

Virtual Laboratories on Wireless Communications: A Contemporary, Extensible Approach

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Abstract—The present work demonstrates a novel, free and open-source educational software package on wireless communications. Targeting graduate and post-graduate studies, the package covers issues of antennas and propagation, wireless channel modeling (fading, shadowing, path loss, Doppler effect), static and adaptive modulation, client mobility and network planning applied to DVB/T and indoor networks (WiFi, femtocell) settings. The corresponding packages are fully interactive and parametric, offering 3D GUIs, ray traced maps and connection to field measurements. Being extensible via the addition of simple text files, the presented package constitutes a concrete approach that was missing from the related approaches that follow the virtual laboratories paradigm.

Virtual laboratories; wireless communications; open-source; free (key words)

I. INTRODUCTION

Wireless communications constitute a dominant field of modern technology and research. Over the past decades a considerable number of theories, models and techniques have been proposed for literally every aspect of wireless dissemination of information. Every expert in this field is expected to have a deep understanding of milestone studies at least. Furthermore, hands-on experience and familiarization with wireless hardware and expected diversions from theory are vital for successful network planning. However, acquiring such experience comes at a high monetary cost for the related institutes and trainees, given the requirements for actual hardware and maintenance of up-to-date testbeds. Virtual labs constitute a promising solution to such issues [1, 2].

Virtual laboratories are software packages that either provide remote access to real testbeds [3, 4], or fully simulate them [5, 6]. The former approach allows for experimentation with real hardware and conditions, but limits the number of users that may take advantage of them concurrently. On the other hand, pure software virtual laboratories may be freely downloaded to any PC and be used without restriction. However, care must be taken during the development phase in order to validate the simulation-derived results with actual measurements. This study presents a software-based virtual laboratory environment, which addresses all vital aspects of wireless communications.

The motivation for creating the present package was the fact that the related virtual laboratories were either overly-simplified or overly-complex. In addition, adequate coverage of all major, classic issues of wireless communications could

not be achieved by any package. Furthermore, vital aspects of contemporary communications such as efficient network planning in various environments, energy consumption and estimation of CO₂ emissions were disregarded. As an example, the approaches of [7] and [8] focus strictly on modulation and encoding respectively. Further related studies in [9] address classic channel modeling in conjunction with modulation and encoding issues. The main target is the familiarization of the student with strongly theoretical concepts, offering a user interface that is based on textbook block diagrams. The WiFi Virtual Laboratory of [10] addresses node positioning and networking issues in the context of the IEEE 802.11 standard. On the other hand, commercial research simulators [11-13] have been used for educational purposes, but require familiarization with a complex interface and a programming environment designed for specialists. Finally, another commercial solution, [14], offers technical training by virtualizing actual hardware. However, no connection to theoretical aspects is provided. Most importantly, all related studies, commercial or not, focus on classic issues of wireless communications, disregarding the modern aspects of green engineering and energy efficiency.

The presented software package aims at providing an in-depth, complete coverage of fundamental issues of contemporary wireless communications: antenna design and positioning channel modeling, adaptive/static modulation, mobility, coverage estimation, network planning of indoor and terrestrial networks and green communications are thoroughly discussed through intuitive 2D/3D parametrical interfaces. The applications take advantage of integrated ray tracing algorithms that have been validated with real measurements to increase the accuracy of the findings. Finally, the software package is open-source (implemented in plain MATLAB™ [15] code) and can be easily extended to include more models, metrics, and antenna types.

The package can be freely downloaded through [16] alongside with documentation, examples and proposed exercises.

The remainder of this paper is organized as follows. Section II provides an overview of the topics covered by the software package. Section III analyzes the educational goals and the employed methodology during the design phase. An overview of the user interfaces is given in Section IV. Technical aspects of extensibility and architecture are given in Section V, alongside a log of best practices. Expected impact and conclusive remarks are given in Sections VI and VII respectively.

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II. AREAS COVERED BY THE SOFTWARE PACKAGE

The topics covered by the presented software package follow the general structure of [17, 18], two contemporary textbooks for courses in wireless communications. Each topic is treated through a dedicated corresponding application:

A. Antenna Design and Positioning

The user is introduced to basic principles of antennas, propagation and coverage estimations in a simplified wireless communication environment. The scope is to observe the cell size variation according to basic parameters of a cellular system. These include: a) Transmit power. b) Antenna positioning and patterns of the base station and mobile user terminal. c) Effects of various path loss models.

B. Channel Modelling

This laboratory is designed to introduce the student to basic fading processes, as well as narrowband and wideband channel characteristics. It comprises a single scenario where a base station transmits signals and the receiver is moving along a straight line on a street, surrounded by building blocks, in a 3D GUI. The scenario assumes propagation mechanisms based on empirical models and simple shadowing parameters. The scope is to study channel prediction techniques and understand the concept of Rice and Rayleigh fading, power delay profiles and time-variant channel behavior.

C. Connection to Field Measurements (Drive Test)

This application studies basic principles of a drive test. The drive test is the procedure of testing the wireless channel in real time on a deployed network environment. With a drive test it is also possible to create empirical propagation models for a specific scenario. The lab enables the student to understand real time wireless measurement setups, GIS data and the propagation fit procedure based on measured field characteristics. A 3D GUI and realistic field measurements are provided.

