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

Кафедра телекомунікацій

MATHEMATICAL METHODS OF SCIENTIFIC RESEARCH IN TELECOMMUNICATIONS AND RADIO ENGINEERING

Work program of the course (Syllabus)

Details of the course

Higher Education Level	*Third (Educational and Scientific)*
Branch of knowledge	*17 Electronics and Telecommunications*
Speciality	*172 Telecommunications and Radio Engineering*
Educational and Research program	*Telecommunications and Radio Engineering*
Type of course	*Normative*
Mode of study	*daily study (full-time study)*
Year of study, semester	*2nd year, autumn semester*
The scope of the course	*3 credits – 90 hours*
Semester control / control measures	*exam*
Course schedule	*2 hours a week*
Language	*Ukrainian*
Course Instructors	*Lecturer: Doctor of Technical Sciences, professor Lysenko Oleksandr Ivanovych, 096-225-28-20, Lysenko.a.i.1952@gmail.com* *Practical classes: Doctor of Technical Sciences, professor Lysenko Oleksandr Ivanovych, 096-225-28-20, Lysenko.a.i.1952@gmail.com*
Access to the course	*https://classroom.google.com/u/0/c/MTYzMDEzNjE5NTkw course code 4nufqjn* at the invitation of the teacher

Curriculum

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

The course covers the main of mathematical programming and operations research and provides modern approaches to the application of theoretical principles for solving practical problems in telecommunications and radio engineering.

The course is based on natural-scientific ideas about the existing universe.

The object of the course: mathematical models of phenomena and processes that occur in telecommunications systems (networks) and radio engineering and affect the efficiency of telecommunications and radio engineering.

The course «Mathematical methods of scentific researches in telecommunications and radio engineering» provides in-depth applied mathematical knowledge and thus provides a sufficient level of mathematical training to write a PhD dissertation in the field of electronics and telecommunications majoring in telecommunications and radio engineering.

1. The purpose and tasks of the course

1.1. The purpose of the course

Acquisition of competencies (integral, general (GC1, GC2)), professional (SC2, SC3)), knowledge (KN1, KN2, KN4) and skills (SK5, SK7, SK12) on the basics of construction, identification and practical use of mathematical models of deterministic and random phenomena that occur in information and telecommunications systems (networks) and radio engineering in general and in individual hardware and technological processes.

1.2. The main tasks of the course

According to the requirements of the educational and scientific program, applicants after mastering the course must demonstrate the following learning outcomes:

Program Competencies:

Integral competence

Competence to solve complex problems in the field of professional and/or research and innovation activities, which requires a profound reinterpretation of existing and creation of new core knowledge and/ or professional practice **due to mastering** terminology, definitions, basic concepts, symbolic notation of basic operations and **understanding** their content used in deterministic and uncertain conditions; **understanding** of experimental bases that explain the physical and philosophical content of random phenomena, the differences between stochastic and deterministic processes; formulation of mathematical programming tasks, which are most common in telecommunications and radio engineering; signs and characteristics of random processes: Wiener, Poisson, Markov; stationary and ergodic; discrete and continuous, ways of their identification and imitation.

General Competencies (GC)

GC 1 (Ability to critically analyze, evaluate and synthesize new complex ideas), **GC 2** (Ability to initiate, develop and implement research and innovation projects including own research) **due to mastering** the most common problems of mathematical programming in telecommunications and radio engineering; signs and characteristics of random processes: Wiener, Poisson, Markov; stationary and ergodic; discrete and continuous, ways of their identification and imitation; criteria and methods for testing statistical hypotheses; mathematical models of criteria and methods of technical and economic optimization of queuing systems; criteria and methods for assessing and optimizing the reliability of telecommunications and telecommunications systems.

Special professional competencies (SC)

SC 2 (Ability to apply mathematical methods of scientific research, simulation modeling, applied aspects of systems analysis in various kinds of professional), **SC 3** (Ability to perform theoretical and experimental research, mathematical and computer modeling of processes in telecommunications and radio engineering systems and devices) **due to mastering** classical mathematical methods of analysis and synthesis of rational, quasi-optimal and optimal ***telecommunication and radio systems***; information technologies for solving classical problems of linear, nonlinear, discrete (including integer), stochastic, dynamic programming, modeling operations by statistical tests, justification of decisions by methods of game theory, network planning, vector optimization; methods of problems formalization of structural-functional analysis, general strategy of their solution and system optimization of ***complex structural elements of telecommunication and radio systems and devices*** based on the use of numerical methods in nonlinear programming problems: zero-order method; direct search method (Hook-Jeeves method); deformed polyhedron method (Nelder-Mead method numerical methods of the first and second orders unconditional optimization: the method of steepest descent; conjugate gradient method; algorithms based on Newton's method; methods for solving nonlinear programming problems in the presence of limitations: gradient projection method; Box's complex method; penalty function method; dynamic programming.

