Національний технічний університет України
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

Department of Radio Engineering

[RE-233] MOBILE TELECOMMUNICATION SYSTEMS

Curriculum of the academic discipline (Syllabus)

Course details

Level of higher education	First (bachelor's)
Field of knowledge	G - Engineering, manufacturing, and construction
Specialty	G5 - Electronics, electronic communications, instrument engineering, and radio engineering
Educational program	All
Discipline status	Elective (F-catalog)
Form of higher education	Full-time
Year of training, semester	Available for selection starting from the 3rd year, fall semester
Scope of the discipline	4 credits (Lectures: 16 hours, Practical classes: 30 hours, Laboratory work: 30 hours, Independent work: 74 hours)
Semester control/control measures	Exam
Class schedule	https://schedule.kpi.ua
Language of instruction	Ukrainian
Information about the course leader/teachers	Lecturer: O. Kalyuzhny, Independent work: O. Kalyuzhny
Course location	https://oleksa-site.blogspot.com/p/mobile-telecom.html

Curriculum

1. Description of the course, its purpose, subject matter, and learning outcomes

Objective of the credit module: *to develop basic knowledge of the principles of construction and operation of modern and promising mobile communication systems.*

Objectives of the credit module.

After completing the course, students should demonstrate the following learning outcomes:

knowledge:

- *physical characteristics of mobile communication radio channels;*
- *modulation formats for data transmission and methods of multiple access in GSM networks;*
- *frequency ranges, network architecture, second, third, and fourth generation GSM protocol stacks;*
- *noise-resistant coding and data transmission technologies;*
- *technologies for receiving signals in SMZ channels with time and Doppler dispersion.*

skills:

- *select parameters for SMZ network signal transmission paths;*
- *calculate the efficiency parameters of SMZ networks for given radio signal reception conditions;*
- *master the basics of radio planning for SMZ networks.*

Experience:

using modern software tools for planning and modeling modern generations of SMZ networks.

2. Prerequisites and post-requisites of the discipline (place in the structural-logical scheme of training under the relevant educational program)

The credit modules that provide for the study of SMZ are: Methods of probability theory in radio engineering (3/c), Signals and processes in radio engineering (4/c), Fundamentals of telecommunications and radio engineering theory (5.6/c). The discipline is part of the final cycle of professional training for bachelor's degree specialists.

3. Contents of the academic

discipline Lecture material.

Topic 1. Subject of the discipline.

Telecommunications networks, their classification and general structure. The concept of network convergence. The ISO/OSI reference model for open systems interconnection. The general structure of mobile communication systems and their classification. The cellular principle of mobile communication and frequency planning. Overview of the course content.

Topic 2. Mobile communication channels.

The main physical characteristics of the transmission environment that affect signal characteristics: frequency range, multipath propagation, temporal and Doppler scattering. Noise and interference in SRZ channels. Predicting mobile communication radio signal levels using the Okamura-Hata and COST231 methods. Predicting using the radio ray tracing method, taking into account diffraction effects.

Signal fading. Time dispersion and Doppler broadening of the signal spectrum in a multipath mobile communication radio channel. Concepts of radio channel bandwidth and coherence interval.

Fading scales. Statistical description of large-scale and small-scale fading. Concepts of Rayleigh and Rayleigh radio channels. Types of small-scale fading (smooth and frequency-selective, fast and slow). WSSUS model. Modeling of small-scale fading in radio channels according to the GSM 05.05 standard.

Topic 3. Encoding of speech signals.

Physical characteristics of speech signals. Model of the human vocal tract. Speech codecs and their classification. Encoding of speech signals using the PCM method. Encoding of signals using the linear prediction (LP) method. DPCM encoders and decoders. Encoding of speech signals with short-term and long-term prediction (LPC and LTP codecs). Vector quantization and CELP technologies. Statistical signal compression (DTX technology).

Topic 4. Digital signal modulation and multi-station access.

General principles of digital modulation. Intersymbol interference (ISI). Raised cosine filters. Characteristics of modulation methods: error rate and spectral efficiency. Nyquist filters and eye diagrams. Memoryless digital modulation. Digital modulation with memory (CPFSK, MSK, GMSK, relative (difference) modulation, offset modulation).