D. Network Planning: DVB/T

The user is introduced to the basic principles of Radio Planning of DVB-T broadcast cellular systems. A real, ray-traced GIS raster map of the North West part of Greece (Western Macedonia Region) and various possible Tx positions are given. Principles of Single Frequency Network Planning are examined through computations regarding Carrier/Interference ratios and data rates. Energy efficient radio planning procedures and connection to CO₂ emissions are discussed. The connection between received image quality and field metrics is visualized based on empirical models. The application comes with a 3D GUI and interactive coverage illustrations.

E. Indoor Network Planning

Deterministic channel estimations based on ray tracing algorithms are studied, as well as basic principles for indoor network planning at 2.4GHz. Two application scenarios are studied. Scenario 1 refers to deterministic channel estimations whereas scenario 2 refers to indoor network planning (WLAN or femtocells). The indoor environments comprise walls (brick), doors (wood) and windows (glass) and different

transmission positions operating at 2.4GHz frequency. Interactive, 3D coverage illustrations are produced, subject to adaptive modulation, transmission power and transmitter position.

III. EDUCATIONAL GOALS AND METHODOLOGY

The broad spectrum of areas covered by the package serves the main educational goal of discussing all vital aspects of contemporary wireless communications. Furthermore, the presented package seeks to promote both the qualitative and quantitative study of a wireless system. The user is expected: a) to better understand the interaction between the components of the system, b) to be able to produce a rough link budget when presented with some basic environmental attributes. However, since intuition cannot be built on bare numbers, the package strives to connect numerical results (e.g. power levels) to real-world matters. For example, in package D (DVB/T), the received signal strength is directly mapped to image quality, visualizing the effects of the user's design choices on the television of a virtual receiver.

The educational goals are summarized as follows:

- Study the wireless communication system as a whole.
- Discuss the qualitative and quantitative interactions between the components of the system.
- Connect theoretical results to practical issues, in order to promote the intuitive understanding of wireless communications.

The adopted methodology for accomplishing these goals is based on the creation of a series of Graphical User Interfaces per covered topic, with special characteristics:

3D worlds from block diagrams. The GUIs strive to represent a block-diagram model of the wireless system in an animated, 3D environment. The 3D scenarios exemplary include the movement of car through a city (package B), while visualizing the propagation of rays emitted from a transmitter. At the same time, the interactive block diagram of the system is provided, and the user can observe the impact of his configurations on the link quality, visually and in real time.

Simple, clean, single-tabbed. The GUI controls are gathered in a single tabbed form and are grouped by corresponding network component. The 3D visualization and the controls are designed to fit in the monitor of a desktop PC, laptop or netbook. Simplicity was a major concern while performing the graphical design. Thus, special care was taken to avoid cluttering the GUIs with overly-specialized controls. The outcome is a graphical environment that provides direct overview and access to all features, enabling the user to become more familiar with issues of wireless networking rather than with software quirks.

Quasi-realistic degree of freedom. In realistic situations, the quality of a wireless link is not selected from a list of tabulated values. Each system component may be configured in a multitude of ways, and the engineering challenge is to use the theoretical modeling as a guide towards optimality through the possible paths. To this end, tabulated inputs have been avoided where possible. The user is free to choose parameter combinations that are far from efficient operation. This

approach favors structured thinking and understanding of the inner workings of the wireless system.

Task-driven incorporation to a course. Each GUI comes with a set of exercises specifically designed to: a) explore the full potential of the application b) pinpoint the possible pitfalls in system configuration c) demonstrate key-points in the design of each studied system. Essential elements of theory on each studied system are also provided. These act as a self-contained guide, and serve as a substitute of the typical software manual.

Incremental complexity. The topics addressed by the GUIs are arranged by incremental complexity, favoring structured learning. Indicatively, the first package, A, deals with antenna patterns and path loss models, while the last one, E, addresses advanced femtocells issues, adaptive modulation and ray-tracing principles.

IV. THE USER INTERFACES IN DETAIL

a. Antenna Design and Positioning Lab

The first lab studies a topology of a single transmitter and a single receiver. The user may regulate: a) The positioning of an emitting antenna at an arbitrary position and direction in a 3-D space, over the earth plane. b) The characteristics of the driving signal (i.e. the Power and Frequency of a sinusoid). c) The propagation medium and loss model. d) The positioning of a Receiving antenna at an arbitrary position and direction in a 3-D space, over the earth plane.

The main user interface is shown in Fig. 1. There are five colored panels through which the user can set all the environmental variables corresponding to the Sender, the Receiver, the driving Signal and the Medium. Geometrical parameters are distributed among the respective entities. The bottom panel shows 2D and 3D power pattern previews for the selected antenna types. Any change of antenna type at the Sender or the Receiver will result in an automatic update of these panels.

Once the topology has been setup, measurements can be performed at an arbitrary point, line of points or plane in the 3-D space, through the panel of Fig. 2. Measurement types include coverage, radial power, received power, electromagnetic field vectors and antenna directivity. The user may freely populate the list of measurements by adding single MATLAB class files with a predefined interface.

Once the measurement configuration has been defined (including measurement units) the results are illustrated in the form of contour plots and 3D surfaces (received power), vector plots (E/M field measurements) or any other user-defined plot type supported by MATLAB™. Specific numerical results may be extracted and studied via the incorporated plot editor. A 3D visualization of the defined setup in also provided. Fig. 3 exemplary presents a coverage plot for an arbitrary system setup. Notice that the antenna radiation patterns are included at the top of the visualization panel. The application comes with more than 20 predefined types of measurements which may be freely tuned and extended according to the educational needs.

