AC 2012-3975: AN ALTERNATIVE MODEL FOR COMPUTER NETWORKS EDUCATION IN COMPUTING DISCIPLINES

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An Alternative Model for Computer Networks Education in Computing Disciplines

Abstract

Computer networks is an important area in the body of knowledge of multiple degree programs, such as Electrical Engineering, Computer Engineering, Computer Science, Information Engineering Technology, Software Engineering, and other programs. As one of the fastest growing areas, computer networks is experiencing a dramatic need of professionals with solid foundations and practical hands-on experience. In this paper, we present a hands-on intensive model for an Information Engineering Technology program that includes 4 computer networks courses at different levels and starting during the freshman year. The model includes an innovative mix of industrial and academic components that provide students with skills needed by both industry and academia. The proposed model also targets retention, breaking up long-term goals (e.g., obtaining a bachelor degree) into milestones, where a milestone can be the completion of the 4 courses in the area of computer networks. By doing so, the model provides a safety net to students, who are able to acquire skills demanded by the job-market early during their studies. Moreover, the program helps in avoiding high dropout rates during early semesters, where institutions have historically experienced higher dropout rates because of lack in students incentive and limited hands-on experience. The model is articulated with the 2008 ACM and IEEE Computer Society Guidelines for Engineering Information Technology, and enables students to achieve multiple ABET program outcomes. Results of the implementation of the computer networks model in a minority serving institution are included.

Index Terms

Computer networks, computing disciplines, curriculum development, student learning outcomes, ABET.

I. Introduction

Computer networks is an important area in the body of knowledge of multiple degree programs, such as Electrical Engineering, Computer Engineering, Computer Science, Information Engineering, Software Engineering, and other programs. As one of the fastest growing areas, computer networks is experiencing a dramatic need of professionals with solid foundations and practical hands-on experience. This need has been reflected, to some extent, into the curricula of computing degrees such as Computer Engineering, Computer Science, Information Engineering Technology, and others, where computer networks is now unquestionably included. For example, the curriculum guidelines for undergraduate degree programs in Information Engineering Technology of ACM and IEEE Computer Society consider networking as a pillar for any modern program [1].

Despite these recent guidelines, most computing disciplines still do not provide appropriate and attractive programs including computer networks. Most colleges and universities only introduce the students to the computer networks area at their senior year. In fact, courses that expose students to actual computer networks environments are still mostly absent in an undergraduate curriculum. As a result, students are only exposed to computer networks in their graduating semesters, at a relatively abstract level.

In this paper, we present a hands-on intensive model for an Information Engineering Technology program that includes 4 computer networks courses at different levels and starting during the fresman year. The model includes an innovative mix of industrial and academic components that provide students with skills needed by both industry and academia. The model combines material from the *Cisco Exploration Program* (CEP) [2], which is enriched with well-known academic materials such as [3, 4, 5, 6, 7, 8] commonly used in traditional 4-year institutions. The former is a hands-on educational program that focuses on the fundamental and operation of networks, while the latter focus on the foundation of computer networks through a more rigorous approach. The resulting model provides a strong foundation of computer networks where topics are systematically reinforced through hands-on activities, providing students with skills needed by the job market. Additionally, students benefit from a critical methodology in approaching problems required by further advanced studies in the academia. Thus, the model combines best practices of university and technical types of curricula, closing the gap between both environments. The proposed model also contributes to stimulate the under-explored area of computer networks in computing disciplines. By exposing students to hands-on networking topics starting during their freshman year, the model helps in attracting students to this area and in improving recruitment and retention, as we shall see in next sections. As a result, students get engaged on the second fastest predicted growing occupation among more than 1,000 occupations in the U.S. for the years 2008-2018 [9]. Table I shows some technical occupations and predictions for them for that period. Note the projection for computer networks (network systems and data communications).

The proposed model also targets retention, breaking up long-term goals (e.g., obtaining a bachelor degree) into milestones, where a milestone can be the completion of the 4 courses in the area of computer networks. By doing so, the model provides a safety net to students, who are able to acquire skills demanded by the job-market early during their studies. Moreover, the program helps in avoiding high dropout rates during early semesters, where institutions have historically experienced higher dropout rates because of lack in incentive for students and limited hands-on experience. The model is also articulated with the 2008 ACM and IEEE Computer Society Guidelines for Engineering Information Technology, and enables students to achieve multiple program outcomes mentioned in the ABET criteria. Results of the implementation of the computer networks education model in a minority serving institution of 2500 students composed of 73% of Hispanics, 11% Native American students and 16% others are shown.