Criteria for selecting modulation formats in CDMA. Intra-system interference. Methods for improving spectral efficiency. Modulation formats for second, third, and fourth generation CDMA.

Basic methods of multi-station access: FDMA, TDMA, CDMA. Duplex transmission FDD and TDD. Combined methods of multi-station access Random (arbitrary) access protocols.

Wideband modulation (WBM). Frequency hopping (FH-SS) and direct spread spectrum (DS-SS). Comparative analysis of BSD methods.

Multifrequency modulation and its advantages. Orthogonal frequency division multiplexing (OFDM). Cyclic prefix and water filling algorithm.

Topic 5. Noise-resistant coding in mobile communication channels.

The channel coding theorem and Shannon's limit. Error-correcting codes and their classification. Principles of block coding and Hamming's limit. Linear codes, their generator and check matrices. Cyclic codes, generator and check polynomials of a cyclic code. Generation of a systematic cyclic code, error detection and correction. Cyclic code encoders and decoders. BCH and Reed-Solomon codes.

General structure of convolutional encoders and methods of their description: state diagram, tree diagram, and trellis diagram. Error correction in convolutional encoding. Viterbi decoders with "hard" and "soft" solutions. Interleaving of symbols as a method of combating packet errors. Turbo coding and LDPC coding.

Topic 6. Signal reception in mobile communication channels.

General formulation of the problem of communication signal reception. Optimal signal reception based on the criteria of maximum a posteriori probability and maximum likelihood.

Coherent signal reception in a channel with ABGSH. Reception of a message "as a whole" and element-by-element reception. Optimal coherent reception of PSK and QAM signals. General scheme of PSK and QAM signal reception.

Features of mobile communication radio signal reception. Adaptive power control with open and closed loops. Mobile communication channel equalization. Adaptive linear equalizers. "Blind" channel equalization. Decision feedback equalizers (DFE equalizers) and the Viterbi equalizer.

Topic 7. Spread spectrum reception in mobile communication channels.

General principles of spread reception. Spread reception of signals in channels with dispersion. Multibeam RAKE reception and its application in third-generation GSM networks.

Multi-antenna signal transmission and reception systems (MIMO systems), their classification. Transmission channel matrix and its estimation. Dependence of MIMO system efficiency on the number of antennas.

Spatial-temporal block and convolutional coding. The Alamooti algorithm and its advantages. Spatial multiplexing, areas of application, and its advantages. Application of MIMO technologies in third- and fourth-generation mobile communication systems.

Topic 8. Architecture and system aspects of GSM cellular telephony.

Fundamentals of GSM architecture. Cell, zone, service area. MSC, HLR, and VLR subsystems and their functions. AUC and EIR registers, SIM module. IMEI, IMSI, and TMSI identifiers.

GSM radio transmission parameters: frequency bands, transmission speed, time slot parameters. Time structure: frame, multiframe, superframe, hyperframe.

Multiframe structure in downlink and uplink. Packet structure. Main types of logical channels and their representation at the physical level. Connection procedures: initial registration and activation of MS after switching on, call procedures. Handover and its types. Confidentiality and user authentication. Encryption of user information.

Topic 9. IS-95 cellular telephony standard and 2G+ networks.

DS-SS technology and its capabilities. Pseudorandom sequences (PRS) and their properties. Maximum length shift register sequence, Gold and Kasami sequences.

Extension of the signal spectrum in the IS-95 standard for the forward and reverse channels. Synchronous and asynchronous CDMA. Forward and reverse channel architectures. Physical channels and their structure. Mapping of logical channels to the physical layer. Evolution of 2G standards. HSCSD, GPRS, and EDGE technologies.

Topic 10. General concept and organization of 3G networks.

IMT-2000 protocols and their main characteristics. Difficulties in the practical implementation of the IMT-2000 concept. Basic requirements for 3G systems and their fundamental differences from 2G and 2.5G systems.

UMTS radio access network architecture, its main nodes and their purpose. UMTS protocol stack, layers, sub-protocols and their purpose. Control and user planes in the UMTS protocol stack.

Main characteristics of the UTRAN radio interface: bands, transmission speeds, chip rate, frame duration, time slots, etc.