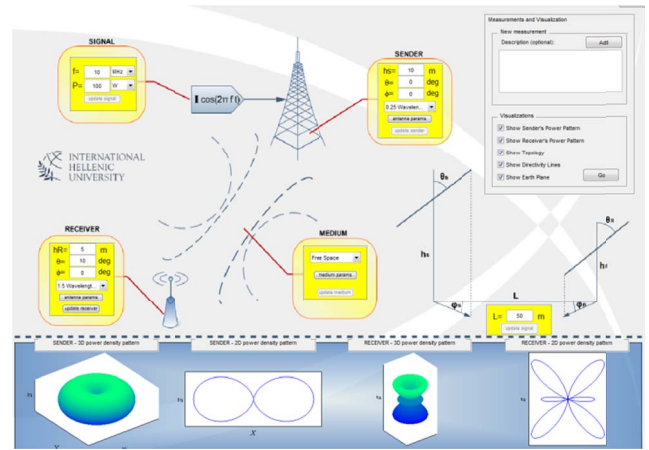


Figure 1 - The Graphical Interface of the Antenna Design and Positioning Lab. The user can directly define a setup, selecting antenna types and attributes, path loss models and positioning.

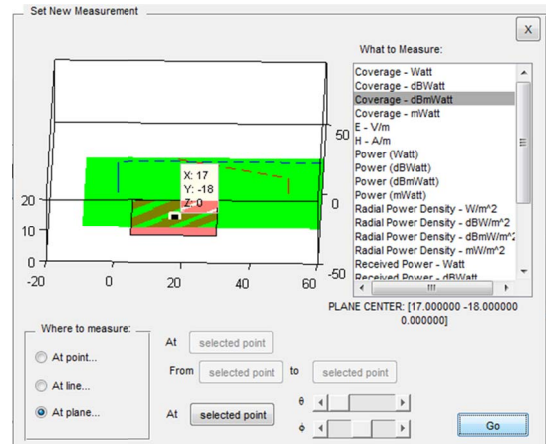


Figure 2- Performing measurements in the antenna design and positioning lab. The user may select the area of interest and the measurement type. A panel provides a direct preview of the selected parameters.

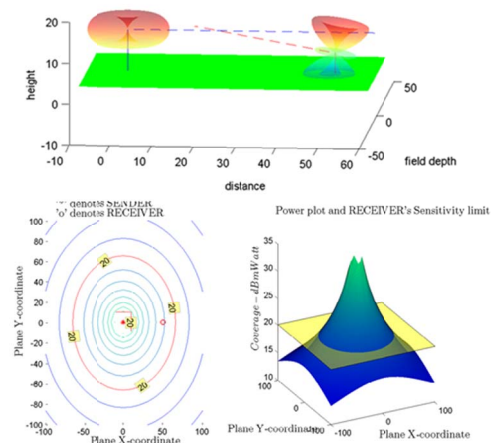


Figure 3 - An indicative measurement depicting achieved coverage. In the lower right panel, the flat plane represents the receiver's sensitivity, while the skewed surface illustrates the power level around the transmitter. The intersection of the plots defines the achieved coverage, which is depicted in the accompanying contour plot (lower left panel). A 3D visualization of the current setup is also provided (top panel).

b. Channel Modeling Lab

The second lab considers a vehicle moving on a road between two rows of buildings. A transmitting antenna is placed at an arbitrary point on the plane. The car is equipped with a receiving antenna. Due to the obstruction of buildings and the movement of the client/vehicle, shadowing, fading and Doppler (frequency shift) phenomena occur. The user can study the effects of these phenomena on the signal reception quality, while varying the system's geometry and the signal's modulation parameters. The main form of the lab is shown in Fig. 4. An animated, 3D visualization panel (Fig. 5) displays the effects of the user's choices on the topology, as well as the propagation of the signal in a synchronous fashion.

A signal source is modulated, altered (in terms of gain) by the transmitting antenna, endures losses according to the selected medium model, suffers the effect of shadowing (only when obstructed by one of the four buildings) and fast fading (according to the selected Line-of-Sight Rice factor and the number of active propagation paths). White noise is then added at the entry point of the receiving antenna. The gain of the antennas is taken into account based on the respective radiation patterns, which are studied in the first lab. The signal is then demodulated and the number of erroneous bits and symbols is measured. The communications channel as a whole is modeled in Simulink™. Once all parameters have been set, the vehicle begins to move alongside the road and several attributes are measured and illustrated. The results are gathered in two distinct forms (Fig. 6).

The leftmost form illustrates the time variant antenna gains, shadowing effects and path losses as the car moves along the road. The effects of fading are added in the form to the right. The user may study the time variant impulse response and the power delay profile. By defining the receiver's sensitivity and the time window of interest, the user may extract statistics on the distribution governing the form of the signal (e.g Rician), calculate the Average Fade Duration and the Level Crossing Frequency. Thus, a spherical coverage of the main issues of user mobility and wireless propagation is achieved.

