In Process Development of an Advanced Undergraduate Communications Laboratory∗

Michael Muñoz and Susan Garrod
Department of Electrical Engineering Technology
Purdue University
West Lafayette, Indiana

Abstract - The current and future growth in telecommunications (National Information Infrastructure) requires technical expertise at all levels to develop, install and operate the equipment. From discussions with the telecommunications industrial leaders, telecommunications and networking professionals are needed. To meet this need, the Electrical Engineering Technology (EET) department at Purdue University has expanded the communications curriculum to include courses in RF circuit design, wireless communications, and fiber optics. To support these new courses the existing laboratory needed to be expanded, but rather than just add new equipment, we wanted to design a completely integrated communications lab that would provide true hands-on experience for our students.

This paper describes the in process development of an advanced telecommunications lab integrated around a fully operational cellular base station. The communications system consists of a cellular base station, a fiber optic backbone, and a digital telephony switch. Each communications course will work with a different aspect of the overall communications system. For example, the RF course can use the cellular telephony system to understand the effects of RF propagation and to study, design and develop the RF circuits used for transmission and reception of the cellular signals. Alternatively, the fiber optics course can use the cellular system to study and measure the performance of the fiber optics backbone. The advantage of this approach is that both the students in the RF course and fiber course will be working with the complete system and not just an isolated part of a communication system.

Introduction
The Electrical Engineering Technology Department at Purdue University is currently developing an advanced communications and computer networking curriculum that will focus on the areas of intense development in the public network: wireless communications, wireless wide area networks and optical fiber communications. The curriculum includes advanced courses not generally available to undergraduate students, like fiber optic communications, data networking, RF and microwave design, wireless communications, and international communications. The new communications curriculum will allow the students to choose one of two different course sequences. The first course sequence is targeted at graduates working in the wireless communications area. The second course sequence is targeted at graduates working in the telecommunications networking area.

The Advanced Telecommunications Laboratory Project was developed with knowledge gained from a close working relationship with GTE Mobilnet. We have worked closely with GTE Mobilnet since 1990 to better understand the application of wireless telecommunications and the needs of the industry. This has included: (a.) a detailed review and discussion of course topics and hands-on exercises; (b.) definition of the equipment and software required for supporting a wireless course; and (c.) spending time in the field with GTE Mobilnet engineers to better understand the operation and maintenance requirements of real systems. The telecommunications courses were also reviewed by other telecommunications companies and the Purdue EET Industrial Advisory Board.

The telecommunications curriculum development plan was started in the Fall of 1995 with major revisions to an existing introduction to communications course and the introduction of a course in RF circuit design and field theory. The second course, Wireless Telecommunications, was introduced in the Spring of 1996. Followed by fiber optics communications in the Spring of 1997. The international telecommunications course has been approved to run in the Fall of 1997. The digital signal processing applications course is currently under development. There are two possible course sequences that the students can follow as shown in Table 1. In addition, there are related data communications courses taught in the Computer Technology (CPT) department of the School of Technology that are appropriate electives to broaden the student’s knowledge in this area.

∗ Partial support for this work was provided by the National Science Foundation’s Division of Undergraduate Education through grant DUE #9650891
Traditional Lab Approach
Prior to implementing the telecommunications project, the EET department offered two courses in communications: EET303, “Introduction to Communications,” and EET463, “Digital Telecommunications.” The communications lab equipment consists of ten lab stations each equipped with an 1GHz RF signal generator, RF counter, 50MHz function generator, and a 200MHz oscilloscope. In addition there are six RF spectrum analyzers and a RF shielded room for student use. This equipment was sufficient to support the existing telecommunications courses using a traditional lab approach. The traditional lab approach provides the student with hands-on experience for the topics covered in the communications courses. The primary weakness of the traditional lab approach is that the student concentrates on one aspect of the course at a time and may never see the “big picture.” Our vision is to provide students with the “big picture” by integrating into the communication courses a complete fully functional cellular telecommunications system.

The Advanced Communications Laboratory Project
The goal of this project is to increase and improve the telecommunications curriculum by integrating the proposed telecommunications system into each telecommunications course. We expect that because students will be working in lab with a complete telecommunications system, they will be able to relate each concept to the overall system.