Logical, transport, and physical channels of the 3G network. Their purpose and categories. Dedicated and common channels and their use.

Generation of uplink and downlink physical channels. Expanding and scrambling pseudo-random sequences, modulation method. Time structure of channels.

Features of relay transmission in 3G networks. Features and differences between the cdma2000 standard and the UMTS standard.

Topic 11. General concept and organization of 4G networks.

Evolution of 3G standards. The IMT Advanced concept and its main features.

LTE network architecture and its main nodes. LTE protocol stacks, their composition and main functions.

Construction of LTE network interfaces. Their composition and main functions. Logical, transport, and physical channels of the LTE standard. Their composition and main functions. Mapping of logical channels to the transport layer and mapping of transport channels to the physical layer.

Frequency plan for LTE networks. OFDM and SC-FDMA technologies. Time structure of LTE signals and their frequency-time organization. Placement of physical channels. Uplink and downlink data transmission. MIMO technologies in LTE networks. Heterogeneous networks. The LTE Advanced standard and its main features.

Topic 12. The concept of promising 5G mobile access networks.

Concept and program for the creation of 5G networks. Basic requirements and main tasks of the IMT2020 project. Frequency resource, architecture, and radio interface of IMT 2020 networks. Methods of multi-frequency modulation with non-orthogonal channel spacing: N-OFDM, FBMC, F-OFDM, UFMC, GFDM, BFDM, etc. Massive MIMO technologies and service area organization.

Topics of practical classes:

1. Modeling signal transmission in SMZ using the Matlab-Simulink computing environment. Review of modeling examples.
2. Seminar on the topic "Mobile communication channels." Solving problems to determine the characteristics of radio channels with fading.
3. Modeling radio channels with time dispersion and Doppler spread spectrum in the Matlab-Simulink environment. Analysis of signal transmission efficiency in the Matlab-Simulink environment using the BERTool software application. Review of modeling examples.
4. Seminar on the topics "Speech Signal Coding" and "Multi-Station Access." Consideration of software simulators of speech codecs in the Matlab environment.
5. Test on topics 1-8.
6. Seminar on "Architecture and System Aspects of Second-Generation SMZ."
7. Seminar on "Architecture and Organization of Third-Generation SMZ."
8. Seminar on the topic "Architecture and Organization of Fourth-Generation SMZ."

List of laboratory work:

The purpose of laboratory classes is to experimentally verify theoretical knowledge and acquire practical skills in solving SMZ network radio planning tasks.

Laboratory classes are conducted in the form of a computer workshop. Each student has their own workstation (personal computer). Students receive laboratory work assignments in advance. Before the start of the class, a survey is conducted to assess the student's readiness to perform the work. After completing the work, it is defended and the results are discussed. A report on the laboratory work is prepared.

Class topics:

1. BTS site manager
2. Transmission parameter settings
3. Intracom web interface
4. Optimization of the placement of UMTS and LTE base stations in the Atol software environment.

4. Training materials and resources

Basic literature:

1. Hepko I.A. et al. Edited by Prof. Oleynik V.F. Modern Wireless Networks: Status and Prospects. Kiev, EKMO, 2009.

dditional literature:

1. Yong Soo Cho & others. MIMO-OFDM WIRELESS COMMUNICATIONS WITH MATLAB. John Wiley & Sons (Asia). 2010.
2. Andreas F. Molisch. WIRELESS COMMUNICATIONS. John Wiley & Sons Ltd., 2011.
3. Sauter M. From GSM to LTE-Advanced Pro and 5G. An Introduction to Mobile Networks and Mobile Broadband. Third Edition, 2017 John Wiley & Sons Ltd. - 2017. - 530 p.
4. Ajay R. Mishra. Fundamentals of Network Planning and Optimisation 2G/3G/4G: Evolution to 5G. John Wiley & Sons Ltd. 2018. - 427 p.

Educational content

5. Methodology for mastering the academic discipline (educational component)

At the beginning of the course, students get access to electronic resources on the teacher's website, where lecture materials, practical and laboratory classes are posted. For each class, students receive homework assignments to reinforce their theoretical knowledge and practical skills. The completion of assignments is checked by the teacher at the beginning of each subsequent class. The completeness and quality of the assignment is one of the main components of the student's current rating for the semester. Two written tests are conducted during the semester.