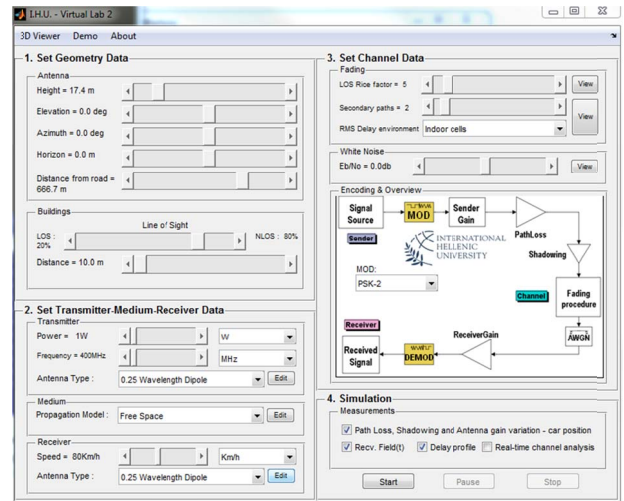


Figure 4 – The main form of the channel modeling lab provides direct access to topology control (size of buildings, width of the road), antenna positioning and type definition, noise level and ray propagation attributes.

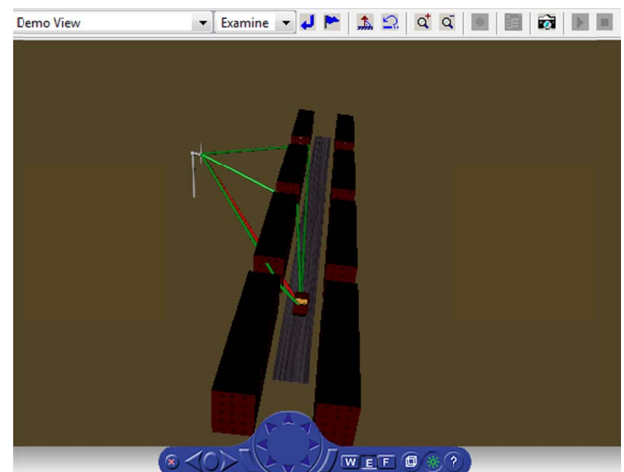
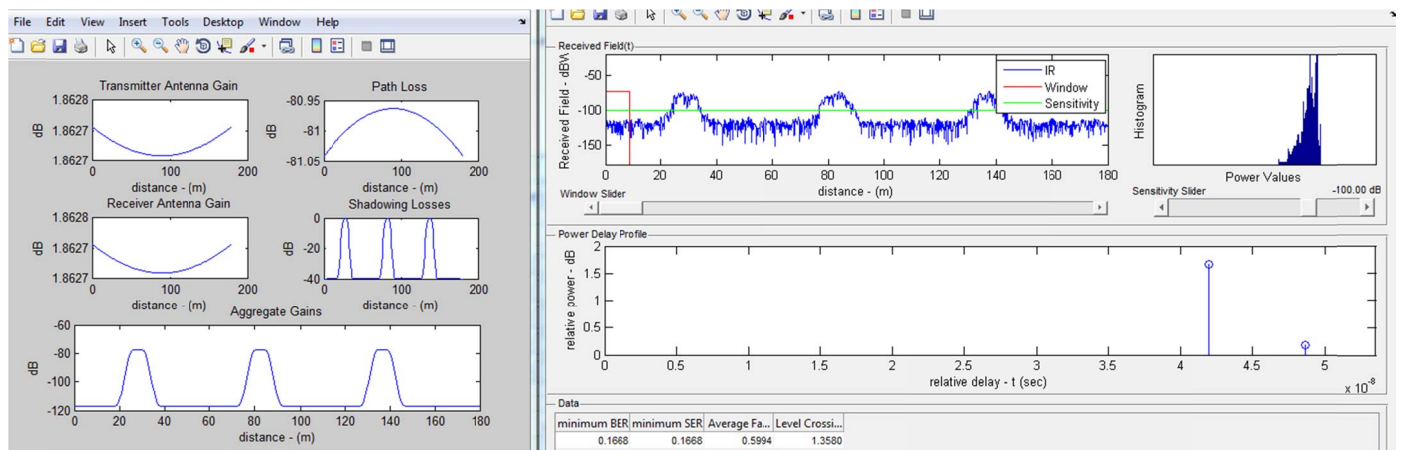
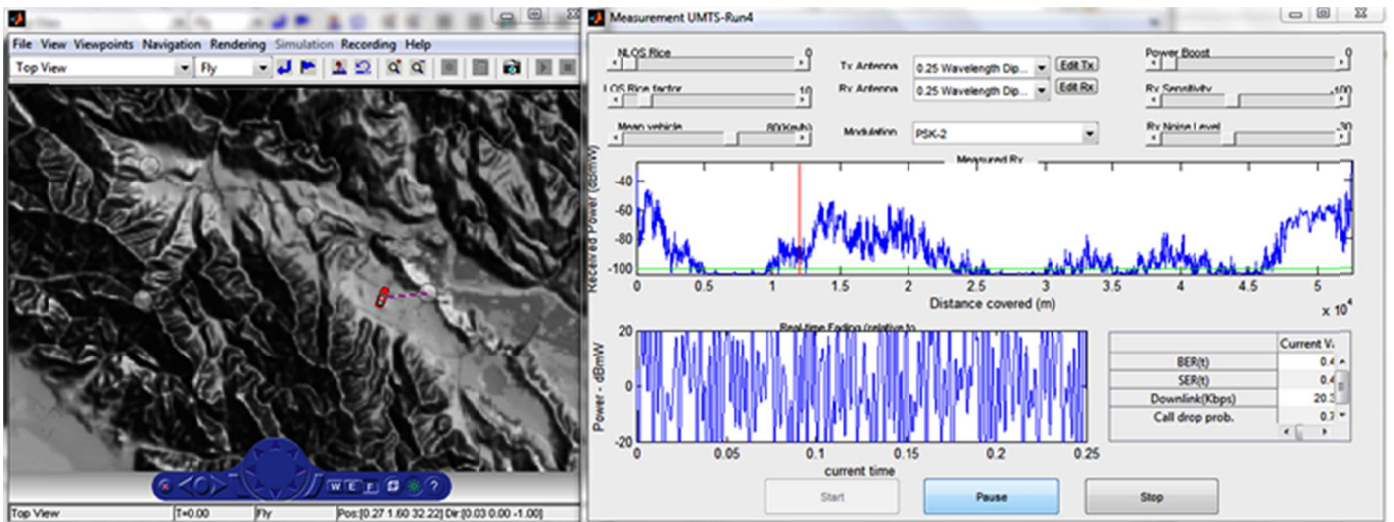