When completed, the advanced telecommunications lab will consist of an end-to-end telecommunications system, supporting test equipment, and workstations for simulation. The lab provides the students with a unique opportunity to be involved first-hand in an integrated fiber-to-wireless communication system that emulates, in an educational setting, the true development of systems in the public telecommunications infrastructure.

The advanced telecommunications laboratory includes the cellular communications system, RF test equipment, wireless test equipment, fiber optic test equipment, and radio planning simulation software.

Table 1: Telecommunications Course Sequences

<table>
<thead>
<tr>
<th>Wireless communications</th>
<th>Telecommunications Networking</th>
</tr>
</thead>
<tbody>
<tr>
<td>EET303 Introduction to Communications</td>
<td>EET303 Introduction to Communications</td>
</tr>
<tr>
<td>EET357 Digital Signal Processing (DSP)</td>
<td>CPT230 Data Communications</td>
</tr>
<tr>
<td>EET499R RF Signals and Circuits</td>
<td>EET463 Digital Communications</td>
</tr>
<tr>
<td>EET499W Wireless Telecommunications</td>
<td>Tech581F Fiber Optic Communications</td>
</tr>
<tr>
<td>EET499D DSP Applications</td>
<td>CPT430 Wide Area Networking</td>
</tr>
<tr>
<td>Tech581I International Telecommunications</td>
<td>Tech581I International Telecommunications</td>
</tr>
</tbody>
</table>

Figure 1. Advanced Communication Laboratory Configuration

Table 1: Telecommunications Course Sequences

The section is divided into four areas: RF simulation, RF field measurements, RF lab measurements, and optical test equipment.

RF Simulation
CelPlan is cellular system engineering software developed by CelTec that runs on a 133Mhz Pentium™ based PC. The software was provided by CelTec at no cost to Purdue. The software includes an environment database for the local area so that students can simulate the radio environment.

CelPlan provides the ability to study system performance as a function of a wide
array of parameters including: transmitted power and antenna gain, frequency channels assigned to various cells for voice and for control, antenna height and pattern, train/topography specific to the area being simulated, specific geographic location of cell sites, and hand-off thresholds.

Outputs provided by CelPlan include field strength contours, hand-off boundaries, and many other useful parameters. The graphical outputs clearly show the effects of the terrain upon field strength, and identify areas where coverage is inadequate. This software is very easy to use in general, however, traffic modeling is very awkward to set up and confusing for students trying to interpret the results.

A typical lab experiment requires that students simulate the coverage of the existing cellsites and verify the simulation by making field measurements using SMRTSAM (see below).

**RF Field Measurement**

**SMRTSAM Portable Cellular Mobile System Access Monitor** Observation of system operation in the field gives students a fundamental “feel” for the system, especially after they measure and compare actual performance with the results of the simulations described above. State of the art field measuring equipment allows students to collect data such as field strength, hand-off boundaries, carrier to noise ratio, co-channel interference, adjacent channel interference in an automobile and in the field. Students can also display, record and play back call processing events such as call origination, voice channel assigned, control and voice channel interference, and voice channel supervisory audio and signal tones. The equipment can also monitor power level changes as the mobile distance relative to the base station changes and observe hand-off events.

A typical lab experiment requires that the students use SMRTSAM to take measurements that allow them to compute the attenuation factor, mean power level, and standard deviation of the power at some fixed distance from the transmitter.

**RF Laboratory Measurement**

**Cellular Base Station and PBX** The cellular base station and PBX have not been purchased yet. We had originally chosen a stripped down cellular base station and minimal PBX, however, some regional wireless companies have convinced us that we need a fully functional base station. We are currently negotiating with several companies for the donation of a cellular base station and switching equipment. The cellular base station will give students the opportunity to observe, measure and analyze the operation of individual system components, to track the audio and digital control signals through the system, and to observe the interaction of the components to perform the system functions. This equipment will be used in most of the telecommunications courses. Specific measurements will be made using the equipment discussed below. The course, Introduction to Communications (EET303), will have labs that examine the transmitter and receiver designs, and measure the frequency deviation and modulation index. The digital signal processing courses (EET357 and EET499D) will discuss applications such as echo cancellation, adaptive noise reduction, and voice compression. The advanced course will implement a real time voice compression algorithm (CELP) for the cellular system. The digital communications course (EET463) will use the T1 tester to examine the T1 protocol and measure performance of the T1. The fiber optics course (Tech581F) will use the optical test equipment to examine the fiber optic signals and measure performance of the fiber optic backbone. The RF course (EET499R) will work design RF circuits that will interface directly to the cellular system.

