probability of error for other types of modulation.

8.4.2 The weakening of the influence of narrow-band interference.

Assume that the capacity of the AWGN bandwidth substantially less power narrow-band interference. It is shown that harmonic interference is the "worst" in the class of narrow-band interference. Use the notation and methods of analysis. The receiver input signal is given by:

$$v_{np}(t) = \sqrt{2P_c}\, d(t) g(t) \cos\omega_0 t + \sqrt{2P_J}\cos(\omega_0 t + \theta), \tag{8.13}$$

where $d(t)$ — message transmitted signal at the input of the transmitter and the receiver output;

$g(t)$ — PS signal with the frequency of the symbols $f_o = 1/T_c$;

ω_0 — the carrier frequency or an intermediate frequency after down conversion;

P_J — interference power at the receiver;

P_c — the power of the useful signal at the receiver;

θ — random phase uniformly distributed in the range [0, π].

When despreading the input signal is multiplied by a synchronous signal PS $g(t)$. In the presence of simplifying assumptions $g2(t) = 1$, so the input signal of the integrator:

$$v'_0(t) = \sqrt{P_c}\,d(t) + \sqrt{P_J}\,g(t)\cos(\theta). \quad (8.14)$$

If the duration of the bit period T is much greater than the carrier frequency of $T_o = 1/f_o = 2\pi/\omega_0$, or it is a multiple of the carrier half-period, at the input of the integrator demodulated interference spectral density $G_J(f)$ is given by:

$$G_J(f) = \frac{P_J\overline{\cos^2\theta}}{2f_0} = \frac{\sin \pi f/f_0}{\pi f/f_0}. \quad (8.15)$$

The modulated interference is broadband, with the first zero spectral density occur with $f = f_o$. Equivalent noise spectral density is located in the vicinity of the frequency frf (see Figure 8.2); her first zeros occur at frequencies $frf \pm f_o$ After integrating filter with discharge having an equivalent bandwidth $f_b = 1/T_b$, have:

$$G_J(f) = \frac{P_J\overline{\cos^2\theta}}{2f_0}, \ |f| \le f_b. \quad (8.16)$$

Since the phase θ relatively narrow-band interference is a random variable with a uniform distribution and independent of the carrier phase of the desired signal, then $\overline{\cos^2\theta} = 1/2$ and the spectral density of narrow-band interference at the output of the demodulator will be determined by the following expression:

$$G_J(f) = \frac{P_J}{4f_0}, \ |f| \le f_b. \quad (8.17)$$

From (8.15) and (8.17) have that the harmonic narrow-band interference, which has the power PJ is the frequency $\omega_0 = 2\pi f_o = 2\pi f_{рч}$ converted into a broadband signal having a substantially uniform spectral density $G_J(f) = P_J/4f_o$. Thus, the spectral density of the noise at the output of the demodulator is inversely proportional to the frequency of the symbol PS (f_o). The spectral density of the interference $GJ(f)$ is defined for positive and negative frequencies $-f_b \le f \le f_b$. How important are only positive frequencies, so introduce the spectral density, defined only for positive frequencies, $0 \le f \le f_b$:

$$I(f) = 2G_J(f), \qquad 0 \le f \le f_b. \quad (8.18)$$

The expression for the probability of error (8.12) can also be used in the case of narrow-band interference, assuming that the interference I in the demodulated baseband signal at the input decision unit has properties AWGN. In the case of coherent demodulation of PSK signals have:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{I(f)}}\right) = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{2P_J/(4f_0)}}\right) = \frac{1}{2} erfc\left(\sqrt{\frac{P_s}{P_J}\frac{f_0}{f_b}}\right). \quad (8.19)$$

The value of

$$P'_J = \frac{P_J}{2(f_0/f_b)} \quad (8.20)$$

It can be regarded as the effective interference power. Therefore, the ratio of signal power P_c to the effective power determine the probability of error in a spread spectrum system

From (8.19) it follows that the ratio of the symbol rate to the transmission rate (f_0/f_b) determines the degree of attenuation of narrow-band interference. Therefore, the processing gain can be defined as

$$G_p = \frac{f_0}{f_b}. \quad (8.21)$$

In subsection 8.2.2, according to the equations (8.4) and (8.5), processing gain is formally defined as

$$G_p = \frac{(S/I)_{вых}}{(S/I)_{вх}} = \frac{BW_{рч}}{f_b}. \quad (8.22)$$

Here $(S/I)_{out}$ is the signal to noise ratio at the output of the demodulator, $(S/I)_{in}$ of I - signal to noise ratio at the receiver input, i.e. here the replacement value of N (the noise power) on the value of I (interference power) that adequately characterizes the situation under the influence of narrow-band interference.

8.4.3 Experimental verification of the degree of suppression of narrowband interference.

To confirm the possibility of suppressing narrow-band interference in spread spectrum system was developed structural diagram according to Figure 8.1 [32]. The experimental model were selected, intermediate f_{pch} frequency = 70 MHz, the transmission rate of messages f_b = 10 Kbit / s and the symbol rate PS f_s = 2 Msps. / Sec. The ratio of the transmission rate and symbol rate roughly corresponded adopted in the direct spread spectrum proposed by Qualcomm. When forming the BPSK signal any filtering absent, i.e. BPSK signals transmitted from the endless strip. The demodulator used simply after modulation selective filter to select the modulating signal and suppress the carrier frequency components of the second and higher orders. In experiments performed the role of such a filter is Butterworth low pass filter of the fourth order with a bandwidth fz dB = 30 kHz. Note that in the transmission rate of 10 Kbit / s Nyquist minimum bandwidth is 5 kHz

8.4.4 Suppression of narrow-band interference.

In principle, the mechanism of suppression of narrowband interference, as described in paragraph 8.4.2, is valid for broadband interfering signals.

Total power wideband interfering signal, e.g., self-interference generated by the system with a direct spread spectrum having a different pseudo-random sequence (spectrum spreading function) $g_1(t)$, $g_2(t)$,…, $g_N(t)$ decreases as a result of compression operation spectrum. And power reduction of broadband interference occurs in the same amount of times as the reduced power narrow-band interference, discussed in the previous sections.

The physical mechanism of attenuation of broadband interference is largely similar to the mechanism of attenuation of narrow-band interference. As a result of the operation of compression of the spectrum of the desired signal power is concentrated in the baseband.

Despreading concerns only the desired signal as transmitted SRP $g_k(t)$ is multiplied with the correlated with a similar sequence $g_L(t)$, formed in the receiver. Broadband noise ratio is multiplied with a reference signal uncorrelated $g_L(f)$, so their work has a wide range. When filter a relatively narrow-band filter is only a small part of the energy of broadband noise will be proportional to the ratio at the demodulator output.

Control questions:

1) List the main advantages of spread spectrum.
2) Describe the systems with direct spread.
3) Describe the characteristics of systems with direct spreading.
4) Explain the process of expansion and contraction of the spectrum.

CHAPTER 9

9 Spread spectrum systems by tuning the operating frequency

9.1 Systems with slow rearrangement operating frequency

In spread spectrum systems, by tuning the operating frequencies of the latter is kept constant, during each interval adjustment discontinuously, but vary from interval to interval (see. Figure 8.4). Transmission frequency generates a digital frequency synthesizer, managed code ("words") entering the serial or parallel manner and at m binary digits (bits). [33]

Each m-bit word or a portion thereof corresponds to one of M = 2m frequencies. Although adjustment of the frequency has M = 2m, (m = 2, 3, ...) frequency, but not all of them are necessarily used in a particular system. Speed adjustment transmission frequencies f_h determined by the number of jumps of frequency per unit of time and is measured in the race for a second (sk / a), a second of kilo jumps (csc / s), a second of mega jumps (msc / s). A spread spectrum system program by tuning the operating frequency divided into the following categories:

a) systems with slow rearrangement;

b) the system agile;

c) the systems with an average speed of adjustment.

In systems with slower restructuring speed adjustment f_h is less speed messaging f_b. Thus, in the range of adjustment before the transition to another frequency can be transferred to two bits or more message (in some systems more than 1000). The interval adjustment T_h associated with bit length T_b ratio:

$$T_h = kT_b, \quad \mathrm{k} = 1,2,3,...; \quad f_0 = f_h = 1/T_h \quad . \tag{9.1}$$

The system with agile operating frequency f_h is longer message transmission rate f_b. In this case, during the transmission of one bit rate may initially change two or more times. Here, the duration of the interval adjustment is related to the length of bits T_b ratio:

$$T_c = T_h = T_b/k, \quad \mathrm{k} = 1,2,3,...; \quad f_h = 1/T_h; \quad f_0 = f_h = 1/T_c \ . \tag{9.2}$$

In systems with an average speed of adjustment is equal to the speed adjustment rate. The most widely used systems with fast and slow restructuring of the operating frequency.

Figure 9.1 illustrate a block diagram of the transmitting and receiving sides of the system with frequency hopping, comprising addition of basic blocks shown in Figure 8.4, the blocks the encoding / decoding with error correction and timing synchronization. The need of administration block encoding /decoding with error correction is due to the following reasons. If one or more operating frequency is overwhelmed by a large interference power, the one or more message bits transmitted on these frequencies may be taken with high probability errors.

