Teaching Telecommunications Fundamentals – A Networking Approach

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Introduction

As with many topics in a rapidly changing technical world, an introductory course in telecommunications and networking presents a challenge to curriculum developers. How does one teach fundamentals, such as frequency, bandwidth, and multiplexing, which change slowly and do not always appear important to the students? How does one teach contemporary networking topics in a way that is interesting to the "techies" while not losing the less knowledgeable? In addition, how does one bring all of the details of networking together as parts of a central theme so students come away with an overall sense of the field, rather than a collection of disconnected facts? This paper addresses one such attempt, that of transforming a "traditional" course, Introduction to Telecommunications, into a new course which is, in effect, an Introduction to Networking.

Background

The Engineering Technology Program at Texas A&M University traces its roots to a program in Industrial Technology, which was organizationally part of the College of Education. Many years ago, the program was transferred to the College of Engineering, becoming the Department of Engineering Technology, with the original program becoming Mechanical Engineering Technology. Subsequently, the Electronics Engineering Technology (EET) program was added to the curriculum.

Telecommunications Engineering Technology (TET) at Texas A&M was an outgrowth of the EET program, beginning in 1975. This was urged and partially funded by several industry groups: the International Communications Association, representing large corporate users; the Texas Telephone Association, representing independent telephone companies; the General Telephone Company of the Southwest (GTE), who was Texas A&M's telephone service provider and became part of Verizon; and large user corporations, particularly Exxon and Texaco from the petroleum industry. These groups wanted a source for new graduates with specialized training in telecommunications topics, both technical (with focus on testing and maintaining transmission and switching systems) and managerial (designing and managing private corporate networks). The TET curriculum expanded in the 1980s from one course to six, remaining a closely affiliated program to EET for accreditation purposes. In 1994 the TET program became separately accredited by ABET.

Industry Changes

While initially the graduates of the program were hired primarily by independent telephone companies and large user firms, this changed during the 1990s. Mergers and outsourcing, particularly in the oil and gas industry, reduced the number of firms with in-house

telecommunications departments; similarly, mergers in the telephone industry reduced the number of independent telephone companies. In addition, increases in starting salaries, while good for the program's graduates, had the effect of pricing them out of the reach of the independents. On the other hand, growth in the telecommunications supplier sector brought about substantial demand for new hires. For several years in a row, one large international equipment manufacturer offered to hire the entire TET graduating class. During this time, the program had fifteen consecutive years where all graduates had job offers prior to graduation. This changed after the "dot-com bust", but pre-graduation placements rates are again approaching 100%.

Student Changes

The changes in the industry between 1990 and 2001 were paralleled by changes in the background and interests of incoming students. The growth of the Internet and the advent of the World-Wide Web as readily available tools for everyday use changed the student population in many ways. Their use of the Internet for school, business, and recreation made students much more knowledgeable about networking, bandwidth, processor power, and many other technical topics than earlier students. Even better, most of them viewed these as fun. We needed to capitalize on that enthusiasm.

The Previous Course

The course that is the subject of this paper, ENTC 215 – "Introduction to Telecommunications", can be better understood in the context of the close relationship of the course to the EET program. ENTC 215 was originally conceived and taught as a broad introductory course, intended for Telecommunications and Electronics majors at the sophomore level. The ratio of EET to TET students was approximately 3 to 1.

ENTC 215 was a typical, broad telecommunications survey for non-majors. The text was *Electronic Communications Systems* by William Schweber, published by Prentice-Hall[1]. The topics and their order closely followed the text, both in the interest of orderly presentation of topics, and because undergraduates (especially) seem to have difficulty in dealing with class content that does not follow the order of text content.

All telecommunications engineering technology students and most of the electronics engineering technology students were required to take ENTC 215. The previous format utilized the traditional sequence of topics, beginning with amplitude and frequency modulation, proceeding to transmission lines and media, antennas and broadcasting, radio and television, and including one or two chapters each on the telephone network, data communications, local-area networks, and the Internet. These topics, while certainly important, were for the most part extremely dry, and did not engage the students, even those whose major was telecom.

An advantage of the previous course, in addition to its breadth, was that the text included a number of example circuits for accomplishing the functions covered in the narrative. While the focus of the course was such that the circuits were not covered in the lecture nor assigned as reading, the availability of circuit diagrams could be useful to the students in later electronics courses. Schweber's text is excellent for its' intended audience; e.g. electronics majors; however, the needs of TAMU's ET students had evolved in a direction different from that

targeted by Schweber.

There were also several disadvantages to the previous course. To the students, the early material on modulation and transmission lines was especially boring. In fact, they did not become interested until the Internet was covered, almost at the end of the semester. At that point, the change in student response to the new course was noticeable. Class discussions were lively. Questions went from almost nil to abundant. In the students' view, after grinding through fundamentals and background for eleven weeks, the class finally addressed subjects that they wanted to know more about. Clearly, as the importance of data communications and the Internet grew, both in society and especially in the lives for the students, there was far too little coverage on those topics.

