Development of a Communications Course Integrating a Virtual Laboratory and Complex Simulations

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Abstract
Faculty in the Electrical Engineering Department at UTEP created a new course in communications to complement the preparation of students in advanced technologies. They implemented a cost-effective solution by the construction of a computer-based laboratory for modeling and simulation of communication systems linked with a customized lecture. The course included approaches such as cooperative learning to enhance students' problem-solving and conceptual-thinking skills. The lab assignments required the real construction of a small network and the simulation in a computer system. The virtual part of the lab was implemented by using PC-based computer simulation tools. Students are able to access a variety of software packages for analysis of different communications systems either locally or remotely. In addition there are several physical devices that will be configured by the students creating a real network. In such way they cover the theory, then have real practice assembling a small network, and finally simulate large scale systems. The topics covered in the lab can be divided into three categories: communication signals, fiber optic & wireless links, and communication networks. Senior and graduate students are the primary users of this lab. Typically, this lab can be utilized as a supplement to the existing communication courses or be taken as an elective course.

I. Introduction
The field of communications is dynamically changing due to the advances in the technologies that support it. Many areas demand highly trained personnel to solve the new challenges such as data communications, wireless networks, security, etc. Now is more relevant than ever the need for communication engineers capable of developing new ideas and implementing systems feasible to maintain and operate. Very often electrical engineering curriculums offer students one or two theoretical communication courses; still this is not enough to train communications engineers with the proper background on the newer technologies. The problem with traditional courses is that they are only focused on the foundations of communications theory, not on the final applications.

The goal of this course is to familiarize students with several different communication systems through a series of laboratory experiments using small-scale test beds and employing computer simulations. The equipment needed to implement laboratories with the newest technologies is expensive and changes constantly[1-4]. This makes it difficult to continuously upgrade such laboratories. Consequently, employing a computer based laboratory with different software packages specialized for communication applications might be a good approach to overcome all
of these aforementioned drawbacks. However a balance with real experiments must be maintained [5].

The electrical engineering curriculum at the University of Texas at El Paso (UTEP) offers several courses in analog and digital communications. In general, students can learn about many communication systems, but have no opportunity to face the performance trade offs involved in designing a system. Broad-scope laboratories have demonstrated effectiveness in linking multiple concepts [6]. For that reason a new course has been proposed to provide a practical view of communication systems using computer modeling and simulation combined with real equipment configurations. The course assumes that students only have a background in signals and systems. Therefore it includes a lecture covering the relevant concepts needed to understand the communication models and their applications.

The proposal for establishing this laboratory was funded by a grant from Lucent Technologies. The grant allowed UTEP to establish a laboratory equipped with computers, small networking equipment and a variety of simulator software. This new course was first offered as a technical elective available to senior and graduate students in the fall semesters of 2002 and 2003. The laboratory has also helped the research activities of students and faculty members since its inception.

II. Course Design

The objectives of this course are that students should be able to: Understand how different concepts are linked in real communication systems. Evaluate properties for different modulation techniques. Understand the effects of link noise and power budget on the transmitted signals. Design different network topologies as well as calculate the performance of network protocols.

Due to the variety of themes in communications involved, the material to cover those topics were selected from several references [7-10], however, the majority of the content was taken from Hioki [8] as the main textbook.

The experiments cover physical link properties, fiber optic links, wireless links, and network performance for packet and circuit switching systems. We use mathematical software, like MATLAB®, for modeling and analyzing signals with different waveforms. The laboratory also employs an optical link simulator, Virtual Photonic Integrated (VPI) Systems™, for modeling of optical devices and design of optical links. The third application is a discrete event network simulator, OPNET Modeler®, to predict the high level behavior of the traffic in a network. For the physical networking experiments we employed several of-the-shelf networking devices such as hubs, computers, cables, WLAN cards, etc. The fiber optic simulation was complemented with the simple establishment of a fiber optic link using a laser, a signal source, two spools of fiber, a photo receiver and measurement instruments.

The software was used remotely using the Remote Desktop utility from MS-Windows to overcome some of the logistic restrictions in the lab. This allowed the students access from their home machines.