Table I. Employment by occupation, 2008 and projected 2018 (numbers in thousands) [9].

2008 National Employment Matrix	Employment				Change, 2008-18		Openings
	Number		Percent distribution		Number	Percent	
	2008	2018	2008	2018			
Computer programmers	426.7	414.4	0.28	0.24	-12.3	-2.87	80.3
Computer software engineers, applications	514.8	689.9	0.34	0.41	175.1	34.01	218.4
Computer software engineers, systems software	394.8	515.0	0.26	0.30	120.2	30.44	153.4
Computer systems analysts	532.2	640.3	0.35	0.38	108.1	20.31	222.8
Database administrators	120.4	144.7	0.07	0.08	24.4	20.26	44.4
Network and computer systems administrators	339.5	418.4	0.22	0.25	78.9	23.23	135.5
Network systems and data communications	292.0	447.8	0.19	0.26	155.8	53.36	208.3
All other computer specialists	209.3	236.8	0.13	0.14	27.5	13.14	72.6
Computer hardware engineers	74.7	77.5	0.04	0.04	2.8	3.77	23.5
Electronics engineers, except computer	143.7	144.1	0.09	0.08	0.4	0.31	33.4

The rest of this paper is organized as follows. Section II reviews traditional models for computer networks education, and Section III presents the proposed model implemented at our institution. Section IV describes the infrastructure support for the proposed model, and Section V shows preliminary results and the impact on enrollment and retention of the proposed model. The paper concludes with Section VI.

II. Traditional models of computer networks education

Traditional computing disciplines curricula include an introductory course in computer networks during the senior year. Figure 1 shows the pre-requisites for such course, in a computer engineering program in a university in our state. Similar programs are found across the word. A student is required to take more than 45 credits before he is *prepared* for the course. In order to analyze this type of introductory course, we will refer to a typical book used in such a course, entitled *Computer Networking* by Kurose and Ross [3].

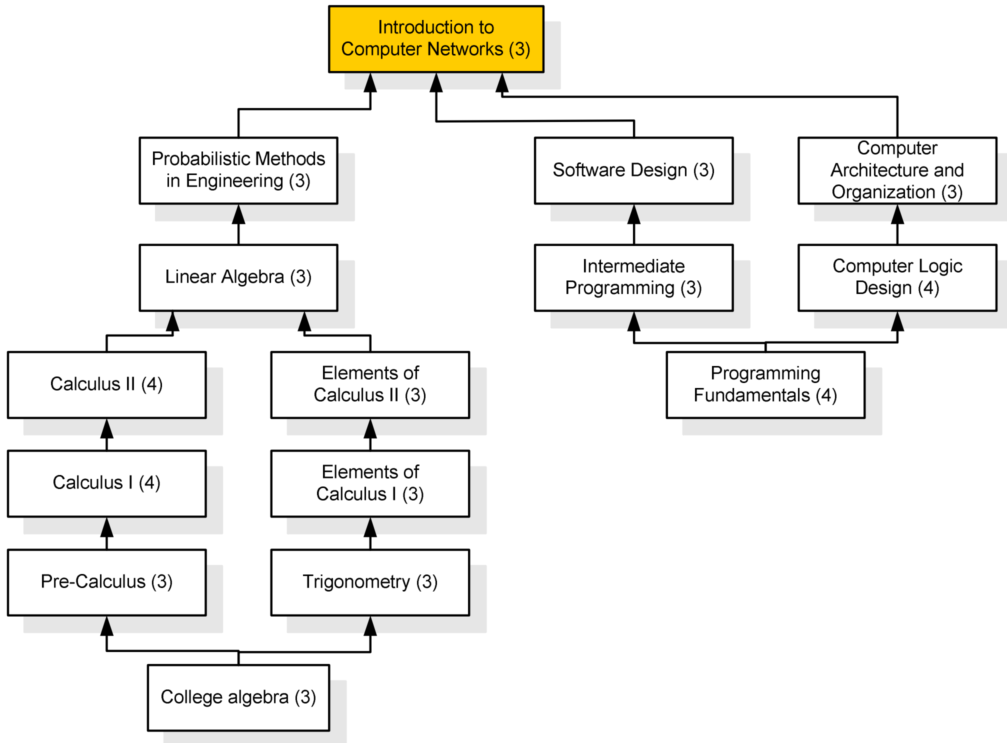


Figure 1. Typical pre-requisites for an introductory computer networks course in a computing discipline. The numbers in parenthesis refer to credit hours.