Program results of teaching

KNOWLEDGE (KN)

KN 1 (Conceptual and methodological knowledge in the field of research and / or professional activity and between the subject fields), **KN 2** (Knowledge of methods of scientific research in the field), **KN 4** (Modern mathematical methods of scientific research, simulation modeling, applied aspects of systems analysis), **which specifically consist in memorizing and understanding** the elements of theory of deterministic linear and nonlinear programming, main sections of stochastic linear and nonlinear programming (stochastic approximations method, multivariate regression analysis, analysis of variance, factor analysis, methods of structure and parameters identification in stochastic difference equations, foundations of theory of hypothesis recognition and testing; foundations of statistical (simulation) modeling methods), methods of extremums numerical search of convex functions on convex sets; methods of dynamic, parametric and integer programming; terminology, definitions, basic concepts, symbolic notation of basic operations and their content used in the theory of mathematical programming, decision theory, game

theory, inventory management theory and simulation; experimental bases, physical and philosophical content of random phenomena, differences of stochastic processes from deterministic ones, features of their reflection in mathematical models in the amount sufficient for mastering the basics of functioning, evaluation of efficiency and optimization of ***modern and perspective technologies and means of telecommunication, theory and practice of telecommunication systems and networks.***

SKILLS (SK)

SK 5 (Carry out independently the scientific and research work in the telecommunications and radio engineering fields using modern mathematical methods of scientific research, simulation modeling, and applied aspects of systems analysis), **SK 7** (Ability to prepare educational proposals and implement the educational process for the Ukrainian and other home audiences, to refine teaching methods for a better understanding of the subject), **SK 12** (Choose the appropriate (the best for certain criteria) method of solving the problem), **which consist in the specific skills and the applicant personal research in relation to** mathematical models construction of means of telecommunications and telecommunications systems and networks, as well as technological processes that take place in them, in terms of the theory of operations research in infotelecommunications and radio engineering, identification of the structure and parameters of these models; processing the results of statistical observations of random phenomena and processes in telecommunications systems (evaluate the parameters of random variables and processes, test statistical hypotheses); interpretation of the statistical processing results of experimental observations, analytical research and computer simulation of telecommunications facilities, telecommunications systems and radio engineering; performing mathematical formulation of optimization problems and improvement of technical telecommunications facilities, telecommunications systems and radio engineering in terms (format) of computer mathematics system MATLAB + Simulink.

2. Prerequisites and postrequisites of the course (place in the structural and logical scheme of education according to the relevant educational program)

To successfully master the course, the applicant must have knowledge of mathematical analysis, analytical geometry, matrix theory, differential equations, probability theory and mathematical statistics.

The courses «Innovative directions of development of telecommunications and radio engineering», «The scientific and innovative activities organization – 1», «The scientific and innovative activities organization – 2», «Applied aspects of systems analysis in telecommunications and radio engineering», «Simulation modeling in telecommunications and radio engineering», «The effectiveness evaluation methods of telecommunications systems», «Models and calculation methods of telecommunication network», «Data analysis in IoT systems», «Big Data Processing Methods» are based on the results of studying this course, as well as academic course for the universal competencies acquisition of the researcher (elective).

The mathematical problems formulations and methods of their solution in the electronics and telecommunications field majoring in telecommunications and radio engineering, which are studied in the dissertations of applicants are based on the results of the study of this course.

3. The content of the course

Title of sections and topics	Number of hours			
	Total	including		
		Lectures	Practices	IWS
Introduction to the course. ***Topic 1. General methodology of operations research in telecommunications and radio engineering***	4	2	-	2
Topic 2. The subject of mathematical programming	8	2	-	6
Topic 3. Linear programming	12	2	4	6
Topic 4. Nonlinear programming	21	5	6	10
Topic 5. Discrete programming	10	2	2	6
Module test	5	-	1	4
Exam	30	-	-	30

Total hours	90	13	13	64

4. Learning materials and resources

Basic literature:

1. . Лисенко О.І., Тачиніна О.М., Алєксєєва І. В. «Математичні методи моделювання та оптимізації. Частина 1. Математичне програмування та дослідження операцій: підручник» – К.: НАУ, 2017. – 212 с. ISBN 978-966-932-063-6 .