In addition, the coverage of telecommunications fundamentals for TET majors, such as time-division multiplexing and the public switched telephone network was insufficient, and difficult for them to relate to their daily routine. Finally, the time devoted to networking, including LANs, datacomm, and the Internet, was too short to adequately develop many important concepts, or to prepare the students for subsequent courses devoted to TCP/IP networks. A first course on telecommunications that did not mention networks until the last half of the semester was simply out of step with the times.

Student Audience

The EET and TET majors, who made up the majority of the students enrolled in the course, had what might be termed a "technical mindset". They could handle a technical course well. An important additional consideration in developing the new course was the presence in the class of students from other programs and colleges. These included the Industrial Distribution (ID) program, housed in the same department as the TET program, as well as the Telecommunications Media Studies (TCMS) program from the College of Liberal Arts. The former, although focused on marketing and supply-chain management, came with a good background in technology, and enrolled in the course as an elective. The latter, while generally interested in the topic, were less well prepared and perhaps less committed to learning the technology of telecommunications, even though it was more central to their major and the course was required. These students from outside ET brought a broader perspective to the class.

The New Course

As result of the changing needs of the students, the changing nature of telecommunications, and changes in the student population itself, it was decided to develop a completely new course under the existing name and number of ENTC 215 – "Introduction to Telecommunications", and in the same position in the curriculum. The course was now required of all EET and TET students. The thrust of the new course would be networking, and it could be divided into three natural areas: voice networks, including the PSTN (Public Switched Telephone Network) with analog, digital, and VoIP (Voice over Internet Protocol) telephony; data communications, including the OSI (Open Systems Integration) model, protocols, and local-area networks; and the Internet, with emphasis on how it actually works. Each of these overall topics was to be covered in approximately one-third of the semester, or four weeks of class.

Sequence of Topics

Beginning with a discussion of the telephone network provides a familiar foundation for all students, regardless of their technical background (or lack thereof). The PSTN is the most common and most used of all telecommunications networks, and an interface with which all students are familiar. Thus, it presents a familiar and understandable context for introducing frequency, bandwidth, decibels, and other fundamental concepts. The author's experience in teaching telecommunications for the past 30 years is that, while the telephone seems rather pedestrian, students with little or no telecom background can easily grasp such complex-sounding subjects as signaling, switching, and multiplexing when the telephone and the PSTN are used for illustration.

The transition to the digital world occurs with coverage of the T-carrier PCM system, and A-to-D conversion. This segue occurs quite naturally in the development of telephony topics, and painlessly introduces digital telephony, as well as such concepts as frames, timing, and compression. While many of the ET students in the course will have already taken the first course in digital logic, it is not a prerequisite for 215, nor can it be when some students have majors other than TET and EET. Ethernet LANs and data communications are next, and the student's familiarity with use of local-area networks stimulates interest in the general subject of protocols and network topologies. The OSI stack is covered, and used to present a glimpse of later discussion of TCP/IP (Transmission Control Protocol / Internet Protocol).

Some colleagues were surprised at the inclusion of sliding-window protocols in an introductory course, but the topic adds a bit of depth, as well as a challenge for the students. Beginning the discussion with coverage of Ethernet (a relatively simple protocol in its' wired LAN versions) provides a good starting place for point-to-point and multipoint topologies, and the effect of topology on protocol structure. Likewise, the coverage of errors and CRC checking is rather detailed, although decimal examples are used rather than binary excess-three arithmetic. Datacomm topics include modems (both voiceband and broadband), serial interfaces, and protocols. It is worth noting that Token Ring is also discussed, even though it is considered an obsolete protocol. This is because the operation of Token Ring is intuitive, relatively straightforward (priority is not mentioned), and its' complexity provides an interesting contrast to the simplicity of Ethernet, allowing the instructor to make the point that, with protocols, simpler is (usually) better.

The course finishes with packet networks, the Internet, and TCP/IP. At this time in the semester most of the students are comfortable with the concepts of circuit-switched networks, frames and addressing, so the segue to packet switching (often a difficult concept for students) is straightforward. By this time, most of the students are enjoying the course. A number of rather complex Internet concepts are described, including classful and classless addressing, routing, DNS (Domain Name Service), DHCP (Dynamic Host Configuration Protocol), and CIDR (Classless Inter-Domain Routing). The students feel that they really understand the basic operation of the Internet.

Choice of Texts

As may be inferred from the foregoing, the course was designed without reference to an existing textbook. Once the topics and their flow were determined, the search for a suitable text began.

