Hamming It Up In Data Communications

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1. INTRODUCTION

Data communication classes are standard in computer-science and computer-engineering programs. These classes typically overview many areas of data communication, using material from EE, CE and CS disciplines, ranging from high-speed data networks to the (plain, old) telephone system. The idea is to give students knowledge of various components of these highly complex systems without requiring deep knowledge of any particular discipline. Moreover, these classes usually attract engineers and computer-science majors. At Grove City College (GCC), for example, I usually have CS, EE and EE/CE majors in the class, which most students take in their junior year.

To get the most out of data-communication classes, students must get a sense of the complexity of the systems they are studying; it is not enough to be simply a user of these systems. Without this, many of the ideas covered in class have no real meaning: they remain abstract concepts. In the past, most students taking a data-communications class had some experience with the actual hardware and software in networks. The majority of students I see today, however, have little experience with these things aside from setting up a network router in their homes. They have little experience with many of the other important technologies needed to make modern communications possible. The dilemma is how to give the students a rich experience with data communications without requiring significant laboratory time. At GCC, we have answered the dilemma with amateur—ham, as it is commonly known—radio.

2. THE IMPORTANCE OF RADIO

For the past two years, I informally polled students about their experiences with different forms of communication. As one might expect, Internet-based communication (e.g., instant message, chat groups, email) are very popular for individual communication, as are cell phones. For entertainment, particularly audio, streaming on-demand media and DVDs are the primary mode; interestingly, TV (terrestrial and cable) is not top of the list. Radio is low on the list in both categories.

The idea of using radio in data communications as a "lightweight" lab component, therefore, seems foreign to many students. As they learn throughout the term, however, radio is an integral part of the communication infrastructure, supporting wireless telephony, wireless data networks (e.g., WiFi) and the telephone system. With the increasing demand for mobile computing and integrated computing/telephony/data communications devices (e.g., the Palm Treo 650), radio will play an even larger role than it does at present.

Lab components for data communication classes usually involve network design and setup, such as programming a switch and monitoring network parameters. At GCC, for example, this is what was done in the past. There is a lot to recommend these types of labs, but I feel that with the drive to wireless communication students need to be exposed to radio technology.

The question arises: how does one give students experience with radio? Ham radio provides students a rich radio experience. Ham radio utilizes cutting edge technologies by combining the Internet, digital data communication and radio in exciting and accessible ways. For example, students can use a computer and the Internet (no radio needed!) to contact operators on the other side of world using VoIP and data-communication techniques. Furthermore, it is easy to make abstract concepts like PSK real: students can listen to data being communicated over the air, and can even adjust the parameters. Thus, students without deep engineering knowledge can gain real "hands-on" experience.

3. TESTING AND EQUIPMENT

All ham operators must be licensed by the Federal Communication Commission (FCC). Getting a license (or "ticket" as hams call it) requires passing an FCC exam that is administered by Volunteer Examiners (VE), hams trained to give these exams. There are currently three classes of licenses issued by the FCC, described as follows:

- Technician: this is the entry-level ticket. Techs have full operating privileges above 50 MHz, meaning they can transmit voice (using any legal modulation scheme), digital data, fast and slow scan TV, and so forth. Below 50 MHz, operator privileges are greatly reduced for voice, but other transmission modes are still available with some restrictions. The best part about this operator class is that there is **no Morse code requirement**. Thus, a major impediment to licensing is removed. The privileges of the Tech ticket are sufficient for students in a data-communications class.

- General: this is the most common ticket, particularly for hams with serious interest in the hobby. Generals have all the privileges that Techs have, plus they have full transmission mode privileges below 50 MHz. The general ticket requires passing both an additional theory component (beyond Tech) and a Morse-code component of five words per minute. Few students opt for this ticket because of the code requirement.

- Extra: this is the ticket for advanced operators with great interest in both the technology and theory underlying radio. The extra exam requires an additional exam beyond the general, covering advanced theory and operating techniques (e.g., satellite and the exotic earth-moon-earth modes) Extras have all the privileges of the general ticket, plus bandwidth devoted exclusively to extra-class operators.

Of the 30 students taking the course in Fall, 2005, one student came into class with his Extra license and remaining students all took and passed the Technician exam. One of the students in the class went on to take all exam components, thus gaining his Extra ticket.[1]

2.1 The Exam

An important resource for both hams and instructors is the American Radio Relay League[2] (ARRL), which is an organization of ham radio operators. The ARRL promotes the hobby, lobbies on its behalf, supports operating activities and research, produces many publications, and provides instructional materials.

