WIP: New Course Development for 5G Connectivity: Lessons Learned in Matlab Simulations

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***Abstract* — Our ongoing efforts to develop a new course on intelligent wireless connectivity is presented in this research-to-practice WIP paper. The ICon concept unifies the fifth-generation (5G) mobile networks, Internet of Things (IoT), cloud computing (CC), and artificial intelligence (AI). The convergence of technological trends accelerates digital transformation in majority industrial sectors. Consequently, to acquaint students with the skills and information necessary for success in these disciplines and to satisfy this need, academic institutions must revise their curricula. New course proposal and lessons learned in 5G mobile networks simulation, along with the software applications are presented. The Matlab toolbox was chosen for modeling, configuration, simulation, and end-to-end analysis wireless links. The evaluation of 5G NR model codes serves to demonstrate preliminary stages of planning for the creation of 5G courses and may yield simulated outcomes for the development of ICon course.**

Keywords — course development, simulation model, 5G NR App

I. INTRODUCTION

Intelligent connectivity ICon is a concept that predicts the fusion of fundamental technical developments of fifth-generation (5G) mobile networks, Internet of Things (IoT), cloud computing (CC), and artificial intelligence (AI). ICon significantly influences industry, individuals, and education [1, 2, 3, 4, 5]. In developing new curricula, we prioritize the incorporation of AI with 5G and IoT. In recent articles, we discussed 5G mobile system R&D technical requirements and IoT interoperability and standardization prospects and challenges [6, 7, 8].

Preparing students for professions in the sectors of 5G-IoT intelligent connectivity requires the establishment of a new core curriculum. ICon curriculum focus is the intersection of these technologies, covering the ways in which 5G and AI support new IoT applications, the role of CC in enabling the deployment and management of these services, as well as the significance of a solid foundation in AI. Educational institutions can increase the labor force by equipping students with the requisite competencies and understanding to succeed in these domains [4, 9, 10].

In the first part of the paper, we present new course proposal and methods for analysis of the current use and lecturing, analysis of situation from the perspective of lecturers, analysis of the requirements of professional engineers, as well as conception of a new ICon course based on the results of the requirement analysis. In the second part of the paper, we present lessons learned in ICon course implementation with focus on development teaching material and design practical lab exercises and projects that involve the simulation, emulation and analysis of wireless networks. We have developed and test interactive Matlab 5G-NR simulation model to teach students the advanced concepts of mobile communication.

II. NEW COURSE PROPOSAL

A curriculum creation strategy that is subject-centered in nature has been implemented, placing particular emphasis on the skills and knowledge that are relevant to the domains of 5G, IoT, CC, and AI. Integrating 5G and IoT with AI is the motivation behind these programs. The immense volumes of data produced by Internet of Things devices are interpreted by artificial intelligence. The ongoing development of 5G networks facilitates the transfer and processing of huge amounts of data. Hence, it is imperative for academic institutions to revise their curricula in order to incorporate the most recent developments in these fields and equip students with the essential competencies required for employment success. To adequately train forthcoming professionals in these domains, it is critical to establish a novel ICon curriculum. Initial stages of the procedure involve extensive investigation and evaluation. The development of curriculum could be approached in a variety of ways. Need/task analysis, objective design, learning/teaching methods, assessment methods, curriculum implementation, evaluation, and review are frequent approaches [11, 12].

A. State-of-the art and requirement analysis

In the first phase, an analysis of the current situation regarding the teaching of 5G mobile networks, Internet of Things, cloud computing, and artificial intelligence was examined. On the other hand, a requirement analysis related to the use of ICon knowledge was also carried out. The results, which were processed using a quantitative method, showed insufficient representation of ICon both from the students' and lecturers' perspective. When it comes to usage, the results indicated the importance of ICon knowledge for greater success in profession.

Requirement analysis procedure represents the first step in the education process, on the basis of which the exact objectives of the teaching are determined, the plan and program are drawn up, the selection is made or adequate teaching material is created and the methodology is determined.

This type of analysis requires additional efforts from the teachers themselves because it implies, on the one hand, an analysis of certain scientific disciplines, and on the other hand, an analysis of the target requirements.

The main goals of first phase of new course proposal are:

- analysis of the current state of use and teaching 5G mobile networks, Internet of Things, cloud computing, and artificial intelligence
- analysis of the current situation from the perspective of teachers
- analysis of the requirements related to the use of the 5G, IoT, CC and AI by professional engineers.