2. Лисенко О.І., Алєксєєва І.В. Дослідження операцій. Конспект лекцій. — К: НТУУ «КПИ», 2016. – 196 с.

3. Ільченко М.Ю., Кравчук С.О. Телекомунікаційні системи. – Київ: Наукова думка, 2017. – 730 с

4. Досягнення в телекомунікаціях 2019 / за наук. ред. М.Ю.Ільченка, С.О.Кравчука: монографія. - Київ: Інститут обдарованої дитини НАПН України, 2019.- 336 с. Рекомендовано до друку ВР КПІ ім.І.Сікорського (прот.№10 від 04.11.2019 р.) ISBN 978-617-7734-12-2

5. Ларіонов Ю.І., Левикін В.М., Хажмурадов М.А. Дослідження операцій в інформаційних системах.- Харків.: Компанія СМІТ, 2005.-364 с.

6. Глоба Л.С., Дяденко О.М., Пилипенко А.Ю., Скулиш М.А. Математичні методи аналізу та керування телекомунікаційними мережами. К.: Інститут обдарованої дитини НАПН України, 2017. – 234 с.

Additional literature:

7. Глоба Л.С. Розробка інформаційних ресурсів та систем. Підручник у 2 т.. – К.: НТУУ „КПІ”, 2014. Т.1. - 376 с.

8. Глоба Л.С. Розробка інформаційних ресурсів та систем. Підручник у 2 т.. – К.: НТУУ „КПІ”, 2015. Т.2. - 376 с.

9. Xin-She Yang. Optimization Techniques and Applications with Examples. Hoboken, New Jersey: JohnWiley & Sons, 2018. – 364 p.

10. Probability and Statistics. The Science of Uncertainty. Second Edition. Michael J. Evans and Je¤rey S. Rosenthal. University of Toronto. - *2009.-750 p.*

11. Probability and Stochastic. Processes with Applications
Oliver Knill. Edition : 2009. Published by Narinder Kumar Lijhara for Overseas Press India Private Limited, 7/28, Ansari Road, Daryaganj, New Delhi-110002 and Printed in India. – 382 p.

12. Probability Theory: STAT310/MATH230. March 13, 2020. Amir Dembo. E-mail address: amir@math.stanford.edu. Department of Mathematics, Stanford University, Stanford, CA 94305. – 400 p.

13. **Information resources**
Lysenko O.I. Distance course. https://classroom.google.com/c/MTYzMDEzNjE5NTkw. Access code: 4nufqjn.

5. Methods of mastering the course (educational component)

Full-time / distance learning

Lecture classes

№	The lecture title and a list of key issues (list of didactic means, literature references and tasks for IWS)
1	**Introduction to the course «Mathematical methods of scentific researches in telecommunications and radio engineering».** The purpose, objectives and structure of the course. **General methodology of operations research in telecommunications and radio engineering.** Basic concepts and definitions. The model of the operation. Basic principles of models construction of operation. Methodology of operations research. Typical classes of operations research tasks. General mathematical model of decision making. *Recommended literature*: [1, 2, 3, 4, 9, 10, 11, 12, 13]
2	**The subject of mathematical programming.** General problem of mathematical programming. Classification of mathematical programming problems. Types of maximums. The Weierstrass theorem and theorem about sufficient conditions for the global maximum. Specific of mathematical programming problems in telecommunications. *Recommended literature*: [1, 2, 3, 4, 6, 9, 10, 11, 12, 13].
3	**Linear programming.** Examples of linear programming problems (LPP). Forms of writing a linear programming problem. Geometric interpretation of LPP. Simplex method of solving LPP.

