AC 2012-4164: A GRADUATE ENGINEERING TECHNOLOGY COURSE IN NETWORKS FOR THE INDUSTRIAL ENVIRONMENT

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A Graduate Engineering Technology Course in Networks for the Industrial Environment

Abstract

This paper describes the development of a new graduate engineering technology course in advanced networks for industrial environments. The course is intended to provide an in-depth overview of high-performance wired and wireless networks for industrial control, communications, and computing. The emphasis is on understanding current and newly emerging network architectures, protocols, and technologies in terms of performance, network services, ease of implementation, maintenance, reliability, risk, and cost. The course is currently offered entirely online. To address the challenge of providing hands-on experience with network protocols, experiments with two industry-standard modeling and evaluation tools, OPNET’s IT Guru and Wireshark, are used. In addition, Adobe Connect is used to support real-time student presentations. Testing of the course material using a group of undergraduate students and one graduate student with little previous understanding of computer and industrial networks indicated that the students learned a substantial amount about these topics.

Introduction

In the past, the subject of industrial data networks focused on networks designed for control, data acquisition, or remote sensing, but increasingly industrial networks are used to connect computers in industrial settings. These computers may be desktops or laptops, or they can be small, single-chip microcontrollers costing less than a dollar, but still connected to a network. Furthermore, few modern companies could exist without email, web pages or web-based accounting and data backup systems. Networks for all these applications are beginning to share Internet-like features, including network protocols and hardware. There are three reasons for this: first, the explosion in Internet-based networking technologies as well as research in improving them have dramatically driven their cost down while increasing availability and quality. Second, the concerns for both applications are the same: performance, cost, reliability, and security. Finally, Internet-based manufacturing is becoming an important new technology. As a result, an Internet-like approach to understanding these networks is taken.

This paper describes the development of a new online graduate engineering technology course in advanced networks for industrial environments at Drexel University. The goal of the engineering technology program is to develop advanced level practitioners in industry who are interested in developing marketable skills to meet evolving workforce demands, seeking professional development, expanding opportunities for professional advancement, or pursuing a managerial position. To support this goal, the new course is intended to enable students to make sensible decisions when selecting and implementing a network protocol for a particular industrial application through an in-depth understanding of currently available and newly emerging wired and wireless networks and components.
The course is currently offered entirely online. Two of the key challenges in developing the online course were an emphasis on hands-on experience and the ability to support real-time student presentations. To provide hands-on experience with network protocols, experiments with two industry-standard modeling and evaluation tools, OPNET’s IT Guru and Wireshark, are used. OPNET is a network traffic simulator used for packet-level performance analysis of metrics such as throughput and delay. Wireshark is an open-source network protocol analyzer. Students can freely download IT Guru and Wireshark and perform the experiments on their own computers. Both Adobe Connect and Wimba Classroom are available to support real-time student presentations.

Course Content

The course syllabus is shown in Figure 1. The course begins with an introduction to what network protocols are, using the example of collision detection in the context of ordinary conversation. The use of this technique in first generation Ethernet is then described. Next, the importance of layered protocols is discussed and the DARPA, OSI and Internet Protocol Suite (TCP/IP) models are discussed. Circuit and packet switching are then compared with respect to performance, ease of implementation, and cost. Statistical methods and industry-standard CAD tools used in performance modeling are then described. The introduction concludes with a discussion of protocol selection criteria, including performance (throughput, latency, jitter, etc.), network services (support for streaming data, in-order delivery, etc.), cost (maintenance, installation, training), component form factor, expandability reliability and availability, industry support, and longevity.

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
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<tbody>
<tr>
<td>1</td>
<td>Introduction to network protocols and technologies, network topologies, the OSI and TCP/IP protocol stacks</td>
</tr>
<tr>
<td>2</td>
<td>Circuit and packet switching, network performance, throughput and latency, selection criteria</td>
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<tr>
<td>3</td>
<td>Application layer, client-server and peer-to-peer models</td>
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<td>4</td>
<td>Transport layer, TCP, UDP</td>
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<tr>
<td>5</td>
<td>Internet (Network) layer</td>
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<td>6</td>
<td>Network Access layer, Ethernet</td>
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<tr>
<td>7</td>
<td>Some typical industry-specific networks (CAN, DNP3, etc.)</td>
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<tr>
<td>8</td>
<td>Physical media</td>
</tr>
<tr>
<td>9</td>
<td>Wireless network protocols</td>
</tr>
<tr>
<td>10</td>
<td>Network security</td>
</tr>
</tbody>
</table>

Figure 1. Topics covered in the 10-week course.

The next four weeks are devoted to detailed descriptions of each of the layers of the TCP/IP protocol stack. A top-down approach is used, starting with the Application layer. Client-server and peer-to-peer models are described together with examples such as HTTP, DNS (Domain Name System), and BitTorrent. Next, the features of the Transport layer are discussed, including connectionless and connection-oriented transport. TCP and UDP, as well as congestion control are described in detail. This is followed by a discussion of the Network Access layer including Internet Protocol, virtual circuits and datagrams, and routing algorithms. Finally, the Network Access layer is described using the example of Ethernet, which is finding wide use in industrial control applications, for example, to interconnect programmable logic controllers. The text for
the course is *Computer Networking: A Top-Down Approach*\textsuperscript{12} by J.F. Kurose and K.W. Ross, early advocates of the top-down approach.

Next, several industry-specific network protocols are discussed, including CAN\textsuperscript{13} and DNP3.\textsuperscript{14} CAN (Controller Area Network) is a multi-master serial bus protocol originally designed to transmit short messages between microcontrollers in an automotive environment. Since its inception in 1986, its range of applications has expanded into such areas as industrial automation and medical equipment. DNP3 (Distributed Network Protocol) is an open standard intended to provide interoperability between computers and intelligent devices in the electric utility industry. The standard provides for an IP-based serial point-to-point link.