The ARRL publishes textbooks for exam preparation: for the Tech license, the book is Now You're Talking! (Straw, 2003), which is relatively inexpensive. This book is intended for a general audience, and is easily read by college students. The book covers everything needed to pass the exam, from regulations to theory to practice. In addition, the book has the complete test-question bank and corresponding answers; yes, the FCC makes all this available to the public. The ARRL also has a variety of teaching aids, including a teacher's manual for Now You're Talking, and lecture material.

I used this book, and found that the students were able to go through it on their own. I devoted a one-hour lecture to an overview of ham radio and answered students' questions; beyond that, I answered questions as they came up during office hours. The students had surprisingly few questions (fewer than a "hard" homework would generate). So, I found that the additional materials were not needed. As I outline later, I did incorporate many the radio concepts into the regular class material.

In addition to the ARRL materials, there are several ham-radio websites that automatically generate and grade practice exams based on the FCC test-question bank.[3] The students found that using these websites was a great way to drill before the exam. I recommend making these sites available to students.

As mentioned earlier, the exams are given by VEs, who typically come from local ham clubs. The cost of the exam is set by the FCC, and is low—about $15.00. Ham clubs are common around the country in both urban and rural areas. Moreover, colleges and universities, particularly those with engineering programs, often have ham clubs. Most clubs periodically give exams, which are open to the public. So, it is easy for students to get access to testing locations. The ARRL website lists both exam times and locations and local ham clubs.

Because of the relatively large number of students taking the exam, and because the local ham club is very accommodating, three VEs came to the GCC campus one evening to administer the exam.

[1] And shaming his instructor, who has a General ticket and promised that he'd take the Extra exam when the rest of the class took the Tech exam. Unfortunately, the instructor didn't take the exam at that time.
[2] The website is: www.arrl.org.. The author is a member of the ARRL.
[3] For example, visit www.eham.org and www.qrz.com/p/testing.pl

One of the great things about the testing process is that the results are given immediately, so students know right away whether they passed. It takes a few days for the FCC to issue the ticket through its database on the Web. As some of our students commented, it was a long few days.

I gave the students about 10 weeks during the semester to prepare for the exam (not including breaks). In hindsight, this was far too long; four weeks would have sufficient time and the students could have gotten more time on the air and I would have been able to better integrate radio-related concepts into the lecture material.

The mechanics of getting materials to prepare for the exam and taking the exam are simple, and the cost of the materials and the exam is low. Thus, ham radio is very accessible.

2.2 Equipment

Getting students on the air is a critical to using ham radio effectively in class. College ham clubs, with appropriate arrangements, are a great way to get students on the air with minimal expense. Typically, ham clubs have experienced operators, who can help students with the mechanics of operating a radio and making contacts.

New and used ham-radio gear are readily available from many reputable dealers and ham-oriented websites, even eBay is an excellent marketplace for purchasing equipment. A serviceable station supporting digital transmissions can be put together for a few hundred dollars. While not cheap, it is neither exorbitant (about the cost of a really good graphics card and a couple of computer games).

There are, however, excellent alternatives based on free software. Hams, as a community, have created a very large collection of software that aids the hobby. In particular, there are programs that allow licensed operators to access repeaters around the world from a computer! (Repeaters are used in the VHF bands to retransmit a signal; repeaters are usually located on towers or high roofs and transmit with high power. Thus, they effectively extend the range of small mobile radios). Hams around the world have set up repeaters that were, until recently, used exclusively for local geographic areas.

That has all changed. A system called EchoLink[4] (Taylor) connects thousands of repeaters around the world using Voice-over-IP (VoIP) techniques. All the more interesting, EchoLink has a free, easy to use Windows client that allows a ham with a computer and a sound card to connect to any EchoLink-linked repeater around the world. As a demonstration in class, I connected from my computer in the lecture room in Grove City to the Munich Olympic Tower repeater and had a conversation (QSO in ham-speak) with a person driving home from work in an outlying Munich suburb. This was a compelling demonstration of VoIP techniques, and the kind of demo that gets students attention. After that demonstration, the students were hooked and were on EchoLink often.

[4] Software is available at http://www.EchoLink.org. Note: one must be a licensed ham to use this software and a simple verification process is necessary before an operator is allowed to use the EchoLink network.

Thus, through EchoLink students can get "on the air" with no equipment beyond a computer. And, they can make contacts worldwide, which is very difficult to do with a Tech ticket working above 50 MHz.

Students at GCC access the Internet through a proxy. Fortunately, EchoLink even provides a proxy server that allows those behind a proxy to get into the EchoLink network. In addition to getting to use ham radio, understanding what the proxy is and how it is setup is great additional practical experience for students.

For those using linux, many tools are available (Hughes).