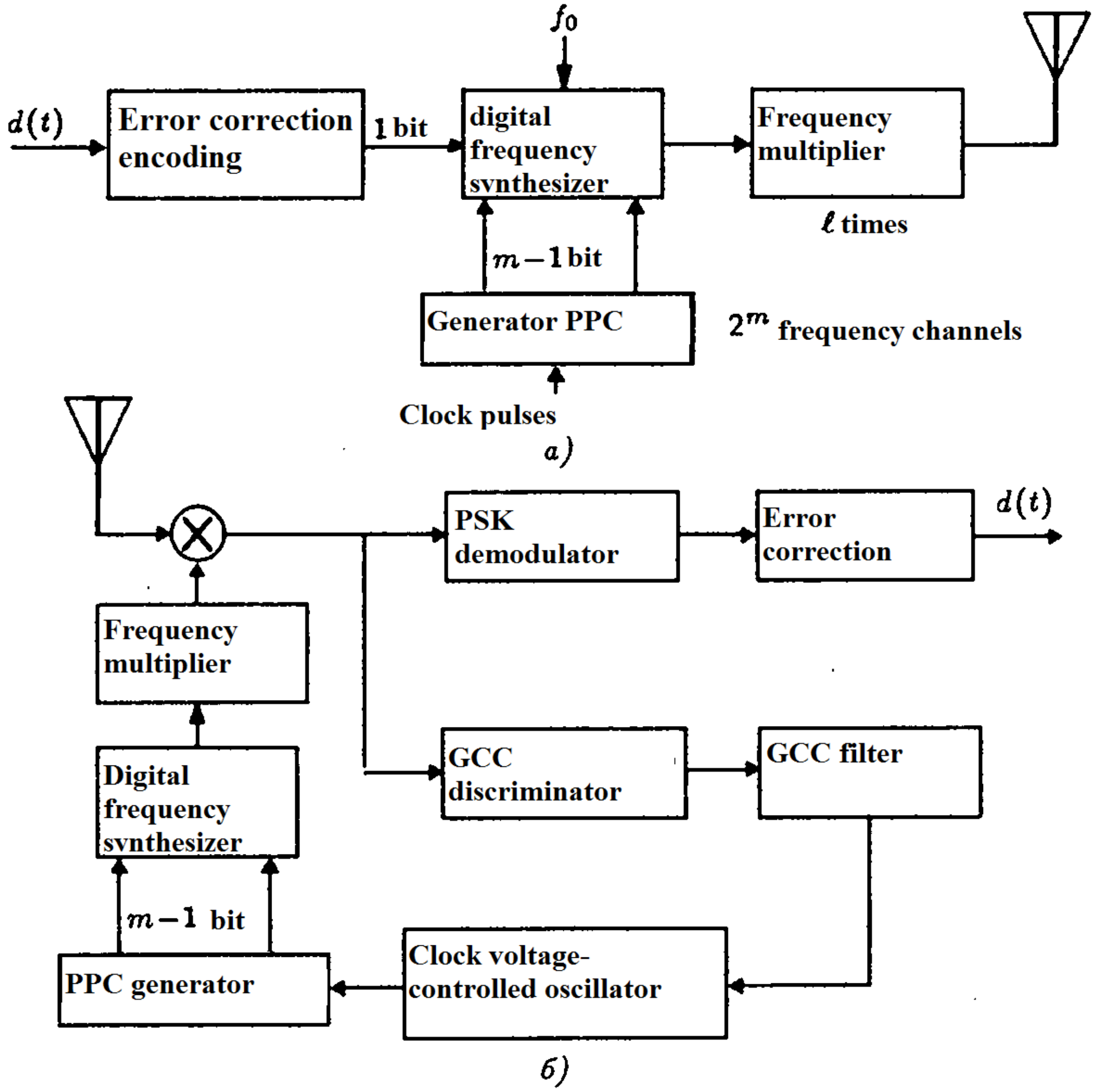


Figure 9.1- The structural scheme of the transmitter (a) and the receiver (b) systems with software tunable

Control word digital frequency synthesizer consists of m bits, one of them may be the information, while others (m - 1) bits formed PS generator. Direct Digital Synthesis for simplicity often forms a grid frequency in the range of the IF and therefore has a limited scope of restructuring. Inclusion of the frequency multiplier after the IF synthesizer allows to increase the value of each of the discrete frequencies available and switch to the RF range, increasing the processing gain signals.

Let the frequency separation between adjacent discrete frequencies of the digital frequency synthesizer is *Δf*. The minimum value of the frequency spacing should be larger than the bandwidth of the RF carrier modulated signal is only transmitted messages at a rate f_b. For example, when the transmission rate f_b = 300 Kbit / s minimum bandwidth QPSK signals in the band-limited linear amplification equal $\Delta f_{min} = f_b/2$ = 150 kHz, which corresponds to the theoretical value indicator spectral efficiency of 2 bits / (s • Hz). For some of the simplest types of FSK signals, allowing the nonlinear gain, spectral efficiency value of the index is in the range from 0.25 to 0.5 bits / (s • Hz). In this case $\Delta f_{min} = f_b/(0{,}24...0{,}5) = (2...4)f_b$. Therefore, for a minimum level FSK signal frequency separation is increased to 600 ... 1000 kHz.

The bandwidth of the RF signal with the rearrangement operation frequency by multiplying the frequency is increased by K times (by multiplying the frequency increases as frequency separation) and becomes equal to:

$$BW_{RF} = lM\Delta f \quad , \tag{9.3}$$

where *l* — frequency multiplication factor;

M = 2m — number of frequencies generated by the synthesizer.

Processing gain (*Gp*) for systems with a restructuring program, the operating frequency is given by:

$$G_p = BW_{RF}/BW_{mod} \quad , \tag{9.4}$$

where BW_{mod} — bandwidth RF modulated signal of transmitted message with the aim to expand.

This means that processing gain in direct expansion systems and spectrum spreading by frequency hopping are the same.

9.2 The system frequency agile

In systems with a frequency agile within the duration of one bit of the k frequency hopping occurs as $T_b = kT_h$ or $f_b = k/f_h$. Therefore, according to (9.3) RF bandwidth:

$$BW_{RF} = klM\Delta f \quad . \tag{9.5}$$

If system performance indicator (without frequency hopping) is 1 bit / (s • Hz), then

$$BW_{RF} = f_b = 1/T_b = \Delta f \quad , \tag{9.6}$$

in this case, the processing gain:

$$G_p = \frac{BW_{\text{RF}}}{BW_{\text{mod}}} = \frac{klM\Delta f}{\Delta f} klM \quad . \qquad (9.7)$$

Thus, the processing gain in the frequency agile depends on the number of different frequencies (M), number of frequency hops within one bit (*k*) and the frequency multiplication factor (*l*).

At the receiver, the signal with the restructuring of the operating frequency, shown in Figure 9.1 (b), the received signal is multiplied by reference, formed by a series-connected generator PS, digital frequency synthesizer and a frequency multiplier. Here the program is determined by changing the frequency generator of the PS, which is identical to the corresponding transmitter PS. If the timing of receiving and supporting the PS are agreed upon, i.e., is an exact time synchronization, then the multiplier is compressed spectrum of the received RF signal (in the same way as for the signals with the direct spreading) to the limits determined by the bandwidth of the signal modulated only by the transmitted message. The most commonly used FSK, for which demodulators are implemented fairly simple means. It is possible to use other methods of modulation / demodulation such as PSK.

The demodulated data signal is input to the decoder with error correcting function. In the decoder output signal power estimate obtained posts *d * (t)*, transmitted over the communication channel. The discriminator circuit monitoring delay (CMD), comprising the two keys to switch from lead and lag, smoothing loop filter CMD and tunable clock generator included in the timing subsystem. As long as synchronization is not established, i.e. undefined beginning to betray the package (if CDMA transceiver operates in batch mode), there will be no compression of the input signal spectrum and its transformation into the bandwidth limits FSK demodulator signals. During the synchronization procedure to the input of the demodulator will act broadband noise signal from which it is impossible to distinguish the useful signal of a transmitted message *d (t)*.

9.3 Characteristics of the restructuring of the operating frequency when exposed to noise

Here derivation of the expression for the probability of error *Pe* arising from an understanding of the principles and possibilities of reducing noise inherent in these systems. Assume that the level of interference significantly exceeds the thermal noise level, so that the appearance of error due to the influence of "strong" interference. In this model, the impact of interference on a system error occurs with a probability of 0.5 whenever interference power within the bandwidth of a frequency channel exceeds the capacity of the carrier (the bandwidth of the demodulator of the receiver frequency approximately equal to the minimum spacing of adjacent frequencies).

For a system with the rearrangement and the operating frequency without any redundancy information, for example by coding / decoding the error correction, the average error probability is [34].

$$P_e = J/M\,, \tag{9.8}$$

where J — number of sources of interference, power is not less than the carrier power of the useful signal;

M — the total number of available frequencies in the system.

In those cases where there is redundancy due to error correction encoding or by repeatedly transmitting the same bits at different frequencies, the average error probability Pe can be determined by the approximate expression:

$$P_e = \sum_{x=r}^{c} \binom{c}{r} p^x q^{c-x}\,, \tag{9.9}$$

where p = J/M — probability of error in the demodulation of one symbol;

J — the number of sources of interference, power is not less than the carrier power of the useful signal;

M — the number of available frequencies in the system;

q = 1 — p — probability of correct demodulation of one symbol;

c — the number of different frequencies used in the transmission of each bit of the message;

r — the number of erroneous decisions necessary for the occurrence of errors in a bit when decoding;

$\binom{c}{r}$ — binomial coefficients.

If three or more frequencies (frequency hopping) are used to transmit each bit of the message, and the receiver in decoding rule applies majority votes (majority voting), the characteristic error probability can be significantly improved.

Example. Lets calculate the average value of the error probability Pe system spreading by tuning the operating frequency. The system has 1000 frequency, and a harmonic interference power measured at the receiver exceeds the power of the wanted signal carrier on 4 dB.

Let’s assume that:

a) one bit is transmitted at each frequency;

b) one bit is transmitted at three different frequencies.

The receiver uses a majority decoding algorithm used in the version b according to which the final decision shall be made right if two of the three preliminary decisions were correcth.

Solution of the example.

a) The transmission of one bit to each frequency based on the expression (9.8) have:

$$P_e = J/M = 1/1000 = 0{,}001.$$

For many applications, this value is unacceptably high;

б) in the case of transmission of one bit at three different frequencies, the mean value of the probability of error is given by (9.9), which should be regarded as c = 3 (the number of frequencies used to transmit one bit), r = 2 (the number of erroneous decisions about the value of the binary characters transmitted at three different frequencies), p = 10^{-3} (the probability of errors in demodulating the symbols of a message transmitted on one of the frequencies calculated in the version a).

$q = 1 - p = 1 - 10^{-3} = 0{,}999$ - the probability of no error.