	Modifications of simplex method: dual simplex method; inverse matrix method. Artificial basis method. Duality (conjugation) in linear programming. Post-optimal analysis of LPP. Parametric programming. Special tasks of linear programming: transportation problem (T-problem); assignment problem. *Recommended literature*: [1, 2, 5, 9, 10, 11, 12, 13].
4	**Classic conditions for an extremum.** Lagrange multiplier method. An example of the simplest nonlinear programming problem (NPP) in the conditions of variables non-negativity. Kuhn-Tucker conditions. NPP and saddle point. Quadratic programming. Frank–Wolfe method. NPP with separable functions. Problems of hyperbolic programming. *Recommended literature*: [1, 2, 5, 6, 7, 8].
5	**Numerical methods for nonlinear programming problems:** zero-order method; direct search method (Hook-Jeeves method); deformed polyhedron method (Nelder-Mead method), numerical methods of the first and second orders unconditional optimization: the method of steepest descent; conjugate gradient method; algorithms based on Newton's method. *Recommended literature*: [1, 2, 5, 6, 7, 8, 13].
6	**Methods for solving nonlinear programming problems with constraints:** gradient projection method; Box's complex method; penalty function method; dynamic programming. *Recommended literature*: [1, 2, 5, 6, 7, 8, 13].
7	**Discrete programming.** General characteristics of discrete problems. Mathematical models of discrete programming problems. Gomorrah method. The branch and bound approach. *Recommended literature*: [1, 5, 6, 7, 8, 13].
8	Exam

Practical classes

№	The lecture title and a list of key issues (list of didactic means, literature references and tasks for IWS)
1	**Examples of linear programming problems (LLP) in telecommunications and radio engineering.** Forms of writing a linear programming problem. Geometric interpretation of LPP. Simplex method of solving LPP. Modifications of simplex method: dual simplex method; inverse matrix method. Artificial basis method. Duality (conjugation) in linear programming. *Tasks for IWS:* [3, 4, 5, 6, 7, 8, 13].
2	**Post-optimal analysis of LPP in telecommunications and radio engineering.** Parametric programming. Special tasks of linear programming: transportation problem (T-problem); assignment problem. *Tasks for IWS:* [3, 4, 5, 6, 7, 8, 13].
3	**Classic conditions for an extremum in telecommunications and radio engineering.** Lagrange multiplier method. An example of the simplest nonlinear programming problem (NPP) in the conditions of variables non-negativity. Kuhn-Tucker conditions. NPP and saddle point. Quadratic programming. Frank–Wolfe method. NPP with separable functions. Problems of hyperbolic programming. *Tasks for IWS*: [3, 4, 5, 6, 7, 8, 13].
4	**Numerical methods for nonlinear programming problems in telecommunications and radio engineering:** zero-order method; direct search method (Hook-Jeeves method); deformed polyhedron method (Nelder-Mead method). *Tasks for IWS:* [3, 4, 5, 6, 7, 8, 13].
5	**Numerical methods of the first and second orders unconditional optimization in telecommunications and radio engineering:** conjugate gradient method; algorithms based on Newton's method; methods for solving nonlinear programming problems in the presence of limitations: gradient projection method; Box's complex method; penalty function method; dynamic programming. *Tasks for IWS:* [3, 4, 5, 6, 7, 8, 13].
6	**Дискретне програмування in telecommunications and radio engineering.** Mathematical models of discrete programming problems. Gomorrah method. The branch and bound approach. *Tasks for IWS:* [3, 4, 5, 6, 7, 8, 13].
7	Module test. *Tasks for IWS:* [3, 4, 5, 6, 7, 8, 13].

Methodology of mastering the course «Mathematical methods of scentific researches in telecommunications and radio engineering» is to acquire practical skills in applying the provisions of probability theory, mathematical statistics, queuing theory and reliability theory to solve specific technical problems arising in the development and operation of telecommunications equipment and information and telecommunication and radio engineering systems, acquisition of stable skills of implementation of scientifically sound, conscious, confirmed by calculations decisions.

6. Independent work of a postgraduate student

The applicant must repeat the material presented in the courses of mathematical analysis and linear algebra, to enhance the perception of mathematical and applied ideas of the course «Mathematical methods of scentific researches in telecommunications and radio engineering».

More attention needs to be paid to solving problems in IWS to increase the speed and reliability of mastering the basic principles of the theory.

Recommended to conduct computer simulation experiments to test the theoretical positions presented in lectures for meaningful and lively perception of the course «Mathematical methods of scentific researches in telecommunications and radio engineering», as well as use methods studied in the course when writing a dissertation in order to build mathematical models of the studied phenomena for further optimize the management of these phenomena.

Quality control of the student's mastery of the course is carried out by questioning in practical classes, checking the MT, as well as during the exam.