Figure 5 – The 3D visualization of the topology, car movement and ray propagation is synchronously updated according to the user's choices and simulation status.



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c. Drive Test Procedure Lab

Drive tests are essential processes that mobile operators perform to establish knowledge regarding the channel conditions in a complex environment. Drive tests aim at collecting field data that can be used for the development of an empirical propagation model, or for real time QoS measurements and characterization of the cell edge. The developed laboratory combines a theoretical description of the basic components required for a drive test, i.e. a GPS module, a receiver and a database, and explores a real life scenario. The laboratory incorporates a GIS map of a hilly area and four different routes followed by the vehicle during the actual measurements. The field strength and the channel gain at a given receiver position is computed by the multi-Shape Uniform Theory of Diffraction (UTD) technique presented in [19]. Two learning outcomes are targeted.

Real time Channel measurement – The drive test option of the GUI simulates the real time channel behavior at the mobile receiver. The receiver appears as a moving vehicle on the hilly terrain and the channel characteristics are presented in a separate window. The user can choose the antenna characteristics, modulation, vehicle speed and Rice factor of the NLOS (Non-Line of Sight) and LOS cases. Whenever the vehicle is obstructed by an object the algorithm identifies the NLOS case and different statistics are applied to the channel. At the end of the run the user is able to observe the Bit Error Rate, the call drop probability and the downlink rate. A snapshot of the above mentioned procedure is presented in Fig. 7.

Empirical Propagation Model- The second learning outcome corresponds to the development of an empirical propagation model that formulates signal attenuation according to the distance from the transmitting station. The lab is linked to the

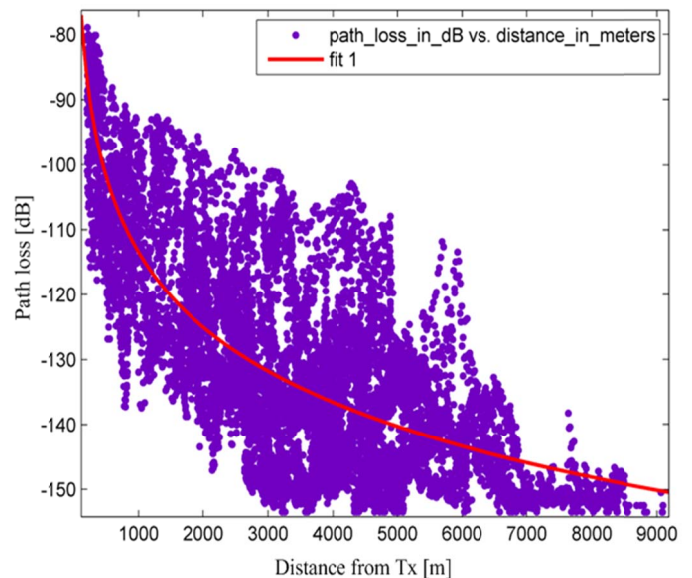


Figure 8 - Propagation model fit of the measured channel. As the vehicle moves over the predefined path on the terrain, power measurements are taken and logged (dots). The student is then asked to construct an approximate, empirical channel model. The exercise takes advantage of the Curve Fitting Toolbox™ of MATLAB™.

curve fitting tool of MATLAB, enabling a wide variety of fitting approximations to be implemented. Fig. 8 presents the case of a logarithmic fit over the curve of channel measurements. The student is free to choose among linear, quadratic or even custom fitting approximations and derive his/her own propagation model.

d. DVB/T Network Planning Lab

This virtual lab focuses on the efficient planning of Single Frequency Networks (SFN). The application covers aspects of DVB-T networks that are deployed over a real hilly area representing the North Western part of Greece. The scope is to study different aspects of SFN planning and understand the importance of the network topology on QoS, energy efficiency and RF exposure to humans (Safety Index – SI). QoS is obtained by the interference level and the employed transmission techniques, whereas energy efficiency is computed according to the dB_e metric presented in [20]. For each transmitting station the user can quantify the emitted carbon emissions assuming a 700grCO₂/kWh analogy. The power consumption of the station is related to the RF out level according to tabulated values of commodity DVB-T stations [21]. Finally, RF exposure (SI) parameter is computed according to the received power density produced by all transmitters of the network. The GUI of the DVB-T lab is presented in Fig. 9. The same computational procedures were validated in [19, 21] as well.

The virtual lab offers the ability to characterize the transmitters of the network deterministically. The user can activate individual stations at every possible transmitter position, or all the stations of the network at once. Each Tx is then described by the RF transmit power, the antenna gain and the cable losses that are used for the link budget analysis. The type of modulation (QPSK, 16 QAM, 64 QAM), the OFDM guard interval, the FFT size and the coding rate can be freely set to custom values, corresponding to realistic types of DVB-T signal transmissions.