As a result:

$$P_e = \sum_{x=2}^{3} \binom{3}{2} \left(10^{-3}\right)^x \left(1 - 10^{-3}\right)^{c-x} = 3 \cdot 10^{-3} \left(1 - 10^{-3}\right)^1 + 3 \cdot 10^{-9} \left(1 - 10^{-3}\right)^0 \approx 3 \cdot 10^{-3}.$$

From the above example shows that the value of the average probability of error due to the introduction of triple redundancy in conjunction with majority rule decoding is reduced by 333 times. However, the number of operating frequencies and the rate of adjustment thus increases three-fold. If the minimum frequency spacing Δf considered fixed (as it is determined by the bandwidth of the modulated signal to the expansion of its range), then the required RF bandwidth is also increased in proportion to the rate adjustment frequency.

9.4 Scattering time: sustainability of the restructuring of the operating frequency to interference due to multipath

Temporary scattering signals due to multipath channel mobile radio shown in Figure 9.2 [35].

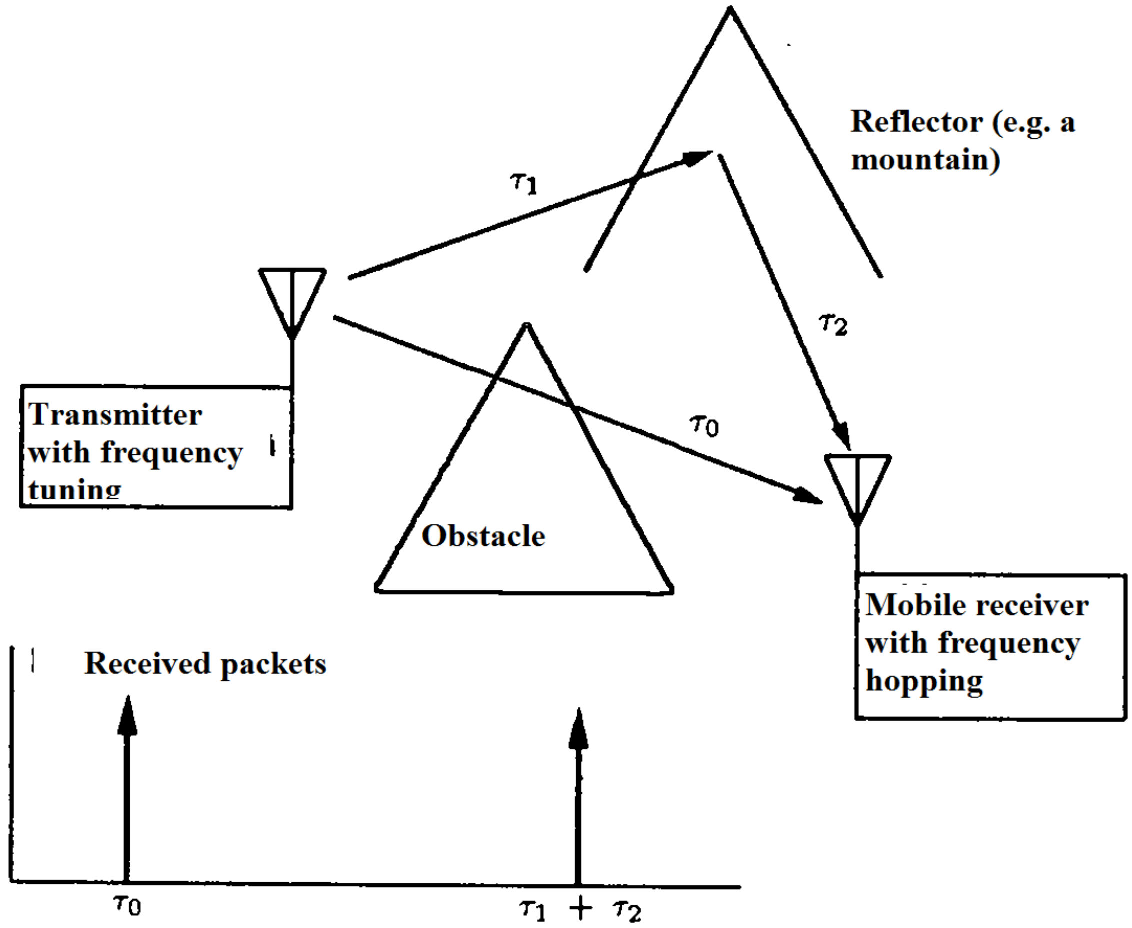


Figure 9.2 - Temporary scattering signals due to multipath

Here on the direct (shortest) pathway from the base station to the receiver of the mobile object is found obstacles like a hill. The time lag in passing on the right path τo and received signal level commensurate with the level of backlight signal that has a delay τ1 + τ2. The delayed signal will interfere with the main signal, creating strong in-band interference, unless the transition to another frequency synthesizer will occur no earlier than the date of its arrival. If the rate of frequency tuning fh is exceed the inverse of the difference between the delays between the direct and multipath signals, i.e.

$$f_h > \frac{1}{\tau_1 + \tau_2 - \tau_0}, \tag{9.10}$$

frequency synthesizer receiver reconstructed on a different frequency reception before the input of the receiver will go re-scattered signal. Thus, at a relatively high speed frequency hopping temporary impact on the deterioration of the scattering characteristics of the system can be minimized.

Example. In the digital terrestrial mobile radio communication system using radio signals with QPSK with a rate f_b = 4,8 Kbit / s. Define the minimum rate of frequency tuning when this multiple access system based on time division multiple access (TDMA) mode enter spreading by tuning the operating frequency to prevent scattering time lag signal exceeding $\tau = 300$ microseconds.

Solution example. Let's assume: $\tau o = 0$ and $\tau 1 + \tau 2 = 300$ microseconds. From (9.10) have

$$f_k > \frac{1}{300мкс - 0} = 3{,}33 \text{ Kbit/s}$$

.

For some applications, the introduction of relatively slow frequency hopping is more simple technical solution, compared with complex adaptive correlation functions necessary for signal correction in the case of large time dispersion. In particular, the development of adaptive equalizers in the coherent demodulation of signals can be a challenge.

9.5 Comparison of CDMA systems with direct expansion and reorganization of the spectrum of the operating frequency

Consider the system architecture, give a brief comparison of the two methods of spread spectrum: direct - through an additional modulation signal pseudo-random sequence and indirect - by tuning the operating frequency. PS generator in the second case, should have a clock frequency $k(m - 1)f_b$, where $f_b = 1/T_b$ - message rate, bit / s, k- bit number in the range of frequency adjustment (9.1), (9.2), and m - length generator PS (register length). Thus, the clock frequency of the PS generator is lower than in the embodiment of the direct spreading. This is - one of the advantages of expanding the range by tuning the operating frequency. Another advantage is the fast synchronization and easier solution interference "close-to-remote", which implies control, transmits power with less accuracy. The disadvantage of the indirect method of spreading by tuning the operating frequency compared to the direct method is the need for complex high-speed frequency synthesizers with low phase noise. In addition, the method of spread-spectrum signal by tuning the operating frequency is of little use to measure the range and range rate.

9.6 Synchronization Spread Spectrum Systems

To synchronize the receiver when receiving a spread spectrum signals may take three lock device:

а) phase synchronization device carrier (carrier recovery);

б) device symbol timing (clock recovery);

в) device timing generator generates code or pseudo-random sequence.

In the case of noncoherent demodulation algorithms FSK and DPSK signal phase synchronization apparatus is not required, since the demodulation is performed by frequency discriminator or demodulator autocorrelation. For coherent demodulation algorithms require three devices to synchronization.

Time synchronization is provided in two stages, during which the following:

а) search (initial, rough synchronization);

б) tracking (fine synchronization).

The following is a description of some methods for synchronization used in systems with direct spreading and rearrangement operating frequency.

9.6.1 Search and tracking signals with direct spreading.

In order to simplify procedures and reduce the time synchronization, i.e. searching for signals with direct spreading modulation signal transmitted message *d (t)* rule, setting *d (t)* = 1.

Unmodulated direct spreading (without modulating the transmitted message) is called a pilot signal, which is defined as follows:

$$v_{вх} = \sqrt{2P_s}\, g(t) \cos(\omega_0 t + \theta). \quad (9.11)$$

This signal is input to a receiver within the search procedure.

A simple search procedure can be illustrated by the circuit shown in Figure 9.3. Initially, the key is in position 1, and one of the inputs of the circuit "N" is connected to a source of positive voltage. Tunable clock generator in stand-alone mode controlled oscillator of PS receiver. Generator PS is the symbol frequency *fo*, Char. / S, roughly equal to the frequency of the symbols of the corresponding transmitter PS.

Before begin the search synchronize transmitting and receiving oscillators PS is absent, i.e. temporary provision of formed PS is not agreed. The output of the multiplier in this case is given by:

$$v_{пр} = v_{вх} g(t - iT_c) = \sqrt{2P_s}\, g(t) \cos(\omega_0 t + \theta) \cdot g(t - iT_c), \quad (9.12)$$

where i =0,1,2,3,...;

T_c — symbol duration PS.