In the next week physical media are described in detail with an emphasis on cost-performance tradeoffs. Wire cable, fiber, and free space (wireless and free-space optical) are described in terms of physical characteristics and application space. The motivation for placing this discussion between the protocols above and the wireless protocols below is that it introduces the latter subject in terms of physical characteristics.

Next, wireless network protocols are discussed in some detail, including Wi-Fi (IEEE 802.11\textsuperscript{15}), Bluetooth,\textsuperscript{16} and ZigBee.\textsuperscript{17} Bluetooth is becoming increasingly useful in industrial applications as cable replacement, in wireless sensor networks, and as an interface to IP-based networks. ZigBee is a suite of protocols designed for low-power, low data rate RF mesh networks used to control consumer electronics, heating/cooling systems, lights, etc. ZigBee is finding increasing use in distributed control and monitoring in industrial settings.

The final topic is network security. Security is an important consideration in the industrial environment. Particular emphasis is placed on securing email, Virtual Private Networks, and security in wireless networks. The networks previously described are compared in terms of performance and security features.

To provide hands-on experience with network protocols, experiments with two industry-standard modeling and evaluation tools, OPNET’s IT Guru and Wireshark, are used. OPNET is a graphical network traffic simulator used for packet-level performance analysis of metrics such as throughput and delay. To use it, components such as routers, hosts, servers, etc. are dragged from various menus and then connected together in the desired topology. Figure 2 shows a typical screenshot of a network defined in this way. It shows three hosts connected through a local 100 Mb/s Ethernet switch to a cable that provides an Internet connection through a WAN to three remote servers. OPNET provides accurate models of real commercial devices—note in the figure that the model for a real, commercially available Linksys cable modem is being used. They also have models for all popular protocols and you can define your own devices or protocols in a high-level language such as C. The link speeds can be chosen as well.

A variety of traffic patterns may be specified. For example, traffic may be generated with a random number generator using several statistical distributions such as normal or Poissonian for packet length and inter-packet time. The simulator can produce useful information such as average and instantaneous throughput, average or instantaneous delay, delay by priority, etc. Figure 3 shows the delay of individual packets as they are generated over time.
IT Guru may be freely downloaded for academic use and students can run it on their own computers.

Figure 2. Typical OPNET screenshot.

Figure 3. OPNET results showing individual packet delay over time.
Wireshark is used to give the students hands-on experience with their own local area network. Wireshark is a GUI-based open-source protocol analyzer used for network troubleshooting and analysis. It can sniff out information such as source and destination addresses or the contents of packets at various network layers in the students' actual local network. Figure 4 shows a Wireshark screenshot showing the capture of packets corresponding to the request of a web page using the http protocol. The image shows the "Get" command, requesting the root document. The hostname is www.paleotechnologist.net.

Figure 5 shows the response from the host. It took about 300 ms for the request to go out (via a VPN connection), reach the webserver, and be processed and returned. Because Wireshark can capture a large amount of information quickly, it is essential for the students to learn how to start it up, capture the needed data, and then shut it down quickly before some other process makes an Internet request. By clicking on the request, then the response, the student can see what information was exchanged.

The software may be freely downloaded by the students under the terms of the GNU General Public License, and versions are available for both PCs and Apple computers.
To give students presentation experience and also to increase their sense of social presence in the online course, students are assigned to select an interesting protocol from any layer of the protocol stack and give a real-time presentation to the class. Both Wimba Classroom and Adobe Connect are available for this purpose and Adobe Connect was recommended by our learning center for this application. Figure 6 shows a screenshot of an Adobe Connect presentation (a practice session using the two authors as presenter and participant is shown). A number of useful features are supported, including archival recording for students who could not participate in real time, on-screen drawing, on-screen pointers, real-time audio comments from participants with requests to speak via a pulldown menu, chat screens, file sharing, and applause indicators.

Adobe Connect preserves full Powerpoint animation, but we encountered several problems with resizing objects and text boxes that required manual correction. The learning time is fairly short but students must try it out before the actual presentation to work out any bugs. A reservation system was used to guarantee students time to test out the features with their actual presentation.
Figure 6. Screenshot of an online presentation using Adobe Connect. (One of the authors is shown giving a sample presentation.)

Results

The course material was pretested on a group of advanced undergraduates and one graduate student. All had little to no experience with computer networks or networks for industrial environments. On completion of the course the students were tested on their knowledge of course content. The students were able to answer questions about layered protocols, network performance, etc. In addition, students were surveyed using a Likert-type scale to assess how much the course contributed to their understanding of these topics. The students responded with an average score of 4.0 ($\sigma = 0.6$), where 1 = “None” and 5 = “A great deal”.

Conclusions

This paper described a new online graduate engineering technology course in advanced networks for industrial environments. The course is intended to provide an in-depth overview of high-performance wired and wireless networks for industrial control, communications, and computing. The course uses a top-down approach to understanding layered protocols such as TCP/IP. The course includes topics aimed at the use of these networks in the industrial environment. These topics include performance/cost tradeoffs of various network topologies and industry specific network protocols such as ZigBee, CAN, and DNP, as well as common commercial networks that are finding their way into industrial applications such as Bluetooth and Wi-Fi. Hands-on experience in the online course is provided using the OPNET for performance modeling and simulation and Wireshark for network sniffing and protocol analysis. Testing of the course material using a group of undergraduate students and one graduate student with little previous understanding of computer and industrial networks indicated that the students learned a substantial amount about these topics.
Bibliography