The receivers of the scenario are selected from a discrete set of possible positions that are derived from real locations of cities, villages and touristic areas on the digital map. However, they can also be placed arbitrary on the terrain. For a given network topology and receiver position, an automatically generated graph of the GUI presents the signals arriving within the guard interval of the signal transmission and the interfering signals arriving from transmitters placed far away from the receiver (Fig. 10). The obtained signal to interference ratio is computed and presented in table form within the GUI. Furthermore, a detailed description of the signal level and the relative delays from each transmitting station are presented on screen, providing the ability to make hands on calculations and gain knowledge on interference computations. An empirical digital reception of a static image is presented to visualize QoS at the specific point of interest (Fig. 9).

The laboratory offers two exercises. In the first one, a large number of transmitters (40 over the digital area) is available to the user. The aim is to experiment with different topologies and provide QoS over the area. Various case studies can be investigated, according to the teacher’s preferences. In the second exercise, a genetic algorithm optimization was performed to optimally position and characterize the transmitters under the objective of energy minimization. This network is provided to the user who has the ability to observe

detailed coverage maps, SFN gains and signal to interference ratio maps. An example of a coverage map is presented in Fig. 11.

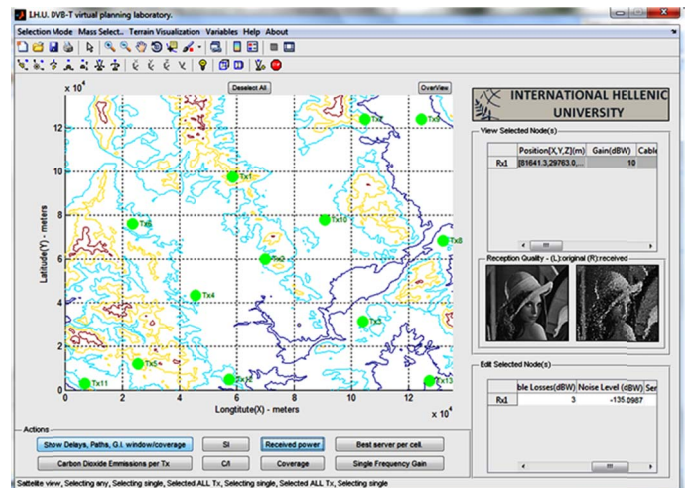


Figure 9 – The GUI of the DVB-T laboratory and QoS for a given receiver position. The expected image quality at the receiver's TV set is graphically illustrated, varying according to the network configuration choices.

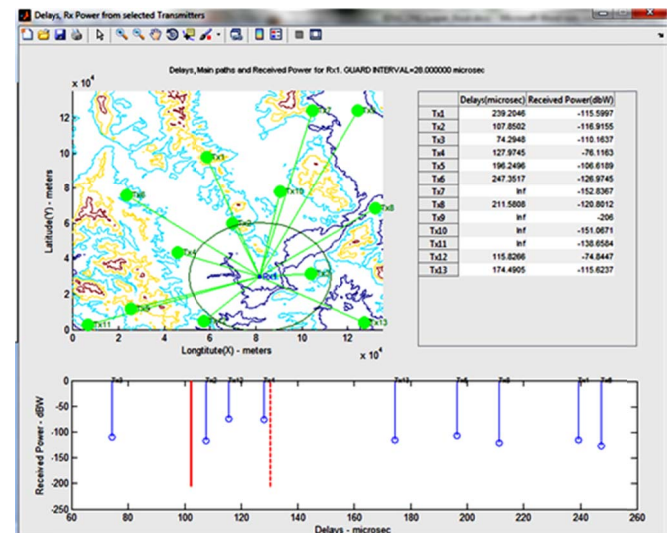


Figure 10 – Received signals and detection window for a given network topology and receiver position. The table presents the relative field strength and delays, in order to promote practicing on hands-on computations of interference levels.

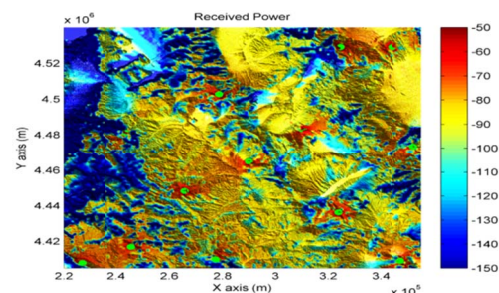


Figure 11 – Coverage map in dB_W for a given network topology. The goal is to observe the effect of clutter on signal level.

e. Indoors Network Planning

The indoors network virtual lab studies the channel behavior in densely cluttered environments and the performance of femtocell networks based on CDMA or OFDM schemes. The GUI presents two scenarios. The first scenario corresponds to channel estimation based on ray tracing algorithms, whereas the second scenario is related to the performance of a femtocell network.

Indoor channel estimation - The GUI for this case is presented in Fig. 12. A single transmitter position is available to the user. The receiver can be placed arbitrary in the indoor environment, or move along a user-defined line. The number of field interactions constitutes an input argument within the GUI, which is translated to multipath propagating rays of the channel. The ray tracer defines all possible interactions and computes the amplitude of the received power and the corresponding delay for each ray. Each ray appears on the power delay profile graph and is plotted geometrically for visualization purposes. When the user selects measurements along a given line, then the virtual lab plots the RMS delay spread, the received signal strength and the Rice factor [18]. These constitute important parameters for narrowband and wideband channel characterization. Since the ray tracer is simplified for educational purposes, a small number of interactions (i.e. up to eight rays) is taken into consideration. Thus, a degree of divergence from real field measurements may be observed. However, the achieved precision is sufficient for conveying all educative points successfully.