**Wavetek 3600 Cellular Test Set, and TDMA Module**

An application specific piece of test equipment -- a cellular system service monitor -- provides a broad view of many of the parameters of interest and provides the ability to interact with the base station. The existing spectrum analyzer and an oscilloscope will provide the ability to examine the signals in the time and frequency domains. This equipment can be used to capture and examine the data that passes between the base station and the user’s cellular radio.

**T-1 Tester - Tektronix CTS 710 T1, T3, SONET Test Set** The T-1 tester will be used to analyze the end to end performance of the digital T-1 line connecting the cellular base station to the switch. The T1 tester will provide observation/measurement of bit error rates as various system and environmental parameters are varied. This equipment (also listed under the fiber optics section) performs T1, T3 and SONET tests and is used primarily in the digital communications and fiber optic courses.

**Ameritech AM-48** This equipment allows students to observe the effects of system and environmental parameters such as transmitted power and fading upon the quality of the voice channel. Measurements of interest include signal to noise ratio, phase and gain jitter, dropouts, and frequency response. The device is portable so that it can be used for field as well as laboratory measurements.

**Wavetek 400, Cellular Antenna Tester** The antenna tester is essentially a handheld field strength meter that will be used by students to measure the field strength of the base station antenna inside and outside the lab. This equipment will be purchased after the base station is operational.

**Hewlett Packard 8753D Vector Network Analyzer**

The HP 8753D Network Analyzer is used to test and evaluate the RF microstrip circuits designed by the students and used to validate concepts like SWR, reflection, and impedance matching.

**Optical Test Equipment**
Within the advanced communications laboratory, the optical fiber test equipment will be used by students to verify the integrity of the optical backbone of the network (when operational) and its interworking with the cellular radio equipment. The basis of most all optical fiber tests is the measurement of optical input and output power, and the loss of optical power.

**Tektronix CTS 710 T1, T3, SONET Test Set**

The CTS 710 is capable of performing many telecommunication channel over time. This type of test is valid for short-distance fiber optic runs, so it is a very practical measurement in the laboratory environment.

**Tektronix TOP300 Optical fault finder -- visual spectrum (635 nm)**

The optical fault finder determines the continuity of the optical channel by applying a visible light source to the channel. Any breaks along the channel will be detected by the human eye as light “leaking” from the channel. This type of test is valid for short-distance fiber optic runs, so it is a very practical measurement in the laboratory environment.

**Tektronix TOP200 Optical power meter**

The optical power meter measures the amount of light received, and is used to evaluate the amount of power lost through the transmission medium. Optical insertion loss tests are performed using an optical source and the power meter to assess the quality of the fiber, connectors, and splices in the optical fiber link.

**Tektronix TOP130 LED optical source, 850/1300 nm, TOP140 Laser source, 1330 nm, TOP150 Laser source, 1550 nm**

These sources serve as a stable and accurate optical light source at the three optical transmission windows. Three windows of transmission and two types of optical sources are required: 850/1300 nm LED source, the 1330 nm Laser source, and the 1550 nm Laser source. These sources will be used to perform insertion loss measurements to determine the amount of attenuation across the fiber optic link.

**Tektronix TFS3031 Optical Time Domain Reflectometer (OTDR)**

The OTDR provides a very thorough analysis of a long-distance optical fiber link. It will be used to locate optical “events” along the communications channel and measure the power reflected or lost at such events. The optical events detected by the OTDR include splices, connectors, cable bends, cracks in the fiber, the fiber loss as a function of distance, and the length of the fiber. The OTDR is also used to analyze the history of the transmission qualities of the topical fiber channel over time.

**Tektronix CTS 710 T1, T3, SONET Test Set**

The OTDR has the properties of the transmission channel. The OTDR reflectometer (OTDR) to measure the optical transmission losses and other performance monitoring tasks.