Detailed plan of lecture material:

No. No	Lecture topic and list of main questions
1	**Topic 1. Subject of the discipline.** Telecommunications networks, their classification and general structure. The concept of network convergence. The ISO/OSI reference model for open systems interconnection. The general structure of mobile communication systems and their classification. The cellular principle of mobile communication organization and frequency planning. Overview of the course content. ***Homework assignment:*** Prepare written answers to the test questions based on the topic materials.
2	**Topic 2. Mobile communication channels.** The main physical characteristics of the transmission environment that affect signal characteristics: frequency range, multipath propagation, time and Doppler scattering. Noise and interference in SRC channels. Predicting mobile communication radio signal levels using the Okamura-Hata and COST 231 methods. Predicting using the radio ray tracing method, taking into account diffraction effects.
3	**Topic 2. Mobile communication channels (continued).** Signal fading. Time dispersion and Doppler broadening of the signal spectrum in a multipath mobile communication radio channel. The concept of radio channel bandwidth and coherence interval. Fading scales. Statistical description of large-scale and small-scale fading. The concept of Rayleigh and Rayleigh radio channels. Types of small-scale fading (smooth and frequency-selective, fast and slow). WSSUS model. Modeling of small-scale fading in radio channels according to the GSM 05.05 standard. ***Assignment for independent work:*** Prepare written answers to test questions based on the topic materials and solve problems. Conduct modeling mobile communication radio channels in the Matlab-Simulink software environment.
4	**Topic 3. Encoding of speech signals.** Physical characteristics of speech signals. Model of the human vocal tract. Speech codecs and their classification. Coding of speech signals using the PCM method. Coding of signals using the linear prediction (LP) method. DPCM encoders and decoders. Encoding of speech signals with short-term and long-term prediction (LPC and LTP codecs). Vector quantization and CELP technologies. Statistical signal compression (DTX technology). ***Assignments for independent work:*** Prepare written answers to test questions based on the topic materials. Conduct modeling of speech signal encoding procedures in the Matlab-Simulink software environment.
5	**Topic 4. Digital signal modulation and multi-station access.** General principles of digital modulation. Inter-symbol interference (ISI). Raised cosine filters. Characteristics of modulation methods: error rate and spectral efficiency. Nyquist filters and eye diagrams. Memoryless digital modulation. Digital modulation with memory (CPFSK, MSK, GMSK, relative (difference) modulation, offset modulation). Criteria for selecting modulation formats in SRZ. Internal system interference. Methods for improving spectral efficiency. Modulation formats for transmission in second, third, and fourth generations.