The Signal Analysis section provides an introduction to analog and digital communications using modulation schemes such as Amplitude Modulation (AM), Frequency Modulation (FM), Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), etc. Then it presents the application of MATLAB for modeling the signals using simple functions and graphical blocks as in Simulink toolbox.
The Link Analysis requires an understanding of the physical or photonic devices, including lasers, photo detectors, etc. thus new applications are introduced for optical modeling. The VPI simulator is one of those modelers, and it contains simple blocks to represent devices with different levels of detail. It is relatively easy to construct links and simulate the effects of power, noise and bandwidth on their performance.

For the analysis of networks, the students configure a small router, some computers and a wireless access point. Later they create larger models using OPNET software. The application relies on discrete event simulations replicating the behavior of each transaction in a communications network. This allows students to measure several performance characteristics such as blocking probability, delay, congestion, etc. in such kind of networks.

A. Course outline for Lab:

The topics are scheduled for a semester with 8 laboratory assignments distributed over 14 weekly sessions. The subjects covered are:

1. Introduction
   a. Objective: Understanding the structure of communication technologies and the approach of this course.

2. Analog Modulation.
   a. Objective: Understanding the common techniques to modulate analog signals and the associated performance metrics.
   b. Concepts: Amplitude Modulation, Frequency Modulation and Phase Modulation. Modulation Index along with the Bandwidth effects. *(Includes real modulation of recorded voice)*

3. Link power budget, noise and its effects
   a. Objective: Analyze the power and noise in a communication system.

4. Baseband digital transmission
   a. Objective: Understand the different representation of Baseband digital signals and the probabilistic effects of noise.
   b. Concepts: Bit Error Rate, Eye Patterns in a noisy digital link

5. Digital Modulation
   a. Objective: Understand the different method of digital modulation and the effects of noise.

6. Coding, Error detection and correction
   a. Objective: Analyze the effects of coding schemes in digital transmission.

7. Fiber Optic Link Analysis
   a. Objective: Understand fiber optic link operation.
   b. Concepts: Power effects in a fiber optic link. Dispersion effects in a fiber optic link. *(Includes construction small link)*

8. Multiple Access Techniques With Fiber Optics
a. Objective: Understand several multiplexing techniques. Apply the multiple access techniques in a fiber optic link.


9. Circuit Switched Wireline and Wireless Networks
   a. Objective: Understand how the telephone circuit switched network works.

10. Blocking, Throughput and Delay
    a. Objective: Understand throughput, blocking and delay in a network.
    b. Concepts: Basic queuing theory.

11. Local Area Networks (Contention mechanisms)
    a. Objective: Understand different Medium Access Control (MAC) protocol mechanisms.
    b. Concepts: Topologies, Access methods, Contention mechanisms. (Assemble small LAN)

12. Layer 2 bridging and switching in Local Area Networks (LANs)
    a. Objective: Understand and compare the behavior of bridging systems vs. switching systems for LAN communications.
    b. Concepts: Bridging. Switching

13. Internet protocol (IP) and Routed protocols
    a. Objective: Understand the operation of the Internet Protocol (IP) and its associated applications.

14. Switching packet networks (Asynchronous Transmission Module (ATM), Frame Relay (FR), etc.)
    a. Objective: Understand the operation of virtual circuit switched networks.
    b. Concepts: Virtual Circuits. Switching in Wide Area Networks (WANs). FR and ATM.

A list of proposed topics is shown in Table 1, including the laboratory number, software to use, real hardware experiments and related chapters in the textbook. The students have to implement the corresponding computer simulation, construct the experiment and write a comprehensive report.

<table>
<thead>
<tr>
<th>Week</th>
<th>LAB#</th>
<th>Topic</th>
<th>Software</th>
<th>Real Exp.</th>
<th>Textbook Chapter</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Introduction, Analog Modulation Part I</td>
<td>Matlab</td>
<td></td>
<td>3,4</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Analog Modulation Part II</td>
<td>Matlab</td>
<td>Real Exp.</td>
<td>3,4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Power and Noise</td>
<td>Matlab / VPI</td>
<td></td>
<td>2,3,4</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>Digital Baseband Transmission</td>
<td>Matlab</td>
<td></td>
<td>5, partial</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Digital Modulation</td>
<td>Matlab</td>
<td></td>
<td>(6,8,10)</td>
</tr>
</tbody>
</table>

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III. Sample Experiments

Four sample experiments are discussed below to demonstrate the major areas of this course. The first experiment shows how to use MATLAB and its toolbox to study and implement communication modulation systems such as AM, FM, ASK, PSK, etc. Another experiment shows how to construct a real fiber optic link and use VPI software to study the performance parameters. The last couple of the proposed experiments show how to construct a small real network and use OPNET Modeler software to evaluate different types of network topologies.