Most readers of this paper are aware that there are a great many texts covering the general areas of communications and/or telecommunications and networking. Although most of these focus on the electrical engineering or computer science aspects of the topic, there are many that are intended for a first course. The problem was that almost all of these are written from an Internet perspective, and have little if any discussion of the PSTN. After much searching of catalogs and reviewing of sample copies, a text was found: *Voice & Data Communications Handbook* by Bates and Gregory[2]. While the authors do not include all of the above topics in the depth or order desired, the book contains a wealth of material, including much that cannot be covered in one semester. For this reason, the TET majors are urged to keep the book, rather than sell it back to the bookstore at the end of the semester. It is used as a secondary text for several following courses.

The required reference for the revised course is *Newton's Telecom Dictionary*, by Harry Newton[3]. This book, which is currently in its' twentieth edition, is an extremely useful reference to telecommunications terminology: technical, managerial, and regulatory, as well as the acronyms, which are abundant in the field and intimidating to the newcomer. While the author editorializes in his definition of some terms, particularly in the policy area, the book is so thorough that it is almost a second textbook for the course.

Comparison with Other Approaches

In an excellent discussion of teaching in the related area of information technology, Joseph Ekstrom and his co-authors from Brigham Young University suggest that IT be taught as an integrative technology. They recommend "a change in orientation from focusing on the technologies to focusing on the interfaces between technologies."[4] Telecommunications engineering technology has, in the opinion of the author of the present paper, two central themes: network design, and interfaces. In other words, TET focuses on how to design a near-optimum network to accomplish the required business functions within the prescribed budget, and how to interface and manage the equipment and software that comprise that network. In this way, TET differs fundamentally from EET, which focuses on the design of the hardware and software "boxes" to implement a function. TET, on the other hand, focuses on tying the boxes together to build a network. Our experience with ENTC 215 parallels, in several ways, the BYU experience with their *Introduction to Information Technology.* Students responded better to an integrated approach. Teaching telecom networks as single subject rather than disconnected topics proved useful, and fundamental concepts, such as bandwidth, are more understandable when discussed in the context of a network. Contemporary undergraduates are network-aware, and they can easily envision how equipment and software operate in a network.

It could be said that this is simply the "Top-Down" approach applied to telecommunications, and indeed in many ways it is. In arguing that "Most computer organisation courses are built upside down", G. W. Scragg points out:

> …most (perhaps all) first courses in computer hardware are created "upside down" - both pedagogically and pragmatically. This has the consequence that 'Pedagogically, this approach provides no "cognitive hooks", which might enable students to relate new material to that of previous courses - until the semester is almost complete'…[5]

Scragg defines the top down approach as beginning with material already familiar to students and then introducing concepts that are new to them. Aburdene et al state that "bottom-up, … starts at the lowest (physical) layer of the protocol and works its way up; (while) top-down … starts from higher layers such as applications"[7]

Our approach in beginning with the PSTN, utilizing the familiar model of a call over the telephone system, and using that metaphor to develop telecommunications concepts would seem to fit the top-down model. It is not coincidental that these comparisons with other curricula are drawn from the Information Technology field. Telecommunications at the overview level is much closer to IT's systems focus than to EET's component focus.

Voight's philosophy in teaching the fundamentals of information technology at the U.S. Naval Academy is similar:

> The one thing we were certain of is that we did not want to give the appearance of a training course. To train or to educate was not a question although we often walk that line in a survey course such as this one. We did not want to train students to be better users; we wanted to educate them to understand the underlying technologies thus enabling them to train themselves.[6]

This is what we are trying to accomplish at Texas A&M as well. Telecommunications changes rapidly; it is unlikely that the interfaces and protocols that we cover today will still be in wide use in twenty years. On the other hand, the services that telecommunications provides will, in the broad sense, be fundamentally the same, and the approaches will still combine bandwidth, electronic (or photonic) intelligence, and connectivity to implement them. If we can help the students to view systems from that perspective, we have done our job.

Traditional Communications Fundamentals

So where are all of the fundamental topics that were formerly covered? They are now taught in a one-semester-hour laboratory that is part of ENTC 215. It was decided to utilize a modular, self-contained "Training System" produced by Degem Systems. This consists of hardware trainers and associated software, known respectively as the Modcom and TeleSim Training systems[8].

While the idea of a lab to provided hands-on understanding of fundamentals not covered (at least in any depth) in the lecture has proven to be sound, unfortunately the equipment chosen has not been as successful. The Modcom equipment and TeleSim software appeared to be a very versatile, computer-based system that would allow hardware/software simulation of many different telecommunications problems. In fact, our experience is that these training systems are built around a series of pre-defined experiments (courseware), and that it is difficult to modify them, much less to create one's own experiments. The Modcom system appears to work very

well if one follows the structure defined by the manufacturer. In retrospect, we should have done a better job of matching the equipment to our needs.

Conclusions

Changing needs of students, the changing nature of telecommunications, and changes in student background brought about a revision in the introductory telecommunications course, from a focus on discrete topics to a focus on networking. This was the right change for Texas A&M's TET program.

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