The first question that arises is whether or not students need the pre-requisite knowledge shown in Figure. 1. To answer this question, we will refer to the Preface of [3], under the audience section, where the authors state the following:

It (the book) rarely uses any mathematical concepts that are not taught in high-school. We have made a deliberate effort to avoid using any advanced calculus, probability, or stochastic process concepts. The book is therefore appropriate for undergraduate courses...
In terms of programming, the book assumes the student has experience with C, C++, or Java, and even then only in few places.

According to the Preface of [3], pre-requisites on the left of Figure 1 may then be lifted. Or, a program may include a course in college algebra as pre-requisite of introduction to computer networks. Referring to the programming knowledge at the right hand side of Figure 1, authors of [3] clearly state that programming concepts are using only in few places. Thus, an alternative model may be tailored based on these two observations. Additional books used in introductory courses are listed in Table II.

Table II. Typical text books used in a computer networks course.

Book (Ref.)	Mathematical requirements	Programming requirements	Other requirements
3	Minimum (College Algebra)	Minimum (some chapters include a programming assignments using sockets)	State machines, binary system and operations
4	Medium	Minimum (Chapter 3 includes source code of data link layer protocol principles)	State machines, binary system and operations
5	Medium	Medium (some concepts explained with C code segments, lab experiments with OPNET simulator)	State machines, binary system and operations
6	Minimum (College Algebra)	Minimum (no programming material, except for a socket application in the appendix. Some pseudo-code examples)	No
7	Minimum (College Algebra)	No	No

Although the books cited above are used in upper-level undergraduate courses, they may be classified as survey-type of books, which do not emphasize analytical aspects that may require more advanced mathematics knowledge. [4] includes, only in few sections, more advanced mathematical concepts (e.g., Fourier analysis, used to explain bandwidth-limited signals at physical layer; Poisson probability distribution, used to analyze the throughput performance of ALOHA systems; modulo operations, used to explain the operation of Public-Key algorithms; and binary operations). [5] includes binary and modulo operations. Additional tools of [4, 5] are state machines, mostly to model TCP behavior. Despite these more advanced knowledge topics required in few sections of [4] and [5], the texts listed in Table IV answer the basic question of *how do computer networks and internets operate?* in the broadest sense [6]. Main principles and concepts are explained in a logical manner without using sophisticated mathematics or providing mathematical proofs. Additionally, programming exercises are mostly complementary and de-attached from the texts. Perhaps that main reason of placing an introductory course with multiple pre-requisites is the multiple topics involving computer networks. For example, binary system is certainly essential for multiple reasons: IP addressing, binary operations used thoroughly (e.g., cryptography, subnetting, routing, etc.), state machines, and others.

We believe that for an introductory course teaching how networks operate, these essential topics can be incorporated in the course. This teaching concept is not new, and was implemented in mechanical engineering programs under the name Wright State Model [10]. Similar to [10], our resulting model shifts traditional emphasis on *pre-requisite requirements* to an emphasis on engineering motivation for those pre-requisites, with a just-in-time structuring of them. Additionally, the model uses an industrial application-oriented, hands-on approach, to address computer network concepts that are traditionally taught theoretically, at an abstract level. The model enriches the CEP [2] with a critical methodology of approaching problem, based on main networking principles. Advanced topics are also added to CEP, constituting an innovative model to teach computer networks. We believe that this model will contribute in engaging and forming new computer networks professionals in computing disciplines, which are and will be greatly needed in a near future, as demanded by the Department of Labor according to its predictions summarized in Table I.

III. Proposed Model

The proposed model includes 4 courses in computer networks, starting during the freshman year. The rationality of this model spans through our Information Engineering Technology curriculum, which is implemented following a *pillars first* approach. The pillars of an Information Engineering Technology program are programming, networking, human-computer interaction, databases, and web systems [1]. This approach introduces the details of the Information Engineering Technology pillars first (early during program of studies) and provides the integration later in the curriculum. Introductory courses to each pillar, such as Introduction to Computer Networks, Computer Programming Fundamentals, and Introduction to Engineering, have no pre-requisites and are taken during the freshman year. These courses give students a detailed, complete view of each of these knowledge areas on their own. Additionally, the courses extensively expose freshman students to hands-on activities and simple engineering design, which helps engaging and motivating students to persist in the program.

The computer networks courses are: *Introduction to Computer Networks*, *Routing*, *Switched and Wireless Networks*, and *Advanced Networking*. The courses combine instructional material from the Cisco Exploration Program with well-known academic materials such as [3, 4, 5, 6, 7, 8] used in traditional 4-year institutions. Figure 2 shows the articulation of computer networks courses in our institution. In contrast with Figure 1, the course *Introduction to Computer Networks* is offered as a 100-level course with no pre-requisites. Freshman students additionally take *Programming Fundamentals*, *College Algebra* (some students are already at Calculus level), and *Introduction to Probability and Statistics*. Therefore, by the time they enroll in *Routing* they already have C programming, probability and statistics fundamentals, and college algebra or higher knowledge.