A. Sample Assignment Lab#2: Power and Noise

1) Objectives
This experiment aims to visualize the effects of noise with common techniques of analog communications i.e., Amplitude Modulation Double Side Band – Suppressed Carrier and Large Carrier (AM DSB-SC and AM DSB-LC), Single Side Band (SSB), Narrow and Wide Band Frequency Modulation (NBFM and WBFM), and Phase Modulation (PM). Understand how the signal and noise power affects the modulated signal.

2) Tasks assigned:
Generate a modulated signal using MATLAB code. The carrier is modulated using triangular and rectangular waveforms. Add White Gaussian Noise, and then modify the SNR and bandwidth. Observe the effect on time and frequency domains.

3) Discussion:
To fulfill the objectives of this experiment additive white Gaussian noise (AWGN) of various amplitudes was added to the modulated signal in order to determine its effects on the modulation process. Parameters such as the modulation index were varied to determine its effects on the noise susceptibility. The outcomes of these experiments showed that FM modulation is more robust to noise as compared to AM modulation. The disadvantage is that requires more bandwidth. The results can be obtained by simulating these different techniques in the time, frequency and modulation domain using MATLAB, Simulink, and the Communication Toolbox software, which is available on each station in the Communication Laboratory (Commlab).
B. Sample Assignment Lab #5: Fiber Optic Communications

Here, students study different aspects of data transmission over fiber optic systems. To meet the objectives of this assignment, different experiments are conducted to determine the correlation between several parameters such as attenuation, dispersion, etc. in a fiber optic link and the performance of the link itself. They need to establish a simple link with real optical components and later simulate bigger systems using VPI package.

1) Objectives and Tasks assigned

This assignment aims to analyze the effects of attenuation and dispersion in an optical fiber link. This assignment is divided into four parts, the first establish a simple link to transmit a square wave at different frequencies (Figure 1). The second part handles the effect of attenuation on the optical link, and how the optical signal degrades. The third part of this assignment provides the opportunity to design a multi-user fiber link. The last part is about the effect of the dispersion on the optical signal.

![Figure 1 a) b), Fiber Optic Link](image1)

2) Procedures, Results and Discussion:

For each part in this assignment, the fiber link module and component specifications are given to each student. Several steps to do each part of this experiment are provided in the laboratory assignment document. The student should be able to see and obtain a complete required results.

![Figure 2 a) and b), Fiber Optic Simulation](image2)

3) Simple Link Results

In this section, the student should build the link shown in Figure 2 a). The attenuation increases from 3dB up to 30dB in the step of 3dB, 6dB, 10dB, 20dB, and 30dB. The effect of the
attenuation on the signal and its relation with BER are illustrated in the eye diagram observed in Figure 2 b)

C. Sample Assignment LAB #7: Local Area Network construction

1) Objectives
The experiment teaches the students the process to configure and connect several computers to form a small Local Area Network. This assignment prepares the students to understand the basic elements of a LAN.

2) Tasks Assigned:
The students need to construct a simple LAN using a HUB and four PCs Figure 3 a). The second part requires the students to configure an Ad-Hoc wireless connection among some of the computers and the last part requires the association of wireless computers to an access point Figure 3 b) using WEP encryption.

![Figure 3 a) Computers used for LAN connection, b) Hub, Switch/Router and WLAN AP](image)

3) Discussion:
For many students this is the first time they are exposed to the actual cabling or configuration of the devices to form a small LAN. The assignment allows them to understand the behavior of a hub in a shared medium, the isolation provided by the switch and the meaning of some wireless configuration parameters such as SSID and encryption.

D. Sample Assignment LAB #4: Networks and Performance Metrics

1) Objectives
This experiment aims to observe the simulation of a communication network by utilizing a technique known as “discrete event simulation,” where a computer replicates the behavior of an event that occurs in the network. In addition the student must configure several computers and routers to interact in a small network.

2) Tasks Assigned:
To study the properties of different communication networks, the students had to configure and simulate four different scenarios provided with the software tutorial.
3) Discussion:
The program generates events based on source generators (create new packets, initiate telephone calls, etc). Each event has certain properties that are passed from one block to the next. In each block there are defined processing actions based on the event properties; for example we can add delay times, decide which output to take or modify a resource table.