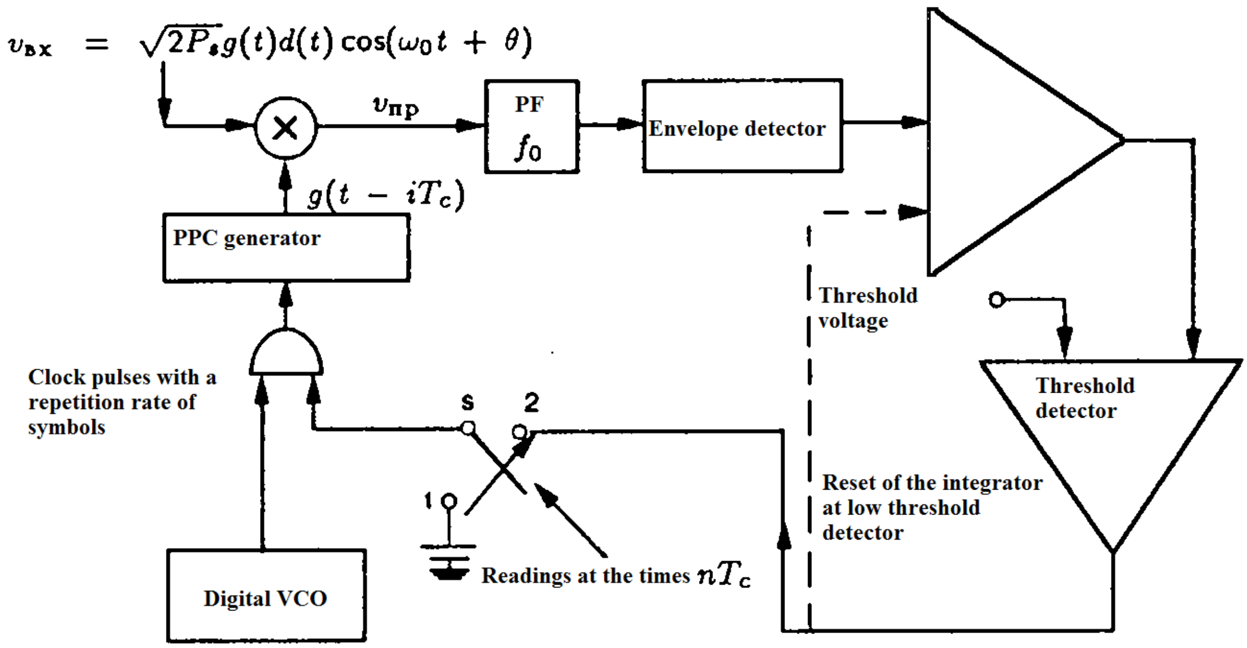


Figure 9.3 - Scheme of searching for signals with direct spread spectrum CDMA system

In this expression iT_c determines the initial timing offset of the received signal with a direct spread spectrum and the reference PS receiver. The multiplication of $v_{np}(t)$ signals (t) for $i \neq 0$ is a signal with direct spreading. This signal has a sufficiently wide range, and low spectral density. Therefore, after a relatively narrowband filtering and isolating the envelope, the signal level is quite low. The output signals of the integrator and the comparator will be low. The key is moved every nT_c second to 2 position. If the output of the comparator at time nT_c when the key is in position 2 is low, a scheme of "N" occurs prohibition receipt of clock pulses from the output of the tunable oscillator clock generator PS.

Due to lack of receipts clock in this time interval generator CAP him forcibly delayed relative to the formation of the PS in PS transmitter. Then reset the integrator, the key is again translated to 1 and the search continues. This occurs every nT_c seconds. Trial and error procedure ultimately leads to a temporary agreement of the received and reference signals, which means that $iT_c = 0$. After the search have:

$$g(t)g(t - iT_c) = g(t)g(t - 0 \cdot T_c) = g^2(t) = 1. \tag{9.13}$$

This results in compression of the spectrum of the received pilot signal, and the expression (9.12) takes the form:

$$v_{вх} = \sqrt{2P_s}\,g(t)\cos(\omega_0 t + \theta). \tag{9.14}$$

it turns unmodulated "pilot tone". Via narrowband bandpass filter tuned to the frequency *fo*, it passes all received signal power at the input of the envelope detector. As a result of integration of the envelope over time nT_c formed a high level signal at the comparator output that indicates the completion phase or coarse timing search. After, the next stage of a full synchronization-tracking and precise synchronization begins.

Tracking or precise timing signals from the direct spread by means of a delay circuit monitoring (DCM), shown in Figure 9.4. Enabling DCM is made immediately upon completion of the search, or rough synchronization. At this stage temporary mismatch generators PS lies within the duration of one symbol, but the support may be formed from PS advance (A) or the delay (D) relative to the received PS. Therefore, the output of the PS generator receiver can be written as $g(t - \tau)$, where $-T_c < \tau < T_c$. The signals at various points in the circuit shown in Figure 9.4 can be expressed as follows:

$$v_D = \sqrt{2P_s}\, g(t) g(t+\tau-T_c/2) d(t)\cos(\omega_0 t+\theta), \tag{9.15}$$

$$v_A = \sqrt{2P_s}\, g(t) g(t+\tau+T_c/2) d(t)\cos(\omega_0 t+\theta), \tag{9.16}$$

$$v_{DF} = \sqrt{2P_s\left[g(t) g(t+\tau-T_c/2)\right]}\, d(t)\cos(\omega_0 t+\theta), \tag{9.17}$$

$$v_{AF} = \sqrt{2P_s\left[g(t) g(t+\tau+T_c/2)\right]}\, d(t)\cos(\omega_0 t+\theta). \tag{9.18}$$

The bandwidth of the filter is chosen is much narrower than the width of the spectrum of the PS, so the passage of signals through the works of bandpass filters are averaged envelopes.

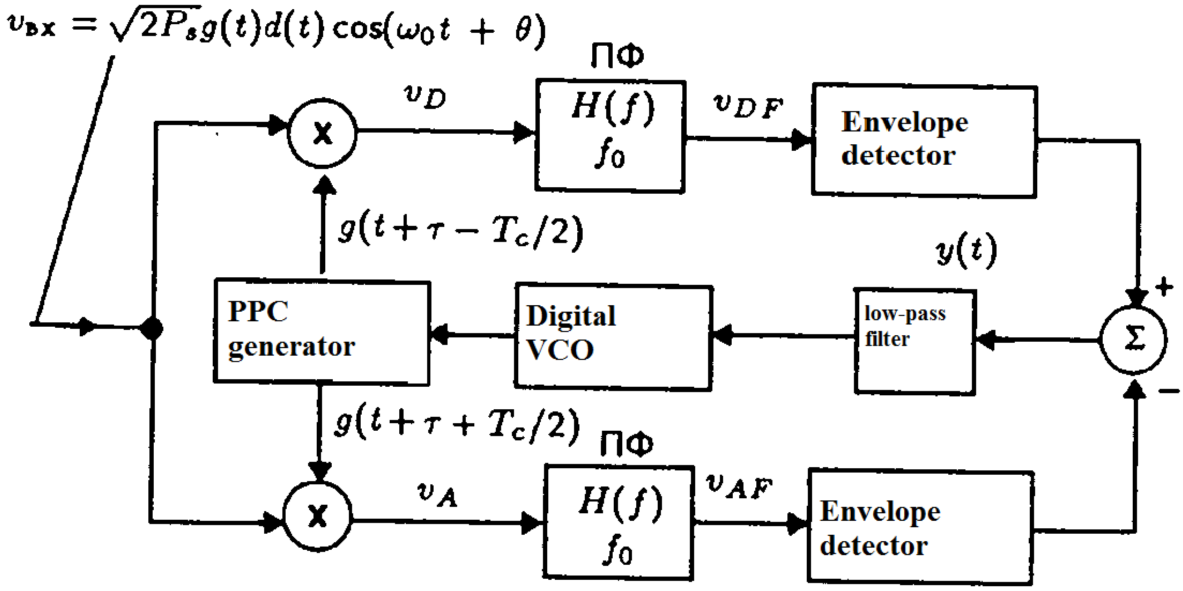


Figure 9.4- Schematic tracking delay in the direct spread

The average value of the works of $g(t)g(t + \tau \pm T_c/2)$ is the autocorrelation function of the PS

$$R_a(r \pm T_c/2) = \overline{g(t)g(t - r \pm T_c/2)}. \qquad (9.19)$$

Envelope detectors emit an envelope signal *vDF(t)* and *vAF(t)*, and therefore excludes the modulation signal transmitted message d (t). Therefore:

$$|V_{DF}(t)| = |R_a(r - T_c/2)|, \qquad (9.20)$$

$$|V_{AF}(t)| = |R_a(r + T_c/2)|. \qquad (9.21)$$

The control signal of the tunable generator *y(t)* is determined by the difference

$$y(t) = |R_a(r - T_c/2)| - |R_a(r + T_c/2)| \ . \qquad (9.22)$$

If *r* is a positive value, the control signal is formed with a positive sign and the frequency tunable oscillator increases. This leads to a decrease of *r*. For negative values of *r* generates a control signal with a negative sign, and decreases the frequency of tunable oscillator. This leads to an increase in *r*. The dependence on the delay control signal *r* (discriminating characteristic) is shown in Figure 9.5.

