COURSE OFFERED IN THE DOCTORAL SCHOOL

Code of the course	4606-ES-00000CM-0065	Name of the course	Polish	**Teoria Kolejek (Systemy Masowej Obsługi)**	
			English	**Queueing Theory**	
Type of the course	General courses				
Course coordinator	Prof. dr hab. inż. Michał Pióro	Course teacher			
Implementing unit	Institute of Telecommunications,	Scientific discipline / disciplines*	information and communication technology		
Level of education	Doctoral studies	Semester	winter		
Language of the course	English				
Type of assessment	Homework and project vcaluation	Number of hours in a semester	60	ECTS credits	4
Minimum number of participants	10	Maximum number of participants	15	Available for students (BSc, MSc)	Yes

Type of classes		Lecture	Auditory classes	Project classes	Laboratory	Seminar
Number of hours	in a week	2	1	1		
	in a semester	30	15	15		

* does not apply to the Researcher's Workshop

1. Prerequisites
Basics of the probability theory and calculus.

2. Course objectives
The aim of the course is to familiarize participants with the concepts and methods of queueing theory that are applicable to the analysis of the ICT-related service systems, ranging from isolated systems (often called queueing systems, e.g., single-server, single-queue system) to networks of queueing systems. It should be noted that fields of applications of queueing theory are much wider than ICT. Examples of such fields are transportation and road traffic, logistics, and production scheduling.

3. Course content (separate for each type of classes)
Lecture
The proposed course is devoted to queueing theory, a fundamental approach to performance analysis of service systems whose behavior is driven by events of probabilistic nature. In particular, the mathematical tools provided by queueing theory are necessary to calculate performance measures of computer systems or communication networks where jobs or packets, respectively, arrive at the system in a stochastic manner and their service times are governed by probability distributions. Typical examples of metrics related to such measures are the average job processing time in the computer system or the average packet delay time in the communication network. Needless to say, evaluating performance measures is of utmost importance to the proper design and operation of service systems. The aim of the course is to familiarize participants with the concepts and methods of queueing theory that are applicable to the analysis of the ICT-related service systems, ranging from isolated systems (often called queueing systems, e.g., single-server, single-queue system) to networks of queueing systems. It should be noted that fields of applications of queueing theory are much wider than ICT. Examples of such fields are transportation and road traffic, logistics, and production scheduling. The course will be divided into two parts: analytical (two-third of the course) and simulation (on-third). Part I will start with the memoryless queueing systems (where both client inter-arrival times and client service times are described by the exponential distribution) that can be efficiently analyzed using Markov chains. The memoryless queueing systems considered will include both single and multiple server/queue cases and the priorities assigned to different classes of users. Next, we will proceed to

queueing systems where the memoryless property is dropped either for inter-arrival times or service times (but not for both); for analyzing such systems the so called embedded Markov chains will be used. The considerations of queueing systems will conclude with how to treat a single-server, single queueing system in which both the inter-arrival and service times are described by general probability distributions. At the end of the analytical part of the course, queueing networks will be considered. In such networks, every client (e.g., job or packet) from a given stream must traverse a specific path in the network while being served sequentially by the queueing system at each node of the path. Here, so called Jackson networks composed of memoryless single-server, single-queue systems will be studied.
Part II will explain the probabilistic concepts underlying the simulation approach and the basic knowledge of writing simulation programs. The importance of simulation in analyzing the performance of queueing systems (and queuing networks) is due to the fact that it is virtually impossible to analytically calculate performance measures for complex systems encountered in practice. In such cases, simulation programs are used to obtain, unfortunately in a time-consuming way, estimates of the required performance measures. In essence, the simulation run reproduces (using a random number generator) a single realization of a stochastic process that models a given queueing system (or network) to obtain confidence intervals for the values of the selected performance measures.
Both analytical and simulation considerations will be illustrated with examples, and selected examples will be discussed in detail during the exercises and projects.
Although the material presented during the course will be self-contained and in particular it will include explanation of all more advanced probabilistic notions used (for example stochastic processes, including Markov processes), the participants should have a good understanding of basic notions of probabilistic theory (for example random variables and probability distributions) and calculus.

Laboratory

4. Learning outcomes			
Type of learning outcomes	Learning outcomes description	Reference to the learning outcomes of the WUT DS	Learning outcomes verification methods*
Knowledge			
K01	The student has knowledge of continuous-time and discrete-time Markov chains.	SD_W2, SD_W3	assessment of activity during classes, assessment of homework
K02	The student has knowledge on the application of the z-transform to analyze queueing systems, which are not memoryless.	SD_W2, SD_W3	assessment of activity during classes, assessment of homework
K03	The student has knowledge of the theoretical basis of discrete event simulation, including the concept of a stochastic processes and statistical analysis of a trajectory of ergodic stochastic processes.	SD_W2, SD_W3	assessment of activity during classes, assessment of homework

Skills			
S01	The student is able to formulate problems of performance analysis appearing in the modeling of systems and processes with the use of queueing theory approaches and share knowledge about them.	SD_U1, SD_U4, SD_U6	assessment of activity during classes, assessment of homework, assessment of project
S02	The student is able to calculate the basic characteristics (such as state probability distributions, average waiting times and variances) of the considered class of queuing systems using an analytical and simulation approach.	SD_U1, SD_U4, SD_U6	assessment of activity during classes, assessment of project
Social competences			
SC01	The student understands the role of queueing theory in the performance analysis of systems and processes in various engineering fields and is aware of the importance and scope of its methods (based on stochastic processes) in this area.	SD_K2	assessment of activity during classes

*Allowed learning outcomes verification methods: exam; oral exam; written test; oral test; project evaluation; report evaluation; presentation evaluation; active participation during classes; homework; tests

5. Assessment criteria

Completion of the course requires completion of homework assignments and project assignments.

6. Literature

Primary references:

[1] L. Kleinrock: Queueing Systems, John Wiley & Sons, 1975

[2] D. Gross and C.M. Harris: Fundamentals of Queueing Theory, John Wiley & Sons, 1998

Secondary references:

[1] H. Kobayashi: Modeling and Analysis – An Introduction to System Performance Evaluation Methodology, Addison-Wiley, 1978

[2] H. Akimaru and K. Kawashima, Teletraffic – Theory and Applications, Springer Verlag, 1993

7. PhD student's workload necessary to achieve the learning outcomes**

No.	Description	Number of hours
1	Hours of scheduled instruction given by the academic teacher in the classroom	60
2	Hours of consultations with the academic teacher, exams, tests, etc.	10
3	Amount of time devoted to the preparation for classes, preparation of presentations, reports, projects, homework	30
4	Amount of time devoted to the preparation for exams, test, assessments	10
	Total number of hours	**110**
	ECTS credits	**4**

** 1 ECTS = 25-30 hours of the PhD students work (2 ECTS = 60 hours; 4 ECTS = 110 hours, etc.)

8. Additional information	
Number of ECTS credits for classes requiring direct participation of academic teachers	
Number of ECTS credits earned by a student in a practical course	