This requirement analysis implies gathering information on the following aspects:

- personal data about participants (previous knowledge, cultural information, reasons for attending the course and expectations, attitude towards learning, methods and subjective needs)
- professional information about participants (analysis of the target situation and objective needs)
- information on the current knowledge of the participants (analysis of the current situation)
- lack of knowledge of trainees (the gap between the current and the target situation)
- information about the way of learning (effective ways of learning skills and shortcomings - learning needs)
- what is expected from the course
- information on the way of realization of the course (analysis of means / ways).

Requirement analysis represents complex and demanding process that, first of all, needs to be well organized and set exact goals in order for the requirement analysis to produce the desired results. Method for collecting data within the framework of analysis are documentation, test, self-assessment, observation, questionnaires (open-ended or closed questions), interviews (classical or structured), learner diaries or journals, and case studies (student, teacher).

After obtaining the results of the requirement analysis, it is necessary to analyze them in detail, to determine whether the needs and wishes of the participants coincide or are in conflict, whether there are limitations in external factors such as time and opportunities, and certainly take into account the personal experiences of the lecturer.

B. ICon course plan and evaluation

The creation of ICon course could be defined as a process in which the results of the requirement analysis are interpreted in order to obtain a series of learning-teaching experiences with the ultimate goal of achieving a certain level of knowledge among the participants.

Taking into account the obtained results of the requirement analysis, the development of the ICon course was started, which was aligned with the researched needs and will be offered to an experimental group of students. The effectiveness and expediency of the new course will be checked in the second part of the research, on the one hand, using a quantitative method, comparing the results of the achievement test between students from the experimental and control groups, and on the other hand, using a qualitative method based on interviews with students.

The plan and program (*syllabus/curriculum*) is considered an official document that prescribes what should be learned in a certain course and what the successful participant will know at the end of the course. In addition to this basic role, the plan and program also plays a role in the organization of the course, so this type of plan and program is *organizational syllabus*. This plan and program more closely determines the order of learning, i.e. determines which subjects should be learned first, what is easier to learn and whether it is necessary for students to learn some subjects first in order to be able to learn others. When it comes to the teaching material that is necessary for the implementation of a certain plan and program, the plan and program of the teaching material (*material syllabus*).

Emerging technologies, their regulatory and professional ethical consequences, and the principles of these technologies are all included in the curriculum. Educational institutions foster innovation in these crucial domains by providing students with the requisite information and competencies.

- In addition to studying the challenges and opportunities that 5G brings for diverse aplications, it is imperative that students acquire knowledge regarding its architecture, protocols, and applications. .
- Communication protocols, data analytics, and security concerns are all elements of IoT that students must comprehend. The Internet of Things (IoT) connects common devices like sensors, actuators, and smart devices to the Internet so that data can be collected, analyzed, and tasks can be automated. Smart cities, intelligent residences, transportation, and logistics are a few of the numerous applications of the IoT.
- Architecture, service models, and deployment models are all key components of cloud computing that must be understood by students.
- Machine learning, deep learning, and reinforcement learning are just a few examples of artificial intelligence techniques that students should familiarize themselves with, along with their uses and limits.

The next step after the analysis of requirements and preparation of the course plan is to translate the course plan into teaching material [2, 3]. In order to prepare teaching material that fully meets the needs of course participants, it is necessary to take into account the following principles:

- The material is an encouragement for learning, and therefore good teaching materials do not teach, but motivate students to learn. Therefore, they should contain: interesting texts, interesting activities that encourage students to think, the possibility for students to use existing knowledge and skills, and content that suits both the students and the professor.
- Good teaching materials are clear and coherent structures that will guide students and professors through various activities aimed at learning. On the other hand, a good organization and coherent structure must be flexible at the same time in order to achieve creativity and diversity.
- Since the teaching material should encourage learning, it should require active thinking from the students.
- At the same time, it is necessary that the tasks are sufficiently complex and interesting, but also solvable.

Since we have already said that the main purpose of ICon course is to meet certain educational requirements, evaluation process of the new course helps us to determine the extent to which the new course meets the requirements of its participants. Therefore, there are four basic aspects of the ICon course evaluation that should be carried out:

- *what do we evaluate*? (does the course meet the needs of its participants?)
- *how do we evaluate the ICon course* (test results, questionnaires, interviews, discussions, conversations)
- *who should participate in this process*? (course participants, professors, course organizers/sponsors)
- *when and how is the evaluation done*?

In addition to the answer to this question, it is also necessary to consider plan and program, teaching material, teaching techniques, and testing procedure.