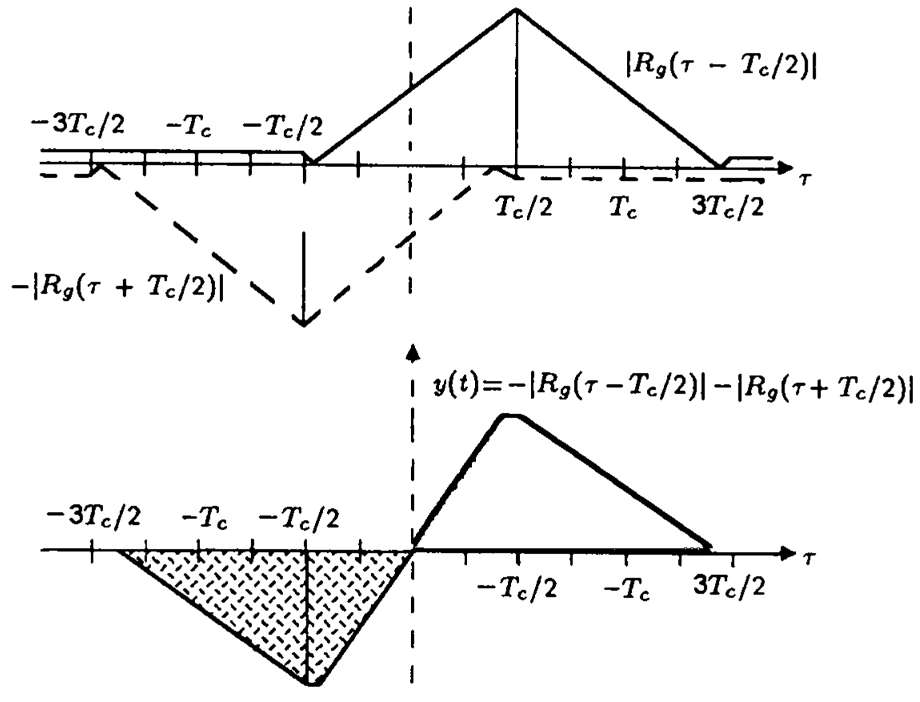


Figure 9.5 - Control signal

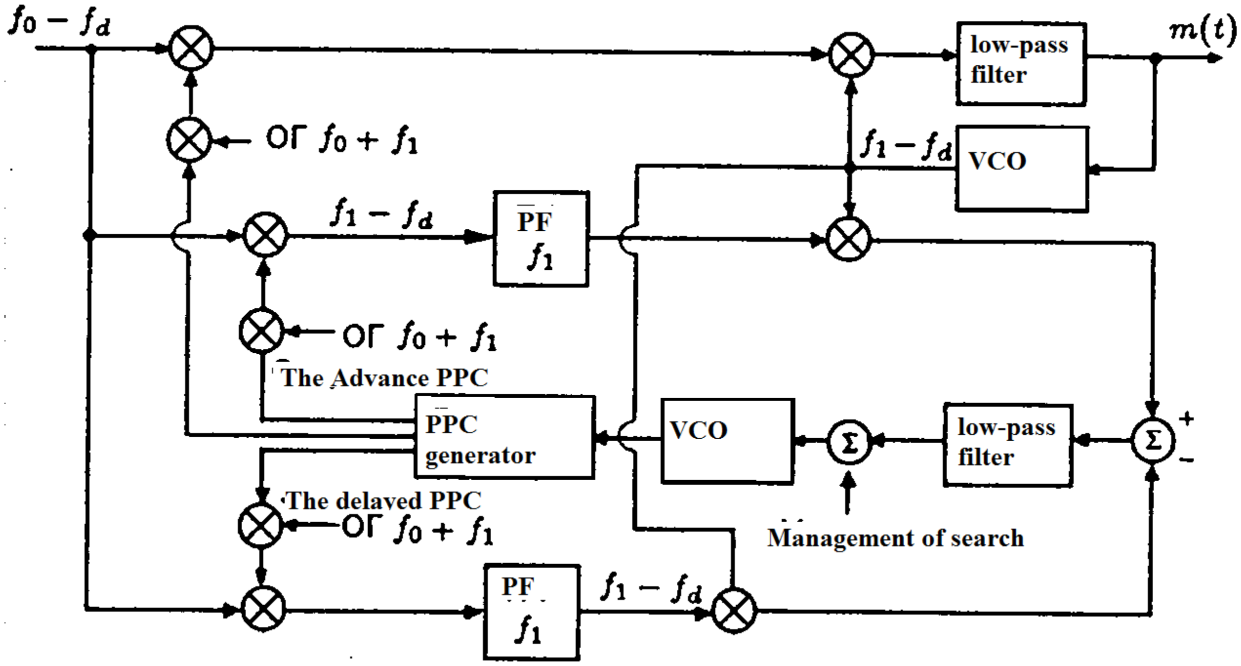


Figure 9.6 - Coherent Receiver Direct Spread

Block diagram of a coherent receiver signals with direct spread, including search and tracking subsystem, shown in Figure 9.6.

9.6.2 Search and tracking signals from the restructuring of the operating frequency

Block diagram of realizing one of the possible methods of searching for signals from the restructuring of the operating frequency is shown in Figure 9.7. If the transmitter of such signals is used m working frequency, for example, r = 1000 then the search pattern (the correlator) comprises 1000 multipliers, band pass filters, envelope quadratic detectors and delay elements. Delay elements produce alignment delay, so the matching sequence elements summation frequency signals v1, v2, ..., vm adder will occur at the same time. Therefore, with high probability threshold is exceeded, indicating that synchronization of the receiver with the received signal is achieved. This forms the main emission correlation function indicating the beginning of the formation of the PS [36].

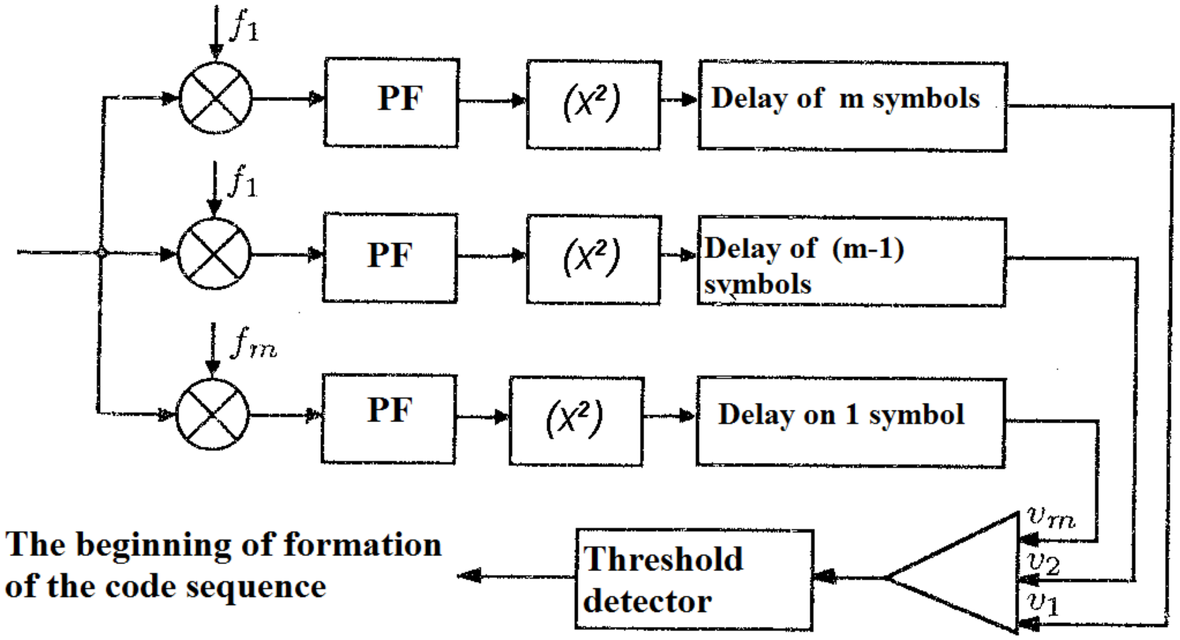


Figure 9.7 - Scheme of parallel search

Although considered a search method using a set of correlators or matched filter allows for quick search, still significantly reduce the complexity, size and cost of the receiver is possible by using one correlator implementing circular search. However, this is accompanied by a significant increase in search time, since in this case it is carried out sequentially rather than concurrently.

The idea of sequential search illustrates a block diagram shown in Figure 9.8. Generator of clock pulses at a frequency f_h, a PS generator and a frequency synthesizer form tunable reference signal. Generator PS generates a pseudo-random sequence similar to the sequence of the corresponding transmitter. Depending on the state of the control signal at the output of the comparator clock generator is in either "on" or "off." The frequency of the frequency synthesizer is given by the digital signal generator PS. As conditions of PS generator change oscillator frequency of the frequency synthesizer "runs" the entire set of values from f_1 to f_M, then returning to the f_1 and etc. The frequency tuning rate is $f_h = 1/T_h$.

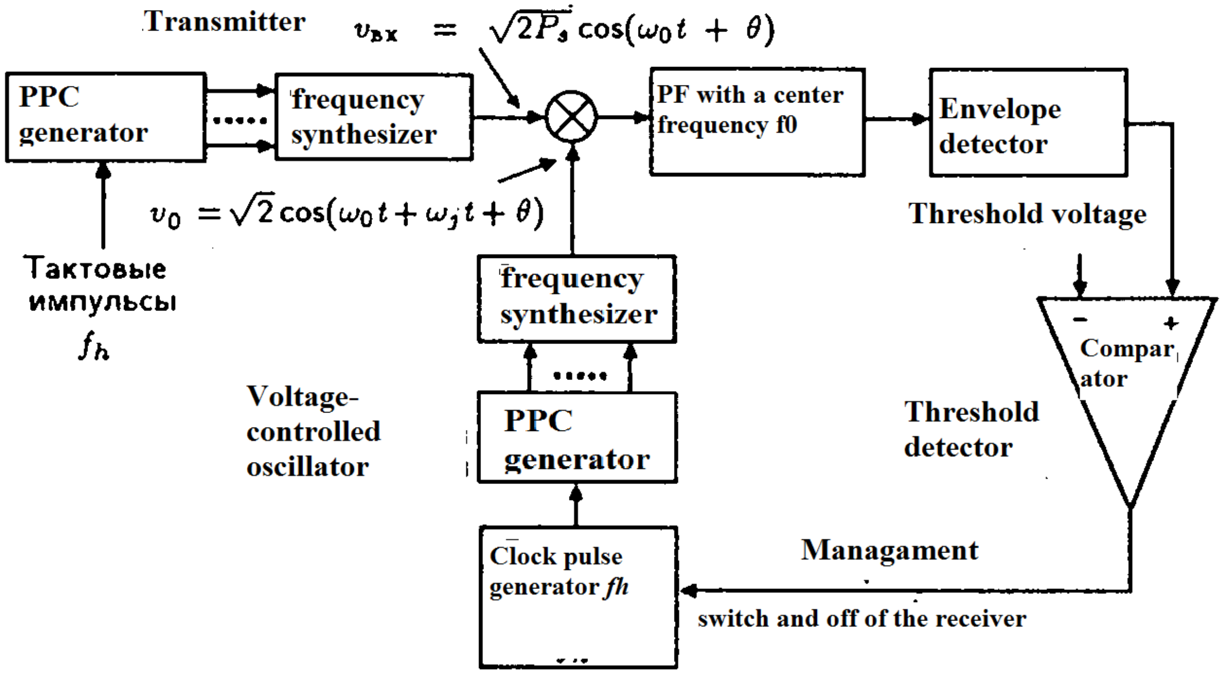


Figure 9.8 - Scheme of sequential search

At the beginning of the search procedure the frequency of the received and reference signals do not match, i.e. $f_i \neq f_j$. In this case, despreading the received signal does not occur because of the lack of correlation and spectrum of the signal at the input of a wide band-pass filter is retained. Through a band pass filter with a relatively narrow bandwidth of about $2f_h$, the input of the envelope detector will pass only a small fraction of the power of the input signal. The output signal of the comparator will have a low level corresponding to the state "off" the clock pulse generator. Generator PS cannot pass to the next state, and in the frequency synthesizer of the receiver will continue the previous frequency $f_o + f_j$, i.e. it will remain in the position of waiting. When finally the frequency of the received signal becomes equal to f_j, difference frequency equal to the frequency setting bandpass filter and its output signal appears.