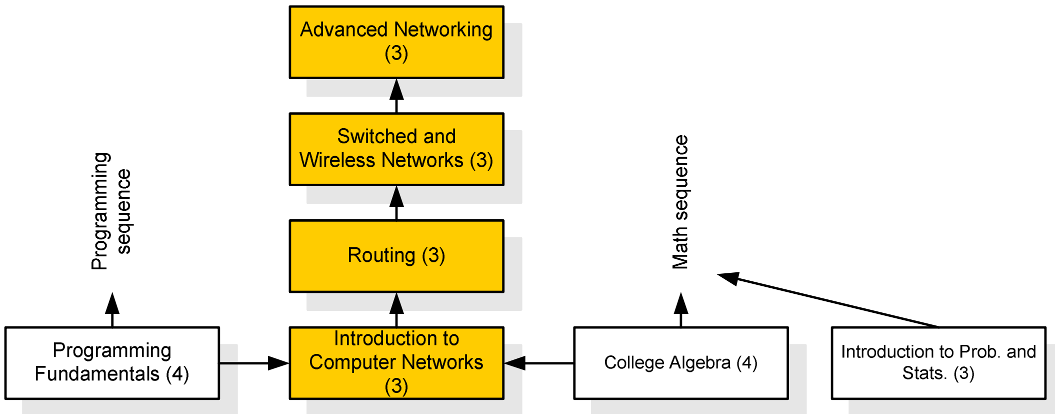


Figure 2. Articulation of computer networks courses at our institution.

A. Introduction to Computer Networks

Content and outcomes

The introductory course in computer networks is intended to answer the question *how do networks operate?*. Topics include OSI and TCP/IP models, nodes and links, LAN, WAN, inter-networks, bandwidth, throughput, components and architectures, layer functionality, protocols, encapsulation principle, and services to the upper layer. The base text book is [11], which is used in the first course of the CEP. The book consists of 11 chapters that cover each layer on a top-down approach. Additional material is extracted from [4, 5, 6, 7].

Introduction to Computer Networks presents opportunities for formative assessment, providing immediate evidence of student learning outcomes and level of engagement of students. Multiple course outcomes adapted from ACM and IEEE Computer Society Guidelines [1] can be mapped to ABET Technology Accreditation outcomes, as shown in Table III. ABET outcomes for the Technology Accreditation Commission (TAC) are listed in the Appendix.

Activities example

Each layer is approximately covered in 2 weeks (4 class sessions), where 1 or 2 lab sessions are held. Additional activities per layer include an online 20/25-question quiz to be completed in a window of time of 60 minutes, and a homework assignment with approximately 10 questions from [4, 5, 6, 7]. One or two questions are simulation or hands-on exercises. Below we give sample activities covering the network layer.

Table III. Outcomes of *Introduction to Computer Networks* and mapping to ABET outcomes.

Course outcome	ABET outcome 1	ABET outcome 6	ABET outcome 12	Activity & Tools
Use OSI, TCP/IP and Internet models as they apply to contemporary communication protocols.				Homework assignment, quizzes, exam questions.
Configure and analyze a client/server application such as email, and analyze data exchange used by the application; e.g., SMTP/IMAP.	X			Hands-on lab assignment. Email server using SMTP, standard IMAP client, and Wireshark.
Analyze the services and operation of the transport layer, including TCP mechanisms for reliable service and UDP best effort.	X			Hands-on lab assignment, Wireshark traffic analysis, Client-server application using TCP and UDP (e.g., FTP and TFTP). Netstat.
Analyze the services and operation of the network layer, including IP mechanisms for fragmentation, reassembly, multiplexing & demultiplexing, best effort service, and routing principles.	X			Hands-on lab assignment. Wireshark, inspection of routers.
Analyze the services and operation of the data link layer, including point-to-point and multi-access protocols and mechanisms for error-detection and multiplexing & demultiplexing.	X			Hands-on lab assignment. Network topology including PPP and multi-access (Ethernet) networks.
Explain components and media of computer networks, and empirically measure attributes of the latter such as bandwidth and latency.	X	X	X	Hands-on lab assignment. Network topology including different layers 1 & 2 technologies and transmission rates. Ping and traceroute.
Deploy and operate an inter-network composed of WANs and LANs.	X	X	X	Final project. Equipment per team: 2 end devices, 2 switches, and 2 routers with layer 2 Ethernet and PPP capabilities

Lab assignment example

Figure 3 shows the network topology used for a lab assignment where students work in groups of two (a pod per group). Students have to analyze IP behavior by encapsulating Internet Control Message Protocol (ICMP) packets on top of it. ICMP is also studied by using commands that generate ICMP packets such as *traceroot* and *ping*. For example, *traceroot* is a real-time command that shows the path from a source device to the destination, including the latency to each hop along the path. One of the multiple questions is the investigation of link latency along the source node (a station in a pod) to the server. Students have to derive the estimated latency, analyze ICMP and how IP encapsulates ICMP through an IP header analysis.