III. Lessons Learned

The ICon curriculum is in continuous improvement. The course can be enhanced through a multi-step, continuous, and cyclical process of creation and enhancement with the help of an iterative curriculum development approach. After redesigning and implementing a new program, we will return to assess the effectiveness of the revised program that we have developed. It is imperative to regularly examine, edit, and update instructional plans in response to emerging and evolving requirements. Due to advancements in the subject area, modifications might be necessary.

A. ICon Lab exercises and projects

We advise instructors to prioritize creating realistic hands-on Lab exercises (practicum) and projects that require network analysis, modeling, and emulation. Practical experience in comprehending the details of 5G-IoT systems can thus be acquired by students.

Kits for 5G development contain every component needed to take the first low-cost experiments in educational Lab. For the creation, optimization, and evaluation of IoT projects, the Raspberry Pi 5G Development Kit (sixfab.com) is an all-encompassing instructional collection of tools. It comes with everything one needs to connect and test one's idea using a real-world 5G infrastructure. The Raspberry Pi is an inexpensive, credit-card sized computer with one board that can be connected to a computer display and controlled using a regular keyboard and mouse (www.raspberrypi.org). Additionally, the 5G kit is compatible with the NVIDIA Jetson Nano single-board computer (developer.nvidia.com), which provides educators, students, and developers with free online training in AI that they can apply in practice. Several well-known machine learning frameworks, such as TensorFlow, Keras, and PyTorch, are also kit compatible.

Combining hardware and software, the 5G network emulator simulates network-side capabilities of the 3GPP standard in a controlled laboratory environment (www.keysight.com). Modeling, configuring, simulating, and analyzing end-to-end communication networks are all capabilities of the Matlab 5G Toolbox (www.mathworks.com). This toolbox is designed to support educational purposes by providing tools for learning and teaching about 5G technologies [2, 13].

Development kits and toolboxes serve as a useful tool to integrate ICon-related topics into academic courses. Students and instructors will find it an invaluable asset due to its simulation capabilities, standard-compliant functions, and educational resources. 3GPP (3rd Generation Partnership Project) is a consortium of standards organizations which develop protocols for mobile telecommunications. Radio Access Networks, Systems and Services Aspects, Core Network, and Terminals are the three streams in which the 3GPP divides its efforts. Developed by the 3GPP for the 5G mobile network, 5G NR (New Radio) is a radio access technology (RAT). Its primary purpose was to serve as the foundation for 5G networks' air interface standards worldwide. The technical details of 5G NR are provided in the 3GPP specification 38 series. 3GPP published Release 15 in 2018, Phase 1 standardization for 5G NR, as well as Phase 2 Release 16 in June 2020. Release 17 was published in June 2022, and Release 18 NR-Advanced in June 2024. Release 19 stepping stone to the next 6G will be locked in March 2025. The first 6G standard, Release 21, needs to be finalized and ratified by early 2028.

B. 5G NR simulation model

For coherent comprehension of the processing principles behind 5G NR air-link connection, we have built a Matlab simulation model that includes code explanations [2]. In 5G NR, downlink channel PDSCH (Physical Data Shared Channel) carries encoded user data from base station (gNB) to user equipment (UE). 3GPP has specified a list of transport block sizes (TBS) which are to be used with Release 15 5G NR in the technical specification (TS) 38.214 *Physical layer procedures for data* [1]. The simulation model is built using functions available on Matlab 5G Toolbox v1.1 [13]. End-to-end PDSCH processing simulation model in which the MATLAB function for each processing block is showed in Figure 1 [2].