At the output of the envelope detector signal will be above the threshold level, and the output of the comparator will have a high level corresponding to "ON" state the clock pulse generator. Generator PS receiver acquires synchronization with the same generator of the transmitter, i.e. coarse synchronization phase ends.

After the completion of this phase is retained relative latency (time-frequency mismatch) of the received and reference signals equal to τ.

In the second stage, the stage of precise timing, this mismatch is eliminated. This is achieved by using the tracking system, shown in Figure 9.9.

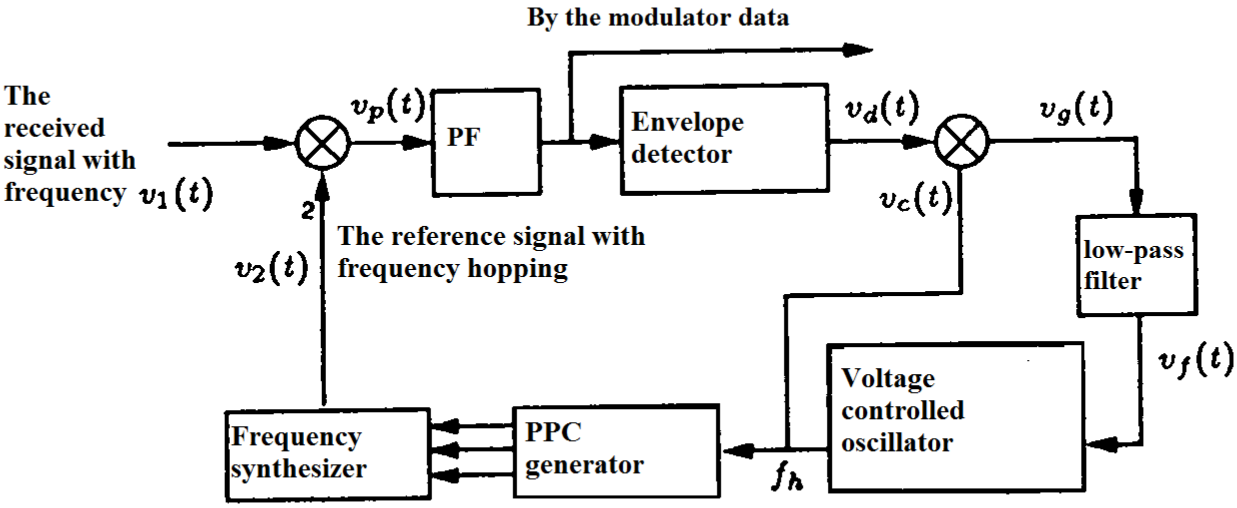


Figure 9.9 - Scheme of tracking delay signal to the restructuring

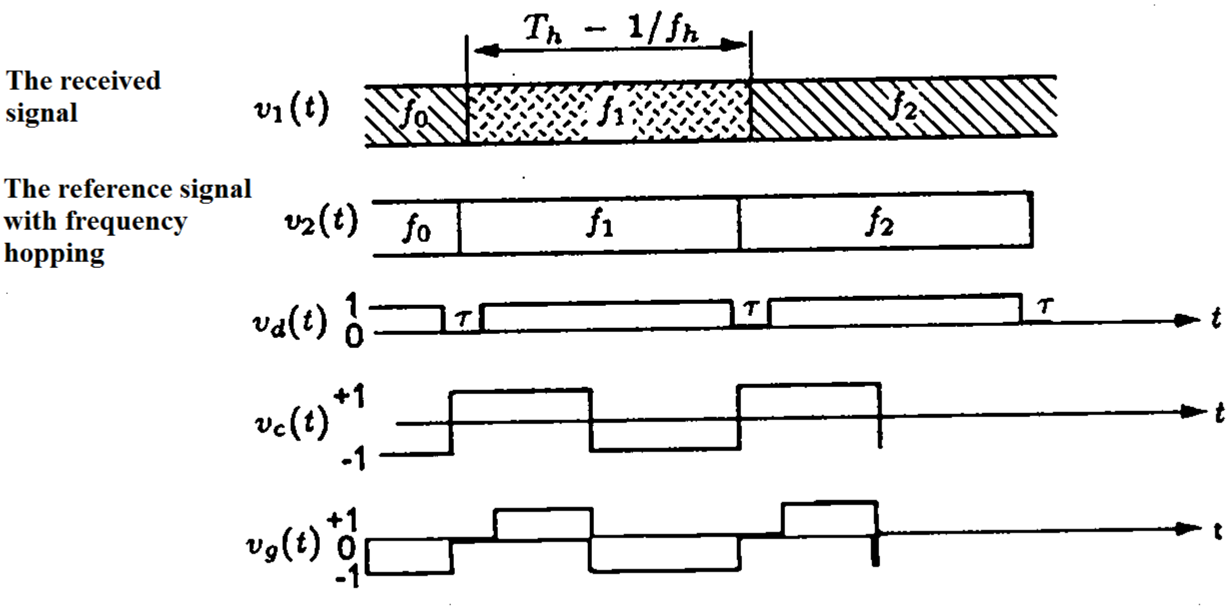


Figure 9.10 - Time diagrams illustrating the operation of track circuits

Timing diagrams illustrating the operation of the system illustrated in Figure 9.10. Here, the bandpass filter has a frequency bandwidth sufficient to pass the intermediate frequency signal contained in multiplying $v_p(t) = v_1(t)v_2(t)$ at the frequencies and insufficient to pass the difference frequency signal contained in the product at a frequency mismatch. Therefore, the output envelope detection signal $v_d(t)$ has a positive level when the frequency of the signals $v_1(t)$ and $v_2(t)$ are the same, and close to zero when the frequency of these signals do not match

The output signal of the envelope detector $v_d(t)$ is multiplied with a square wave signal $v_c(t)$ clock frequency fh. Multiplying of $v_d(t)v_c(t)$ is a three-level signal from the area ratio of the positive and negative fragments, depending on the value and sign of the time mismatch. As a result of the averaging of this signal low pass filter generates control signal to the tunable clock generator, which will be negative if the reference signal is "ahead" of the received, and positive, otherwise. Due to the influence of the control voltage will vary according to the direction of the frequency tunable oscillator clock and the initial mismatch is minimized. At this stage the exact synchronization of the operating frequency with the rearrangement is ended.

Spread spectrum system using direct expansion of the range and the restructuring of the operating frequency and also CDMA technology is widely used in cellular systems, personal, terrestrial, mobile and satellite mobile communications. Research and development of existing equipment, conducted in the late 80s and early 90s by Qalcomm brought CDMA technology to the level of commercial applications of CDMA.

For frequency ranges 902 ... 928 MHz, 2.4…2.48 GHz and 5.4 ... 5.6 Hz allocated by the Federal Communications Commission, has developed various systems and their components, using CDMA technology and soft restructuring of the operating frequency. Studies carried out in the AT & T Bell Laboratories, show that the system operating with slow rearrangement frequency and multiple access based on time-division multiplexing (SFH-TDMA) as compared to conventional cellular TDMA systems have a greater capacity and improved performance. The advantages of these systems are the presence of diversity, high noise immunity, insensitivity to the scattering time signals.

Control questions:

1) Describe the system with a slow frequency hopping.
2) Describe the system with a frequency agile.
3) What are the three locking device used in a spread spectrum?
4) How to avoid interference with the frequency division multiplexing?

CHAPTER 10

10 Wireless LANs

In 1999, the IEEE ratified the IEEE 802.11b standard for wireless networking products that operate at a speed of 11 Mbps (similar to Ethernet). Compatible products from different manufacturers are guaranteed by an independent organization called Wireless Ethernet Compatibility Alliance (WECA). This organization was set up wireless industry leaders in 1999. Currently WECA members are more than 80 companies, including well-known manufacturers such as Cisco, Lucent, IBM, Apple, Dell, Siemens, AMD and others. With products that satisfy the requirements of Wi-Fi (WECA term for IEEE 802.11b), can be found at WECA. [37]

As with all IEEE 802 standards, 802.11 operate at the lower of two layers of OSI model: the physical level and link level. Any network application, the network operating system or protocol (e.g., TCP / IP) will also work well in 802.11 networks, as in the Ethernet.

The basic architecture, features and services of 802.11b defined in the original 802.11, 802.11b specification only affects the physical layer by adding a higher access speed.

802.11 defines two types of equipment - the client, which is typically a computer, complete with a wireless NIC (Network Interface Card), and the access point (AP), which acts as a bridge between the wireless and wired networks. The access point typically includes a transceiver, a wired network interface (802.3), and the software to process data. As a wireless station can act as ISA, PCI or PC Card is network card in the 802.11 standard, or built-in solutions, for example, telephone headset 802.11.

At the physical layer defines two broadband radio frequency transmission methods and the one - in the infrared range.

RF techniques in the ISM range 2.4 GHz band and typically use 83 MHz from 2.400 GHz to 2.483 GHz. Wideband signal used in the radio frequency methods, increase reliability, capacity, allow many unrelated to each other devices to share the same frequency band with minimal interference to each other.

The 802.11 standard uses the direct sequence (Direct Sequence Spread Spectrum, DSSS) and frequency hopping method (Frequency Hopping Spread Spectrum, FHSS). These methods are radically different and incompatible with each other.