No. No.	Lecture topic and list of key questions
6	**Topic 4. Digital signal modulation and multiple access (continued).** Basic methods of multiple access: FDMA, TDMA, CDMA. Duplex transmission FDD and TDD. Combined methods of multiple access Random access protocols. Wideband modulation (WBM). Frequency hopping (FH-SS) and direct spread spectrum (DS-SS). Comparative analysis of BSD methods. Multifrequency modulation and its advantages. Multiplexing with orthogonal frequency division multiplexing (OFDM). Cyclic prefix and water filling algorithm. ***Assignments for independent study:*** Prepare written answers to test questions based on the topic materials and solve problems. Conduct modeling of digital modulation/demodulation procedures and multi-station access in the Matlab-Simulink software environment.
7	**Topic 5. Noise-resistant coding in mobile communication channels.** The theorem on coding in a channel and Shannon's limit. Error-correcting codes and their classification. Principles of block coding and Hamming's limit. Linear codes, their generator and check matrices. Cyclic codes, generator and check polynomials of a cyclic code. Generation of a systematic cyclic code, error detection and correction. Cyclic code encoders and decoders. BCH and Reed-Solomon codes.
8	**Topic 5. Error-resistant coding in mobile communication channels. (continued).** General structure of convolutional encoders and methods of their description: state diagram, tree diagram, and trellis diagram. Error correction in convolutional coding. Viterbi decoders with "hard" and "soft" solutions. Interleaving of symbols as a method of combating packet errors. Turbo coding and LDPC coding. ***Homework assignment:*** Prepare written answers to test questions based on the topic materials and solve problems. Simulate noise-resistant encoding/decoding procedures in the Matlab-Simulink software environment. Simulink software environment.
9	**Topic 6. Signal reception in mobile communication channels.** General formulation of the problem of receiving communication signals. Optimal signal reception based on the criteria of maximum a posteriori probability and maximum likelihood. Coherent signal reception in a channel with ABGSH. Reception of messages "as a whole" and element-by-element reception. Optimal coherent reception of PSK and QAM signals. General scheme of PSK and QAM signal reception. Features of mobile communication radio signal reception. Adaptive power control with open and closed loops. Mobile communication channel equalization. Adaptive linear equalizers. "Blind" channel equalization. Feedback equalizers based on solutions (DFE equalizers) and the Viterbi equalizer. ***Assignments for independent work:*** Prepare written answers to test questions based on the topic materials and solve problems. Conduct modeling signal reception procedures in the Matlab-Simulink software environment.
10	**Topic 7. Spread spectrum signal reception in mobile communication channels** General principles of spread spectrum reception. Spread spectrum reception in channels with dispersion. Multibeam RAKE reception and its application in third-generation GSM networks. Multi-antenna signal transmission and reception systems (MIMO systems), their classification. Transmission channel matrix and its evaluation. Dependence of MIMO system efficiency on the number of antennas. of MIMO systems on the number of antennas.

No. No	Lecture topic and list of main questions
11	**Topic 7. Spaced signal reception in mobile communication channels (continued)** Spatial-temporal block and convolutional coding. The Alamo-Wright algorithm and its advantages. Spatial multiplexing, areas of application, and its advantages. Application of MIMO technologies in third- and fourth-generation mobile communication systems. ***Assignment for independent study:*** Prepare written answers to test questions based on the topic materials and solve problems. Conduct modeling spaced reception procedures in the Matlab-Simulink software environment.
12	**Topic 8. Architecture and system aspects of GSM cellular telephony.** [2], [3], [5]. Basics of GSM architecture. Cell, zone, service area. MSC, HLR, and VLR subsystems and their functions. AUC and EIR registers, SIM module. IMEI, IMSI, TMSI identifiers. GSM radio transmission parameters: frequency bands, transmission speed, time slot parameters. Time structure: frame, multiframe, superframe, hyperframe. Multiframe structure in downlink and uplink. Packet structure. Main types of logical channels and their representation at the physical level. Connection procedures: initial registration and activation of MS after power-up, call procedures. Handover and its types. Confidentiality and user authentication. Encryption of user information. ***Assignment for independent study:*** Prepare written answers to test questions questions based on the topic materials and solving problems.
13	**Topic 9. IS-95 cellular telephony standard and 2G+ networks.** DS-SS technology and its capabilities. Pseudorandom sequences (PRS) and their properties. Maximum length shift register sequence, Gold and Kasami sequences. Extension of the signal spectrum in the IS-95 standard for the forward and reverse channels. Synchronous and asynchronous CDMA. Forward and reverse channel architectures. Physical channels and their structure. Mapping of logical channels to the physical layer. Evolution of 2G standards. HSCSD, GPRS, and EDGE technologies. ***Assignment for independent study:*** Prepare written answers to test questions questions based on the topic materials and solving problems.
14	**Topic 10. General concept and organization of 3G networks.** IMT-2000 protocols and their main characteristics. Difficulties in the practical implementation of the IMT-2000 concept. Basic requirements for 3G systems and their fundamental differences from 2G and 2.5G systems. UMTS radio access network architecture, its main nodes and their purpose. UMTS protocol stack, levels, sub-protocols and their purpose. Control and user planes in the UMTS protocol stack. Key characteristics of the UTRAN radio interface: bands, transmission speeds, chip rate rate, frame duration, time slots, etc.
15	**Topic 10. General concept and organization of 3G networks (continued).** Logical, transport, and physical channels of a 3G network. Their purpose and categories. Dedicated and common channels and their use. Generation of uplink and downlink physical channels. Expanding and scrambling pseudo-random sequences, modulation method. Time structure of channels. Features of relay transmission in 3G networks. Features and differences between the cdma2000 standard and the UMTS standard. ***Assignments for independent study:*** Prepare written answers to test questions questions based on the topic materials and solving problems.