**Laboratory Projects**

While the advanced communication laboratory is still under development, we have managed to develop and evaluate some of the laboratory projects we originally envisioned for this lab. While it is premature to provide a detailed discussion of the laboratory projects, a few of the current projects are discussed to provide a sense of what we are trying to accomplish. The students in the Wireless Communications course spend several weeks making measurements of the existing cellular base station in the area. The SMRTSAM allows the students to measure and track the power of a cellular setup channel or voice channel. The first project requires that the students measure the path loss in a rural and urban environment and compare this value to theoretical results. The students are split into groups of 3 or 4 and each group plans a driving path starting at a commercial cellular base station. Setup channel power measurements are taken at equal intervals along the driving path and the path loss is computed based on these measurements. The actual path loss is different from the predicted path loss and the student must account for the deviation by considering practical issues like terrain, obstructions, and weather. When the advanced communications lab is completed, the students will perform the same project for an in-building cellular system.

Another similar projects involves making measurements at a given distance from the base station and determining the standard deviation of the received power and the probability that the power will be greater than some threshold power level.

One project in the RF Signals and Circuits course requires that the students build a microstrip RF pre-amp in the cellular band. The pre-amp is used in conjunction with an FM receiver to pick up cellular radio transmissions. The RF pre-amp is designed around an MRF571 transistor. The students use a vector network analyzer to obtain the s-parameters and design a microstrip impedance matching network to match the input and output of the transistor to 50 ohms. The completed pre-amp gain and reflection coefficients are measured. A power amp design will be added to drive the cellular base station antenna.

The analog communications course currently builds an FM broadcast receiver from specifications. Each receiver block is custom design by the students to meet the given specifications. When the advanced communication lab is completed, this project will be changed to a cellular FM receiver design that can be used to receive signals from the base station.

The Students in the Fiber Optic lab experience in evaluating the transmission quality of optical links. Based on the assumption that no single measurement tells the complete story, they use the visual fault finder, optical source and power meters, as well as the optical time domain reflectometer (OTDR) to measure the optical transmission properties of the transmission channel. The OTDR has the
capability of storing data on disk. The data can then be imported into a spread sheet for graphing and further analysis. As the students apply the various measurement techniques, they assess the strengths and weaknesses of the test results provided by the individual pieces of equipment.

Students in EET 463, Digital Communications, and TECH 581F, Fiber Optic Communications, use the CTS 710 to test operating parameters of electrical signals – DS1, DS3, STS-1, STS-3, as well as optical signals – OC-1, and OC-3 signals. The test equipment allows the user to perform tests in a loop-back configuration and apply faults, or it allows one to monitor a live network. Their initial use of this test equipment has been to evaluate the BER of the signal, apply bit errors and analyze alarms for the various signal types. This test equipment requires that they specify many signal parameters, such as line coding and framing, which provides them with hands-on experience in dealing with various signal parameters that they previously could only study in lecture. Although it is a very complex piece of test equipment, the CTS 710 brings to life many obscure aspects of telecommunications signals and provides the students a better understanding of the requirements for interoperable networks.

**Future Plans**

The equipment has been purchased through funding obtained from NSF as well as corporate sponsorships. The equipment will be used not only for testing in the EET Advanced Communications Lab, but also for network testing when connecting the EET lab to the CPT Wide Area Networking (WAN) lab via the fiber optic backbone (see figure 1). The backbone is not yet in place, but it will consist of single-mode and multimode fiber. The current complement of equipment in the WAN lab simulates a transcontinental network of corporate data communication equipment connected through telco telecommunications networks. This lab includes telco central office equipment such as T3 lightwave multiplexers, T1 channel banks, and networking equipment such as packet switching equipment, access nodes, hubs, routers, and switches for numerous LAN and WAN traffic. By connecting the EET and CPT labs through the fiber optic backbone, the capabilities of both labs and the experiences available to the students are expanded vastly over that which is available through stand-alone equipment or isolated lab environments. The advanced communication laboratory provides students with a unique opportunity for learning about telecommunications transmission within wireless and fiber networks, and provides them with real-world hands-on networking experience.