Implementation of the method of transmission in the infrared diapason (IR) 802.11 based on the IR transmitter omnidirectional radiation (diffuse IR) signal. Instead of directional transmission, requiring appropriate orientation of the transmitter and the receiver, the transmitted infrared signal is emitted at the ceiling. Then there is the reflection of the signal and its reception. This method has obvious advantages over the use of directed radiators, however, there are significant drawbacks - requires ceiling, reflecting IR radiation in a predetermined wavelength range (850 - 950 nm); the range of the whole system is limited to 10 meters. In addition, the IR rays are sensitive to weather conditions, so the method is recommended only indoors.

It supports two data rates - 1 and 2 Mbps. At a speed of 1 Mbps data stream is partitioned into quartets, each of which is then encoded by the modulation during one of the 16 pulses. At the speed of 2 Mbps is slightly different modulation method - the data one of four pulses.

When using the method FHSS frequency hopping band of 2.4 GHz is divided into 79 channels of 1 MHz. The sender and receiver agree on circuit switching channels (there are 22 to choose from such schemes) and data is sent sequentially through various channels, using this scheme. Each data transmission in an 802.11 happens for different switching circuit and circuits themselves are designed so as to minimize the chances that the two senders will use the same channel simultaneously. FHSS method allows to use a very simple circuit transceiver, however, is limited to a maximum speed of 2 Mbps. This limitation is due to the fact that single channel is allocated exactly 1 MHz, which forces the system to use the entire FHSS of 2.4GHz band. This means that there must be frequent channel switching (for example, in the US in the lowest rate of 2.5 per second switching), which in turn leads to an increase in overheads.

The DSSS method divides the 2.4GHz band into 14 overlapping channels. In order to more channels can be used simultaneously in one and the same place, it is necessary that they are spaced by 25 MHz (not overlapped) in order to avoid interference. Thus, in one location can be shared by a maximum of three channels. Data is transferred using one of these channels without having to switch to other channels. To compensate for background noise, using the 11-bit Barker sequence, where each bit of user data is converted into 11 bits of data transferred. Such high redundancy for each bit can significantly increase the reliability of the transmission, thus significantly reducing the power of the transmitted signal. Even if part of the signal is lost, it is in most cases still being restored. Thereby minimizing the number of data retransmissions.

The main addition, that 802.11b brought in the basic standard - is support for two new data rates - 5.5 and 11 Mbps. To achieve these speeds DSSS method is selected, since the method of frequency hopping in the FCC power limitations cannot maintain the higher speed. This implies that the 802.11 b systems will be compatible with DSSS 802.11 systems, but will not work with systems FHSS 802.11.

To support very noisy environments, and work at large distances 802.11b network using dynamic shift speed, which allows to automatically changing the speed of data transfer, depending on the properties of the radio channel. For example, the user can connect a maximum speed of 11 Mbps, but if the noise level is raising or the user will remove to a large distance, the mobile device will begin to transmit at a lower rate - 5.5, 2 Mbps or 1 Mbps. In the case when the stable operation is possible at a high speed, the mobile device automatically begins to transmit at a higher speed. Shift rate - the mechanism of the physical layer and is transparent to the higher levels and the user.

802.11link layer consists of two sub-layers: Logical Link Control (LLC) and Media Access Control (MAC). 802.11 uses the same LLC and 48-bit addressing as other 802 networks, making it easy to combine the wireless and wired networks, but the MAC layer has a fundamental difference. 802.11 MAC layer is very similar to 802.3 implemented in, where it supports a number of users on a common carrier, the carrier checks the user before access to it. For Ethernet network 802.3 protocol is used Carrier Sence Multiple Access with Collision Detection (CSMA / CD), which determines how the station Ethernet access to wireline and how they detect and handle conflicts that arise in the event that multiple devices try to simultaneously establish a connection network. To detect collision, the station must be able to receive and transmit simultaneously. The 802.11 standard provides for the use of half-duplex transceiver, so the wireless 802.11 stations cannot detect a collision during transmission.

To account for this difference, 802.11 use a modified protocol known as Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA) or the Distributed Coordination Function (DCF). CSMA / CA attempts to avoid collisions by using explicit packet acknowledgment (ACK), which means that the receiving station sends an ACK packet in order to confirm that the packet is received intact.

To determine whether the channel is free, the algorithm of evaluating the purity of the channel is used (Channel Clearance Algorithm, CCA). Its essence is to measure the energy of the signal on the antenna and determining the received signal strength (RSSI). If the power of the received signal is below a certain threshold, then the channel is declared free, and the MAC layer receives the status of CTS. If the power is above the threshold value, data transmission is delayed in accordance with the rules of the protocol. The standard provides another opportunity to determine the idle channel, which can be used either separately or together with the measurement of RSSI - method of checking the carrier. This method is more selective, since it is checked using the same type of carrier, and that on the 802.11 specifications. The best method to use depends on what level of interference in the work area.

Thus, CSMA / CA provide a method for separating radio access. Explicit confirmation mechanism effectively solves the problem of interference. However, it does add some additional overhead that is not in 802.3, 802.11 will always be slower than equivalent Ethernet LAN connectivity.

Finally, MAC 802.11 level allows calculation of CRC and packet fragmentation. Each pack has a CRC checksum, which is calculated and attached to the package. Here they’re unlike networks Ethernet, where the error handling involved higher-level protocols (e.g., TCP). Fragmentation allows breaking large packets into smaller packets during transmission over the radio channel, which is useful in a much “-inhabited” areas or in cases where there is significant interference, since smaller packages less likely to be damaged. This technique is in most cases reduce the need for retransmission, and thus increases the performance of the entire wireless network.

802.11 MAC layer is responsible for the way in which the client is connected to an access point. When a client enters the 802.11 coverage areas of one or more access points, it is based on the signal strength and the observed value of the number of errors selects one of them and is connected thereto. Once the client receives confirmation of the adoption of an access point, it is tuned to a radio channel in which it operates. From time to time, it checks all the feeds for checking of the other access point of higher quality. If this is the access point, the station is reconfigured to its frequency.

The dynamic connection and reconnection allows network administrators to install wireless networks with very broad coverage, creating a partially overlapping "cell." The ideal situation is one in which the overlapping neighboring access points will use different DSSS channels so as not to interfere with each other.

Since the mobile station and the access point are microwave devices, many questions arise about the safety of use of components of Wave LAN. It is known that the higher the frequency of the radio, the more dangerous it is for a human. In particular, it is known that if look into the rectangular waveguide transmitting a signal frequency of 10 GHz or more, with a capacity of about 2 watts, then inevitably there will be damage to the retina of the eye, even if the exposure duration is less than a second. Antennas of mobile devices and access points are sources of high-frequency radiation, and, although the power of the emitted signal is very small, yet should not be in close proximity to a working antenna. As a rule, a safe distance is the distance of the order of tens of centimeters from the transceiving units [38].

Currently, it is started the implementation of two competing standards for next-generation wireless of next generation networks - IEEE 802.11a standard and the European standard HIPERLAN-2. Both standards operate in the second ISM band using a band around 5 GHz. The speed of data transmission in the new generation is 54 Mbps.

Bluetooth is a modern wireless communications technology, created in 1998 by a group of companies: Ericsson, IBM, Intel, Nokia, and Toshiba. With Bluetooth, user can connect with each other virtually any device: mobile phones, laptops, printers, digital cameras and even refrigerators, microwave ovens, air-conditioners. Bluetooth - a small chip, which is a high frequency (2.4 - 2.48 MHz) transceiver operating in the range of ISM (Industry, Science and Medicine - range designed for use in industrial, scientific and medical purposes). For data transmission can be used asymmetrical (721 kbit / s in one direction and 58 kbit / s in the other) and a symmetric methods (433 Kbit / s) [39].

Bluetooth is depending on the power allows communication between 10 and 100 meters. The difference in distance is certainly great, but the connection within 10 meters allows keeping low power consumption, compact size and fairly inexpensive components. Thus, a low-power transmitter consumes 0.3 mA in standby mode, and an average of 30 mA at the exchange of information.

The main direction of Bluetooth was the creation of so-called personal area networks (PAN - private area networks), including such diverse devices as mobile phone, PDA, MP3 players, computers and even microwave ovens to refrigerators.

The main structural element of the Bluetooth network is the so-called "piconet» - a set of 2 to 8 devices operating on the same template. In each piconet one device operates as a master, and the rest - as a slave. Master defines a template on which to run all of its slave-device piconet, and synchronizes its work. Bluetooth standard provides for the connection of independent and even synchronized with each other piconets (up to 10) in the so-called «scatternet» (one of the meanings of the verb to scatter sounds like "dissipate"). For each pair of piconets must have at a minimum of one common device, which is a master and one slave to another. Thus, within a single scatternet with Bluetooth interface can be connected simultaneously, a maximum of 71 device but not to limit the application device using the Internet.

In the range of 2.4 MHz and operate a variety of medical devices, appliances, cordless phones, wireless LAN of standard IEEE. To avoid interference with them Bluetooth operates on the principle of frequency hopping FHSS (Frequency-Hopping Spread Spectrum).

Control questions:

1) List and briefly characterize the levels of IEEE 802.

2) What is the difference between an access point and a portal?

3) What are the characteristics of a wireless local area network is the unique safety issues do not arise in a wired network?

4) What do you know about the technology of Bluetooth, Wi-Fi, Wimax, Zigbee?