No. No	Lecture topic and list of main questions
16	**Topic 11. General concept and organization of 4G networks.** The evolution of 3G standards. The IMT Advanced concept and its main features. LTE network architecture and its main components. LTE protocol stacks, their composition and main functions. Structure of LTE network interfaces. Their composition and main functions. Logical, transport, and physical channels of the LTE standard. Their composition and main functions. Mapping of logical channels to the transport layer and mapping transport channels to the physical layer.
17	**Topic 11. General concept and organization of 4G networks (continued)**. Frequency plan for LTE networks. OFDM and SC-FDMA technologies. Time structure of LTE signals and their frequency-time organization. Physical channel allocation. Uplink and downlink data transmission. MIMO technologies in LTE networks. LTE Advanced standard and its main features. Heterogeneous networks. ***Assignment for independent study:*** Prepare written answers to test questions questions based on the topic materials and solving problems.
18	**Topic 12. The concept of promising 5G mobile access networks.** Concept and program for creating 5G networks. Basic requirements and main tasks of the IMT2020 project. Frequency resource, architecture, and radio interface of IMT 2020 networks. Methods of multi-frequency modulation with non-orthogonal channel spacing: N-OFDM, FBMC, F-OFDM, UFMC, GFDM, BFDM, etc. Massive MIMO technologies and service area organization. ***Assignments for independent work:*** Prepare written answers to test questions questions based on the topic materials and solving problems.

Laboratory classes

The main task of the laboratory class cycle is to develop the relevant skills and experience in students. Laboratory classes are conducted according to the methods described in the manual [9].

No.	**Name of the class topic and list of main questions**	**Number of classroom hours**
1	Practical introduction to SMZ frequency-territorial planning software tools, as well as methods of their interaction with geoinformation systems (GIS). information systems (GIS).	2
2	Selection of antenna characteristics and base station parameters for SMZ UMTS and LTE standards in the Atol software environment.	2
3	Predicting radio coverage of UMTS and LTE base stations in the Atol software environment.	2

Practical and seminar classes.

Classes are held for better assimilation and in-depth study of lecture material. The topics of practical classes are communicated to students in advance.

Each student may receive an individual assignment for independent work on the topic of the practical class to assess the quality of their understanding of the material. The materials for practical and seminar classes are based on the sources listed in the recommended reading list.

No.	Modeling signal transmission in SMZ using the Matlab-Simulink computing environment. Consideration of examples of modeling radio channel blocks, transmitters, receivers, modulation/demodulation, encoding/decoding. Analysis of signal transmission efficiency in the Matlab-Simulink environment using the BERTool software application. Consideration of modeling examples.
1	

2	Seminar on "Block and convolutional error-correcting coding in mobile communication radio channels." Consideration of software models of signal transmission systems with error-correcting coding in the Matlab-Simulink environment.

6. Independent work

Independent work consists of regular completion of current homework assignments.

Policy and control

7. Policy of the academic discipline (educational component)

The student's grade for the discipline consists of points awarded for:

1. Attending lectures and taking notes.
2. Attending and doing independent work in practical classes.
3. Completion of coursework or calculation work.
4. Completion and defense of laboratory work.
5. Completion of a modular test.
6. Taking an exam.

The rating scale for the discipline is 100 points

8. Types of control and rating system for assessing learning outcomes

Table of correspondence between rating points and grades on the university scale

Number of points	Grade
100	Excellent
94	Very good
84	Good
74-65	Satisfactory
64-60	Sufficient
Less than 60	Unsatisfactory
Admission requirements not met	Not admitted

9. Additional information on the discipline (educational component)

Description of material, technical, and informational support for the discipline

Base station in room 503-17, building.

Work program for the academic discipline (syllabus):

Compiled by O. Ya. Kalyuzhny;

Approved by the RI Department (Minutes No. 06/2025 dated 06/24/2025)

Approved by the methodological commission of the faculty/research institute (protocol No. 06/2025 dated 25.06.2025)