Policy and control

7. The policy of the course (educational component)

The material of the «Mathematical methods of scentific researches in telecommunications and radio engineering» credit module is studied in the second year and in the second semester in lectures and practical classes. Theoretical material is presented and further used to solve exercises and problems on the basis of textbooks and manuals recommended by the Ministry of Education and Science of Ukraine for higher education applicants. Examples of application of mathematical programming (deterministic and stochastic, linear and nonlinear, static and dynamic), game theory, network planning, vector optimization, structural and functional analysis of complex hierarchical systems to solve practical problems in telecommunications and radio engineering are given in the textbook, recommended Methodological Council of KPI, and scientific and technical publications.

Quality control of the student's mastery of the course is carried out by questioning in practical classes, checking the MT, as well as during the exam. The assessment of the applicants success for the credit module is determined on the basis of the rating system.

Academic integrity

The policy and principles of academic integrity are defined in Section 3 of the Code of Honor of the National Technical University of Ukraine «Kyiv Polytechnic Institute named after Igor Sikorsky». Details: hhttps://kpi.ua/code

Norms of ethical behavior

Norms of ethical behavior of students and employees are defined in Section 2 of the Code of Honor ofthe National Technical University of Ukraine «Kyiv Polytechnic Institute named after Igor Sikorsky». Details: https://kpi.ua/code

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

1. The rating of the applicant from the credit module is calculated based on a 100-point scale, of which 60 points is the starting scale. The starting rating (during the semester) consists of points that the applicant receives for:
   - performance of test (6 express tests);
   - performance of module test (MT);

2. The assessment criteria.

2.1. Each express tests are evaluated at 5 points:
- «excellent» – complete answer (not less than 90% of the required information) – 5 points;
- «good» – fairly complete answer (not less than 75% of the required information) or complete answer with minor inaccuracies – 4 points;

– «satisfactory» – incomplete answer (not less than 60% of the required information) and minor mistakes – 3 points;
– «unsatisfactory» – the answer does not meet the requirements for «satisfactory» – 0 points.

2.2. The Module test is evaluated at 30 points:
– «excellent» – all tasks are done correctly and completely (not less than 90% of the required information) – 27-30 points;
– «good» – tasks are done partly (not less than 75% of the required information) – 22-26 points;
– «satisfactory» – tasks are done with errors (not less than 60% of the required information) – 18-21 points;
– «unsatisfactory» – tasks are not done or contained serious errors, MT is not credited – 0 points.

3. Calendar midterm attestation of applicants is carried out according to the value of the current rating at the time of attestation. If the value of this rating is not less than 50% of the maximum possible at the time of attestation, the applicant is considered attested. The condition for a positive first attestation is to obtain at least 8 points. The condition for a positive second attestation is to obtain at least 22 points.

4. The condition for admission to the exam is a starting rating of at least 30 points.

5. At the exam, applicants answer the questions from the examination paper. Each examination paper contains four questions (tasks). Each question (task) is evaluated in 10 points according to the following criteria:
– «excellent», complete answer, not less than 90% of the required information (complete, error-free solution of the task) – 9-10 points;
– «good», fairly complete answer, not less than 75% of the required information, there are minor inaccuracies (complete solution of the task with minor inaccuracies) – 7-8 points;
– «satisfactory», incomplete answer, not less than 60% of the required information, there are some mistakes (the task is performed with certain shortcomings) – 6 points;
– «unsatisfactory», the answer does not meet the requirements for «satisfactory» – 0 points.

6. The sum of starting points and points for the exam is converted into the examination grade according to the table:

Number of points	Assessment
100…95	Excellent
94…85	Very good
84…75	Good
74…65	Satisfactory
64…60	Sufficient
< 60	Unsatisfactory
calculation and graphic work was not credited or starting rating is less than 30 points	Not allowed

9. Additional information on the course (educational component)

- the provisions on the rating system of assesment are notified at the first lesson of the course;
- preliminary rating assessment R of the credit module (course) is brought to the applicants in the last lesson;
- calendar attestation of students is carried out by teachers according to the value of the current rating of the applicant at the time of attestation t. If the value of this rating is not less than **50%** of the maximum possible (R_t) at the time of attestation $RD_t \geq 0{,}5R$, the applicant is considered satisfactorily attested. Otherwise, the attestation statement is displayed **«not passed»**.

Work program of the course (syllabus):

Compiled by: Doctor of Technical Sciences, professor Lysenko Oleksandr Ivanovych

Approved by the Department of Telecommunications (Protocol № 14 dated 27.05.2021)

Agreed by the Methodological council of ITS (Protocol № 5 dated 09.06.2021)