Questions

@1
What is the procedure used when moving the subscriber from one cell to another?
1@
A) handover from one BS to another
B) roaming
C) Authentication
D) Identification
E) Registration
@2
What is the procedure used when moving the subscriber to the territory of another system?
2@
A) Roaming
B) Handover from one BS to another
C) Identification
D) Registration
E) Authentication
@3
What is called a cluster?
3@
A) The group of cells with a different set of frequencies
B) The frequency band provided for the organization of cellular communication
C) Device that provides a repetition frequency
D) Repetitive frequency
E) No answer
@4
What is called the dimension of the cluster?
4@
A) The number of cells in the set
B) The maximum size of a cell system
C) The minimum size of a cell system
D) The average size of a cell system
E) The number of frequencies used in the set
@5
Why use a frequency reuse patterns (clusters)?
5@
A) Increasing the number of channels per cell without expanding the total bandwidth
B) To increase the number of channels per cell with the expansion of the total bandwidth
C) To expand the bandwidth and reduce the number of channels per cell
D) To reduce the number of channels per cell and narrowing the overall bandwidth

E) No answer
@6
What is authentication subscriber?
6@
A) Procedure authenticate the subscriber cellular system
B) A procedure to detect lost, stolen vehicles
C) A procedure to detect faulty devices
D) Procedure for determining the types of services for a given mobile station
E) No answer
@7
What is the structure of a cellular communication system?
7@
A) Switching center, base stations, mobile station
B) Base station, switching centers, mobile station
C) Mobile station, base stations, repeaters
D) Public telephone network, the mobile station
E) Telephone network, switching center
@8
For what is designed an equalizer of the receiver of the mobile station?
8@
A) for the partial compensation of signal distortion due to multipath propagation
B) to control the operation of the mobile station
C) from the input flow control information
D) recovers the channel coming from a speech signal encoder
E) to perform all of these functions
@9
For what is designed a modulator of the transmitter of the mobile station?
9@
A) to transfer coding information to a video signal carrier frequency
B) to separate from the modulated RF signal coded video
C) to carry information coded radio signal at video
D) for the allocation of the encoded video signal modulated RF signal
E) to perform all of these functions
@10
For what is established on the base station several transmitters and receivers?
10@
A) for simultaneous operation on multiple channels with different frequencies
B) at the base station sets a plurality of receivers and one transmitter
C) at the base station is set several transmitters and one receiver
D) at the base station sets one transmitter and one receiver
E) to align with multiple receiving and transmitting antennas
@11
What is the switching center?
11@

A) is an automatic telephone exchange system of cellular communication, providing all network management functions
B) is a station run by the base stations
C) a station which manage the mobile stations
D) is a station duplicate the work of the base station
E) No answer
@12
Which unit of switching center includes information on subscribers' guests?
12@
A) visitor location register
B) a home location register
C) register equipment
D) the switch
E) communication controller
@13
Which unit of switching center includes information about the stolen user devices or devices which have technical defects?
13@
A) register equipment
B) a home location register
C) communication controller
B) guest register
E) switch
@14
Why in CDMA signals are called noise like?
14@
A) for those who do not know, on what was the sequence of the desired signal is multiplied, it looks like a noise
B) at the frequency spectrum of the signals are similar to noise
C) spectrum of the noise signal spectrum is wider
D) signal and noise is difficult to discern
E) No answer
@15
Which factor of CDMA provides higher bandwidth compared to other technologies?
15@
A) using the entire frequency resource
B) a higher data transfer rate
C) using only frequency resource portion
D) the use of statistical economical coding
E) No answer
16@
What modulation is used in modern radio transmitters of grassroots communication?

16@
A) amplitude
B) the angular and momentum
C) phase
D) frequency
E) angle
@17
What kind of a multiple access wireless communication systems, there is currently no?
17@
A) based on code division multiple access
B) based on frequency division multiplexing
C) based on phase separation channel
D) on the basis of time-division multiplexing
E) FDMA / TDMA
@18
The advantage of trunked radio systems compared to cellular systems is
18@
A) little time establishing a connection,
B) an increase in the service area through the creation of a multi-zone network
C) the set of service capabilities,
D) do not have benefits
E) roaming
@19
European standard digital trunked radio system is
19@
A) TETRA
B) Inmarsat- A
C) D-AMPS (IS-54, IS-136 later)
D) all of the above
E) CDMA
@20
What method of building diversity branches, depending on the propagation characteristics of mobile radio communication systems does not exist?
20@
A) amplitude
B) spatial
C) corner
D) polarization
E) all
@21
In what kind of radio communication systems used 3,4-5,25 GHz?
21@
A) satellite Systems

B) personal radio system
C) trunking system
D) departmental radio dispatching
E) cellular Systems
@22
Which wireless technology allows connecting to each other diverse devices such as mobile phones, laptops, printers, and digital cameras, PDA, MP3 players?
22@
A) BLUETOOTH
B) IEEE 802.11a
C) IEEE 802.11b
D) HIPERLAN
E) AMPS
@23
Bluetooth is depending on the power allows communication within a range:
23@
A) 10 or 100 meters
B) 50 or 500 meters
C) 100 or 1000 meters
D) 500 or 5000 meters
E) 1 or 10 km
@24
What parameters characterize the radio channel?
24@
A) all
B) frequency bandwidth
C) time of action
D) bandwidth
E) no answer
@25
What technical channels have the highest capacity?
25@
A) fibre Channel
B) TV channels
C) TV channels
D) telegraph channels
E) satellite TV
@26
In what kind of wireless communication systems, a range of 800-900 MHz is using?
26@
A) cell systems
B) satellite Systems
C) wireless optical system
D) personal radio systems

E) all
@27
Trunking is
27@
A) a method of free access a large number of subscribers to a limited number of channels
B) method to access a limited number of subscribers to the plurality of channels
C) Network Sharing users to multiple channels
D) Method subscribers free access on a "half duplex"
E) all
@28
In comparison with the cellular systems to the benefits of trunked radio systems should include:
28@
A) all the above advantages
B) a flexible system calls (individual, group, broadcast, priority, emergency, etc.).
C) short setup time
D) efficiency
E) No answer
@29
For multiple access frequency division ratio is valid:
29@
A) “one carrier - one channel”
B) "single carrier - more than one channel"
C) “multiple carriers - one channel"
D) “multiple carriers - several channels." The number of carriers> number of channels
E) all
@30
For multiple access time division the following relation
30@
A “one carrier - more than one channel"
B) "single carrier - one channel"
C) “multiple carriers - one channel"
D) “multiple carriers - several channels." The number of carriers greater number of channels
E) all

Abbreviations

A3 — Authentication Algorithm
A8 — The algorithm for generating the encryption key
ALC — Atmospheric laser communication
UT — User terminal
ATE — Automatic telephone exchange
UR — User radio stations
ADC — Automatic distribution channels
SST — Subscriber satellite terminal
ADC — Analog-to-digital converter
DB — Database
BTS — The base transceiver station
BS — Base station
WNI — Wireless network information
IC — Internal call
OSI — Open systems interconnection
TD — Time division
DN — Departmental network
HF — High frequency
HIEO — High inclined elliptical orbit
GC — Group call
GO — Geostationary orbit
CR — Control room
TUC — Two-way user channel
NM — The network manager
ES — Earth station
EC — European Community
IB — Information block
IBS — Information and Billing System
IC — Individual call
CIM — Coded impulse modulation
CID — Caller ID
AES — Artificial earth satellite
SC — Spacecraft
BSC — Base station controller
SV — Space vehicle
SS — Space systems
TC — Traffic channel
CC — Control Channel
EK — Encryption key
LCN — Local computing network
LC — Logical channel
MSC — Mobile subscriber

MATD — Multiple Access Time Division
MAFD — Multiple Access with Frequency Division
IIN — International identification number
IRCC — International radio consultative committee
IFRB — International Frequency Registration Board
ISO — International Standards Organization
MC — Mobile connection
ITU — International Telecommunication Union
LNA — Low-noise amplifier
LAO — Low-altitude orbit
GS — Ground Station
UA — Unauthorized access
LF — Low frequency
OGS — Orbital group of spacecraft
OK — Reverse channel
EN — Endpoint
RR — Reference relay
OCS — Optical communications systems
DT — Data transmission
PIN — Personal identification number
PC — Personal computer
IP — Intermediate point
PD — Packet data
PRROF — Pseudo-random reorganization of the operating frequency
MS — Mobile station
PS — Pseudorandom sequence
MSS — Mobile-satellite service
IST — Individual satellite terminal
IF — Intermediate frequency
RS — Radio Subscriber
RC — Radio channel
RTS — Real time scale
RS — Radio station
TSR — Trunking system (network) radio
RCS — Radio-communication system
BSS — Broadcasting satellite service
RT — Repeater
RF — Radiofrequency
BSS — Base station system
MO — Medium-orbit
CSN — Circuit switching network
PSN — Packet switching network
MCS — Mobile communication system
RPS — Radio paging system

MN — Mobile network
PSCN — Personal satellite communication network
RST — Relay satellite
SCS — Satellite communications system
STD — Schemes tracking delay
CCS — Cellular communication system
CNRC — Cellular network radio communication
CDCS — Cellular Digital Communication System
PTN — Public telecommunications network
SCM — Systems with centralized management
TC — Technical Committee
MOT — Maintenance and operation terminal
DCT — Data communication terminal
TN — Telephone network
PSTN — Public Switched Telephone Network
TCC — Trunking Communication
AM — Amplifier
CD — Control device
PC — Physical channel
PM — Phase modulation
FNPR — Federal network personal radio
FSS — Fixed satellite service
SC — Switching center
CS — Center System
FM — Frequency modulation
BS — Broadband signal
GW — Gateway
E- mail — electronic mail

Conclusion

This book is intended for a wide audience of readers, which will be useful to study the techniques of modern wireless communications and networking, as well as related technologies.

As a result of studying the discipline "Wireless technologies" a student must:

- To have an idea about the trends of development of wireless technologies, the laws that determine the relationship between indicators of the quality of the channel, the energy parameters, indicators of efficient use of the frequency bands and power economic performance;

- Must know the technical concept of building wireless communication systems; the basic parameters of radio channels and methods for the determination of these parameters; basic methods of calculating the energy parameters of wireless communication systems, and the technical parameters of networks; Features and functions of the wireless communication scheme centers; principles of network management systems; multiple access methods and their applications; technical parameters of the standards of wireless communication systems, methods, diversity signals; Block diagrams of spread spectrum systems; methods for measuring the characteristics of the main channels, devices and systems; principles of wireless LANs;

- Be able to evaluate and select major energy equipment parameters: the radius of the cell, the sensitivity of the receiver, and etc., based on the existing rules on the quality of the channel and the real parameters of the wireless route; develop frequency-territorial plan for the given standard wireless communication system for a given area; optimize the architecture of a wireless communication network for integrated performance criteria.

The authors hope that this manual will serve as a sufficient basis for a thorough study of the issues of interest to the attentive reader and self-development of specific new disciplines forming competent and thoughtful bachelor's degree in contemporary art theory and wireless communication.

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