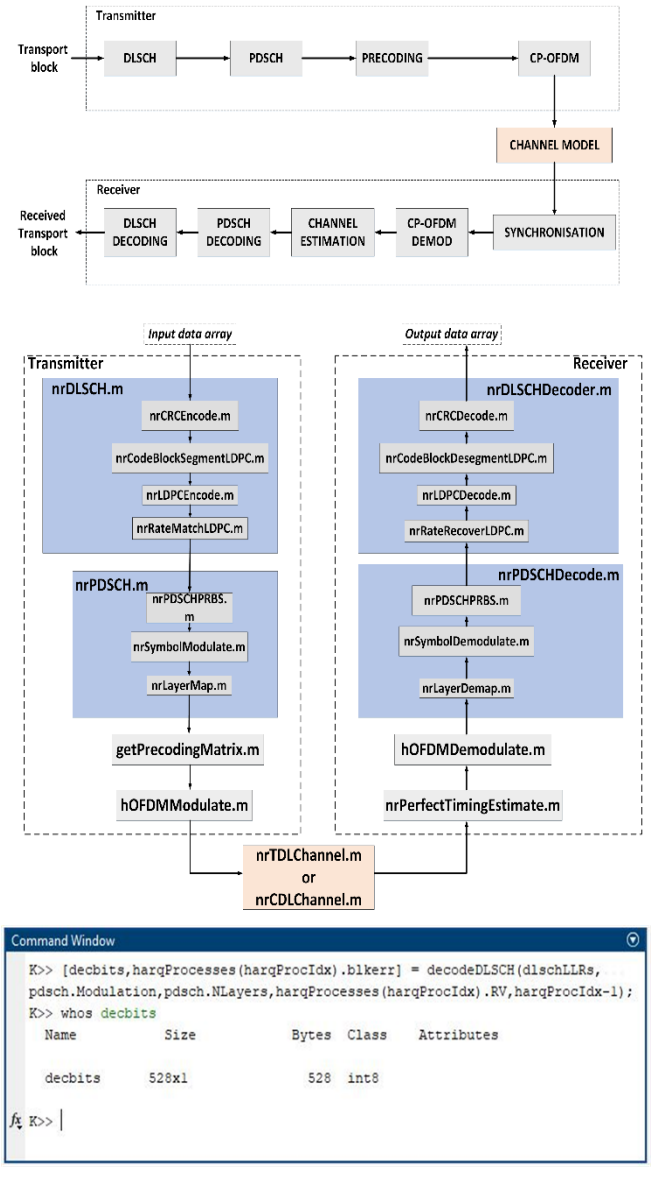

Fig. 1. 5G NR Physical Layer PDSCH processing loop, Matlab end-to-end 5G-NR simulation model, and command windows for blocks processing.

The implementation involved the utilization of Matlab scripts to simulate processing blocks and the transmission of data blocks over the PDSCH channel. The simulation results consisting of the PDSCH throughput, BER (Bit Error Rate) and BLER (Block Error Rate). Numerical examples were additionally prepared in [2].

Matlab App Designer is a rich development environment that can be used to create interactive apps out of Matlab codes. It provides a Design View in which the graphical user interface (GUI) of the app can easily be built by adding visual components (such as buttons, drop-down menus, and edit fields) using drag-and-drop operations. The App Designer automatically generates the object-oriented codes for the GUI and the behavior of those visual components can then be defined in the Code View. The App Designer project can be saved as an mlapp file. By opening the file, user will be prompted with the GUI in which student will need to input the system simulation parameters.

The first step is to create the GUI over which the App user will be expected to input parameter values. In Figure 2, the DesignView-generated GUI is displayed with data regarding the selected visual component. The outputs of the program after execution, which consists of performance results and plots and a wait bar showing the progress of the program's execution, are also shown in the figure [2].

Fig. 2. 5G NR simulation model: interactive input panel and results [2].

The SIMULATE push button has the purpose to launch the simulation, using all the user-determined parameters as input. The system simulation parameters, which will be made available to the App user to control from the GUI, are defined as inputs to the model functions. The generated value-changed function for the SIMULATE button must be modified as follows to allow the App to feed all the student-defined inputs. The outputs of the program after execution consists of performance results and plots: results text area are populated with PDSCH throughput results as well as BER/BLER generated graphs are displayed [2].

Advantages of our simulation include performance results analysis to teach students the concept of wireless/mobile communications. The 5G NR model of the physical layer of PDSCH processing was programmed and analyzed using Matlab Toolbox methods to calculate throughput, BER, and BLER. Regarding the educational approach, it is important to establish main benefits of 5G efficient connectivity for IoT intelligent devices. To teach such concepts, we have proved that Matlab App codes could be used.

IV. CONCLUDING REMARKS

Preparing students for professions in 5G, IoT, CC, and AI requires the establishment of a new core curriculum in these areas. The ICon curriculum should emphasize on how 5G and AI enable new IoT applications, how CC enables the deployment and management of these services, and the significance of a strong AI foundation.

We propose analysis of current situation from the perspective of lecturers and professional engineers, as well as conception of a new ICon course based on the results of the requirement analysis. In development teaching material, we select Matlab environment for modeling, configuration, simulation, and end-to-end analysis wireless links. We create and test educational interactive application 5G-NR App for teaching students advanced concepts of mobile communications. Future work will include ICon plan and program in details and testing procedures.

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