4. LABS AND LECTURES

There are many areas where ham radio can be used to support lecture and textbook material, as well as provide lab experience. In this section, I will overview a few of these areas. This is not an exhaustive enumeration, rather it is meant to suggest *some* areas of application. In particular, I will limit the list to those things covered by the Tech exam or requiring only Tech privileges.

Labs provide hands-on experience and practical application of course material: this is particularly relevant to ham radio as the ability to transmit allows student to "push" signals rather than just receive them. I believe that transmitting data or voice using radio is significantly different than transmitting using a data network (e.g., Internet): data networks are plug-and-play, they work so well and are so simple to use that it is easy to overlook their complexities. Ham radio, however, exposes these complexities, requiring that the user be involved by selecting modulation modes, dealing with noisy channels, signal fading, propagation, and protocols.

The following are a few lab ideas:

- One of the simplest, yet very rewarding labs is to establish communication using EchoLink with different sites around the world. While EchoLink is essentially plug-and-play, it does exercise ideas of protocol, it can be used to demonstrate the Internet and VoIP. When I used this lab, I found that students also became aware of the limits of PCM encoding and latency issues on the Internet, as they directly experienced the audio problems that arise.

- With radio equipment, it is possible to allow students to play with a variety of modulation methods, all of which are covered in lecture. In particular, they can gain experience with sidebands, something they normally never experience (except in the original Stars Wars movie!). In addition, the students can get an idea of bandwidth and filtering; I am planning to use our radio gear to demonstrate different filters and have students listen to what happens to a signal. This is a very important demonstration of why telephony requires about 3.5 KHz of bandwidth, for example.

- With radio equipment and a computer, it is possible to play with different digital transmission modes. Another free software application, Digipan[5], supports a variety of digital modes, including phase-shift keying (PSK) and frequency-shift keying. Not only do the students get to heard what these schemes sound like, but they can realize how a very narrow bandwidth signal can punch through a noisy channel with little power. This is important to understanding how data transmission works regardless of medium.

The following are few ideas of how different lecture topics can be supported by drawing on material from ham radio. As a point of reference, I use Forouzan (2004) as the textbook.

- Regulation: the communication industry, particularly telephony and radio, are regulated by the FCC. Through their licensing experience, students will understand what the FCC does, what regulations mean, and how the radio spectrum is divided.

- Propagation: we discuss propagation methods, both in wires and fiber and through the air. The license exam covers this material with practical applications.

- Modulation: we cover a variety of analog and digital modulation methods, as described earlier. The license exam also covers this material.

- RF safety: the textbook does not cover this material, although it is important and certainly in the news (e.g., cell phones and their affect on the human body). The FCC requires that ham operators understand safe RF exposure limits and provides simple ways to estimate exposure. This is very useful supplemental material.

- Basic concepts: some of the most difficult things for students to understand are the basic, albeit opaque, concepts used in communication, such as: bandwidth, channel, noise, and the relationship between bits and bauds. Much of this material is part of the licensing exam and is demonstrated through radio labs.

5. ANECDOTAL DATA

All students took the FCC exam and passed it, becoming licensed Technician operators. All students were required to make at least one contact, which the majority did using EchoLink. I guided most students through their first contact, as it can be intimidating to speak with someone on the opposite side of the planet. After the students built their confidence, most of them were and are still active users of EchoLink.

The FCC exam counted on the students' final grade as a lab component. I did not get the scores of the Tech exam, so I gave pass/fail (fortunately, no fails) credit.

On the end-of-semester course evaluations, the students were asked to comment on the radio project. Their written comments were uniformly positive, with some legitimate grumbling about

[5] http://www.nvbb.net/~jaffejim/digipan.htm

delays in getting the EchoLink proxy up and running on campus. In fact, several students wanted more radio projects included with the class. I excluded the usual switch programming lab, and the students asked to have that put back in. This can be easily accommodated.

More importantly, however, the students were genuinely excited about the possibilities of radio. Six independent study projects were generated the following semester as a result of the students experience with radio in class, which is an unusually high number of independent projects stemming directly from a class. That is an exciting result.

For EE students, there is additional exposure to radio in our signal-processing courses.

6. SUMMARY

Ham radio allows students to exercise many of the concepts they learn in data communications classes. In addition, it gives students experience with an increasingly important technology with which few have any real experience.

There are almost no barriers to incorporating ham radio into the curriculum: equipment is available on many campuses through ham clubs, there are many websites with good materials, and exams and exam study materials are readily available and inexpensive. EchoLink provides a well-supported network of repeaters, and provides easy access for students with computers to the world of radio. And, expertise is available from local ham clubs, who are usually more than willing to help out.

The student response was so good that we will continue to use ham radio as an integral part of class.

7. REFERENCES

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