Indoor network performance - The corresponding GUI is presented in Fig. 13. A set of possible access points is available to the user. The user can define the characteristics of the transmitters (gain, RF out power) and can also define signal transmission parameters for the OFDM and CDMA cases. For the OFDM-based transmission, parameters such as the number of subcarriers, subcarriers per user, collision probability, bandwidth and sampling frequency constitute the basic input arguments. A simplified model for interference computation was considered. This model assumes flat fading channel and a static collision probability. A collision probability equal to 0 corresponds to a perfect resource allocation management scheme. Thus minimum interference should be expected. For the CDMA transmission, the basic input arguments are the chip and the bit rate, the minimum E_b/N_0 , the power associated to the user and the orthogonality factor. For each type of network, a variety of figures are generated. Characteristic examples are the best server maps, received power maps, signal to interference maps and adaptive modulation index maps. The general purpose of the lab is to provide case studies for experimentation on different network topologies and visualize the network characteristics for the different configurations. Finally, the Monte Carlo option of the GUI simulates a performance test of the network configuration. This is accomplished by generating independent and uniformly distributed users in the scenario and saving their channel statistics during each separate run. The results of the performance test are histograms presenting the uplink

transmit power, the simplified outage probabilities and the modulation indexes.

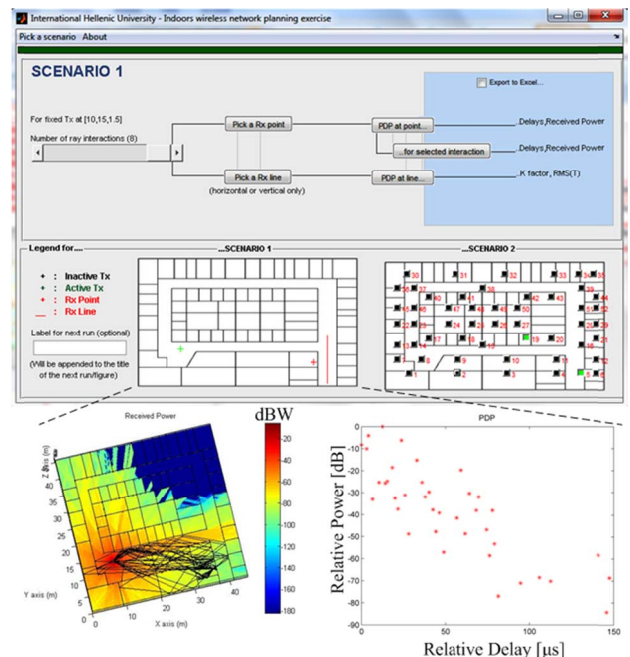


Figure 12 – The Indoor Channel Estimation scenario of the virtual lab. The traced rays are plotted over the received power map for visualization purposes (left figure). The power delay profile is presented in the right part. The user can compute the rms delay spread, the excess delay and the Rice factor for a given number of interactions.

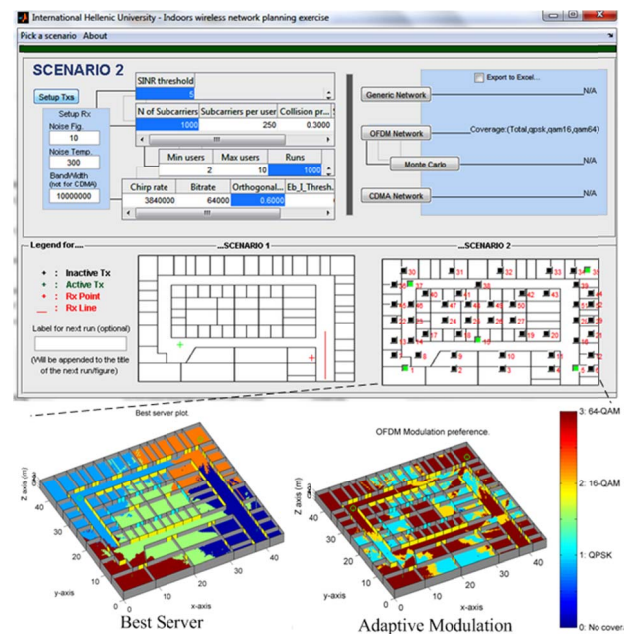


Figure 13 – The Indoor Network Performance of the virtual lab. Five access points were activated from the available discrete set of transmitters and the best server map (left part of figure) and the adaptive modulation index (right part) are presented.

V. TECHNICAL ASPECTS

a. Architecture and Extensibility

The software package consists of several independent applications which share a common architecture. Wireless communications is a highly dynamic field, and extensibility was a major design concern during the development phase. To this end, the package was implemented in plain MATLAB™ code text files. One or more central MATLAB™ Simulink™ models constitute the heart of each application. These models are responsible for synchronizing the GUI and the internal simulation state. Simulation-related computations take advantage of available antenna types, channel models and metrics which are supplied as single MATLAB™ class files implementing a predefined interface. A user may easily add a custom model by simply adding the corresponding class file into a predefined system folder. Static data, such as maps and ray-tracing results may be supplied in any convenient format, provided that it is handled correctly by any user-defined piece of code. The static part of each application is its GUI and GUI-related event dispatcher. All interactive 3D environments are stored in VRML format and handled by the MATLAB Virtual Reality Toolbox™. The architecture is summarized in Fig. 14.

b. Best Practices

The presented software was implemented in MATLAB™ due to the simplicity, the simulation environment and the broad set of libraries it provides. As a result, the produced code has minimal size, making it easier to maintain and expand. However, simplicity comes at the expense of increased runtimes and GUI responsiveness. The present subsection summarizes the main problems that were encountered during the development phase, their current resolutions and prospects for further improvement.