At the end, the program collects statistics associated with each event and they are reported in the final output. The most common parameters are the delay, variance in delay (jitter), blocking (packets lost), utilization of resources and total network capacity.

OPNET is a discrete event simulation program employed to analyze the behavior of communication networks. We use it to understand the behavior of several types of communication networks.

IV Results from first Course
The course was offered for the first time on the fall period of 2002. The enrollment consisted of 8 undergraduate students, and 6 graduate students that elected the class for their study plan. This required coordination with the Teaching Assistant to provide the tutorial sessions for each computer application employed. During the semester we encountered several resource problems with the operation of the computer laboratory. In particular the software licensing created conflicts that delayed the initial experiments. We gave extra time, for assignment completion, to balance the resources and accommodate the student needs. A second instance was offered in the fall of 2003 with nearly 25 students.

This course only had Signals and Systems as a prerequisite, and it was intended to complement the regular lectures on analog and digital communications. However the students had some difficulties interpreting the experiment results because this was the first communications course to some of them. The lectures compensated the problem providing basic theory and focusing on the practical aspects. At the end of the semester all of the students were able to complete all the lab assignments.

The student evaluation of the course reports that 22% took the class for their own interest, 67% as an elective and 11% to fulfill a requirement. In Table 2 there is the rating distribution for the course and in Table 3 we show some quotes from student comments from the evaluations. The acceptance was good but there are some areas that require improvement.

<table>
<thead>
<tr>
<th>Question</th>
<th>Scale</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much you learned in this course?</td>
<td>5 Best</td>
<td>4</td>
<td>3 Avg</td>
<td>2</td>
<td>1 Worst</td>
<td>4.1</td>
</tr>
<tr>
<td>Effectiveness of this course challenging you intellectually</td>
<td>33%</td>
<td>67%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>4.3</td>
</tr>
<tr>
<td>Overall Rating of course</td>
<td>44%</td>
<td>55%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>4.4</td>
</tr>
</tbody>
</table>

V Conclusion
The computer simulation laboratory is an economical alternative to deploy a full equipped real environment. However the use of simple components such as those used in small business, permits the students to understand the application of the simulations. Such a laboratory has a significant advantage over other traditional environments because the capability to upgrade and
update software packages and replacement of economical components is much easier and cost-effective.

We have designed different lab assignments. The lab assignments include analog and digital modulation techniques, the design of fiber optic links along with studying the correlation between the physical characteristics of the link and the transmitted signal, and the design of different network topologies.

To provide an initial assessment, the communication lab assignments have been assigned in senior and graduate level communication systems courses in the University of Texas at El Paso. Students run assignments using computer modeling and simulation, submit individualized lab reports, and complete evaluation forms to give a feedback in order to improve and update the assignments for coming semesters. Students find this lecture course along with lab assignments helpful to them in understanding the theory of communication systems, gaining practical experience, and learning the performance trade offs involved in setting up communication systems.

After the initial course offerings it was decide to expand the lecture time to be a regular 3 hour course. The new proposed structure is to have a regular lecture, acting as an introductory communications course, and supplement the activities through the lab assignments. The changes will be implemented during the spring 2006 course offering. We plan that in the future, more lab assignments will be designed to cover more advanced communication topics. For example, new assignments dealing with wavelength division multiplexing (WDM), wireless network, etc. will be devised.

Table 3, some student comments of the class

| “… Interesting class. I feel labs are important because we get more opportunity to use tools and realize results practically. Also labs help to understand concepts and more in the direction of research. …Please make sure tat labs are equipped with required software with enough licenses. Also make lab available on weekends as students work part-time …” |
| “… two things could be done to improve the course: having lectures more than once a week, and making the number assignments larger but the actual shorter…” |
| “… The only problem was it covered a lot of topics. This prevented us from studying some topics in detail …” |
| “… I think it will be good to continue to tweak it and turn it into a continuously offered course…” |
| “The course is designed to cover a lot of topics and the lecture time is not sufficient to satisfy this. Perhaps incrementing the lecture hours improve this.” |
| “This is an ok course. This is very useful to undergrad not for this graduate student… If he conducts exams then it would be good.” |
| “The communication systems simulation course presents great opportunities to any student understand with more precision the relation of telecomm at an industrial level….” |
| “Great exposure to simulation software.” |
References