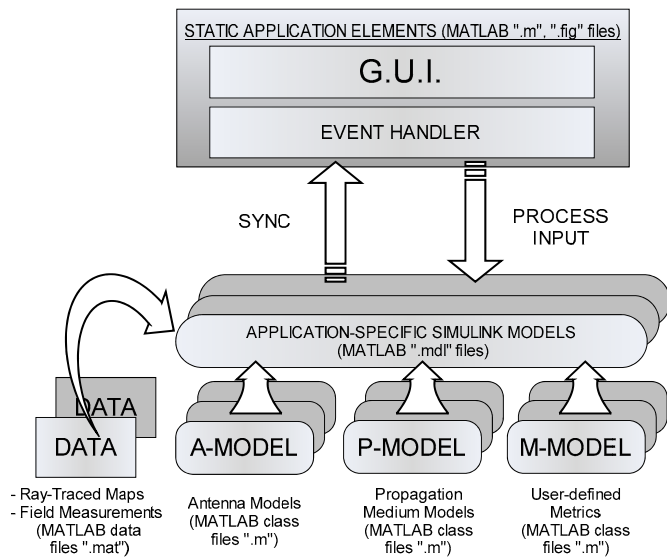


Figure 14 - Generic architecture of the present software package. Each application can employ any of the existing or user defined models and data. A central Simulink™ model handles the synchronization between the G.U.I. and the simulation state. All files are stored in standard text format, fully editable by MATLAB™, promoting extensibility.

Pure Object Oriented (OO) design offers a high degree of code organization, and MATLAB™ supports it natively. However, being an interpreted language, performance drops when adopting a heavily OO approach. In several stages of the development, the initial design was fully revised, rewriting the corresponding code. It was concluded that a best practice is to follow procedural programming for the most part, while scarcely using OO, in a few key-points. In our case, OO was used for providing a standard interface for extensibility, as discussed in Section V-a. A more promising approach would be to adopt procedural design for the totality of the code, while providing an external utility that will handle the incorporation and management of custom extensions.

The incorporation of large data sets, such as field measurements, ray tracing data and terrains requires special handling. MATLAB™ supports saving and loading numerical data from a convenient, native format (MAT files). However, this approach was found to be inappropriate for data sets with more than $\sim 10^5$ entries (platform-dependent). MAT files need to be pre-loaded, resulting into long waiting times. If ease of deployment and migration are not a concern, large data sets should be stored in a dedicated SQL database and be retrieved on demand.

Defining the proper data sampling rate in advance may result in a major performance boost. Highly detailed terrains or measurements sampled per millisecond may not offer much in the context of an educational software package. In several cases it is better to prioritize GUI responsiveness over precision. In the context of the present work, open area terrain resolutions of more than 100x100 points did not add significantly to precision. The user is given the choice to select the resolution level that is appropriate to his available computational power and precision needs. Performance-wise, the number of GUI controls on a MATLAB™ form should also be kept at a minimum.

Finally, the MATLAB™ platform openly supports multiple processors through the Parallel Computing Toolbox™. In most cases, simply parallelizing FOR-loops resulted into major performance gains. It is worth mentioning that there also exist several third-party MATLAB™ add-ons for harnessing the power of Graphical Processing Units [22-23]. Taking advantage of parallelism can effectively resolve the aforementioned, performance-related issues of the chosen platform.

VI. EXPECTED IMPACT

The presented software was designed to facilitate the familiarization of the user with the wireless communications per component and as a whole. However, a piece of software by itself is not a panacea. While self-contained in terms of theoretical documentation, demos and exercises, the package is expected to serve better as an addition to a university course. In this context, the expected impact is threefold:

- Facilitate the intuitive understanding of basic concepts of wireless communications, including antenna radiation patterns, modulation, encoding, shadowing, fading, noise, Doppler effects and ray propagation.

- Sensitize the student on modern issues of wireless communication, such as energy efficiency, radiation standards, green and indoor communications.
- Form a basic introduction to research on wireless propagation issues, channel estimations and network planning, by providing an easily extensible simulation environment.

Above all, the package is intended to act as an interactive means of stimulation, attracting undergraduate and graduate students to the field of wireless communications and engineering in general. This statement is made in the context of the incorporation of the present package into the MSc program on Information and Communication Technology at the International Hellenic University. The feedback from the students enrolled in the program is expected to provide valuable insights on how the presented package should evolve over time. Finally, while the package is not intended for commercial exploitation, it is expected to provide useful insights for future, commerce-oriented endeavors in the field of virtual laboratories for engineering education.

VII. CONCLUSION

A novel educational software package for wireless communication courses was presented. The package comprises several independent applications, each covering vital aspects of wireless communications at graduate or post-graduate level. Thus, a spherical coverage of the course in question is accomplished. Discussing contemporary issues on communications and being extensible, open-source and free, the package aspires to constitute a useful tool for those who teach and study wireless communications.

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