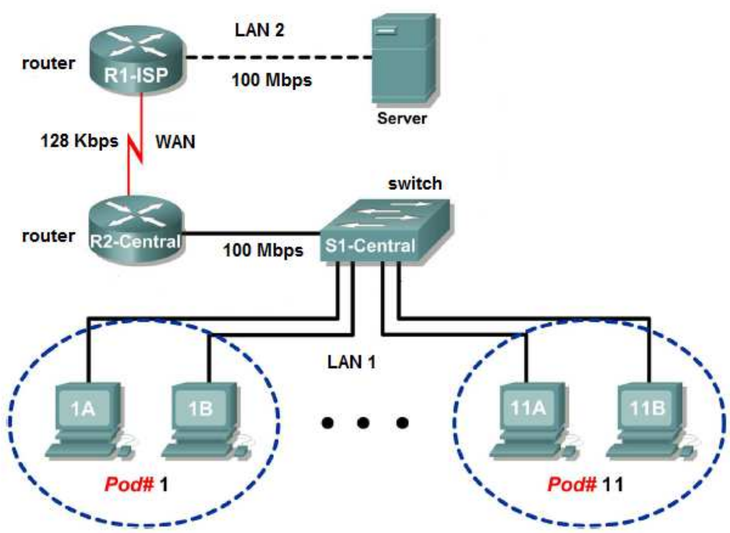


Figure 3. Lab setting.

Homework assignment example

Homework assignments included around 15 exercises adopted and adapted from [4, 5, 6, 7]. The following is an example adapted from [5], Chapter 4:

"Consider the network shown in Figure 4. The network layer at node A receives 4000 bytes from the transport layer, to be sent to node B. Assume that the MTU (in bytes) of the copper Ethernet network, copper serial network, optical fiber network, and copper Ethernet network is 10000, as shown in the figure. Assume also that the final hop, the wireless network, has an MTU of 1420. (a) How will the transfer happen in each router? (b) Explain also, in detail, what R4 will do, including fragmentation process, number of fragments, and fragmentation offset field in the IP packet/s."

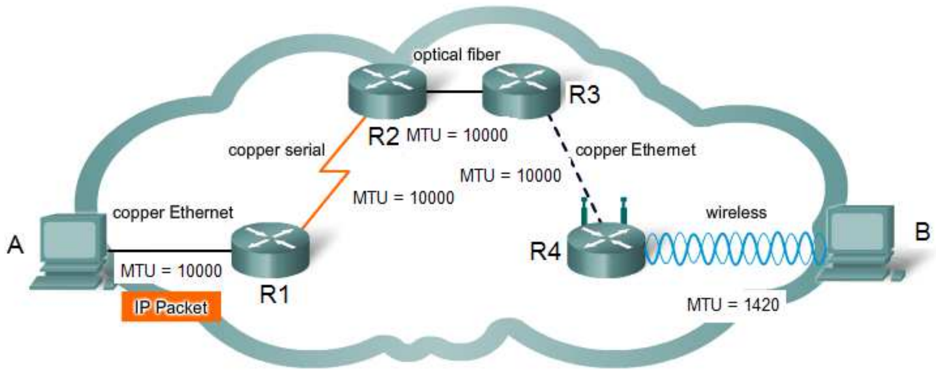


Figure 4. Exercise reinforcing the media independence characteristic of IP, fragmentation and encapsulation processes.

A second example is an extension of an exercise listed in [4], Chapter 5:

"Use the tracert program in Windows (from the command line) to trace the route from your computer to the following Tokyo university: www.u-tokyo.ac.jp. Answer the following questions: (a) draw the path from your computer to the Tokyo university. Include the latency of each link of the path. (b) Identify any intercontinental link. Is there any relevant characteristic on this link? Justify your question."

B. Routing

Content and outcomes

Routing is one of the main tasks of the network layer, which in turn is one of the most complex layers in the protocol stack. Due to its importance, *routing* has been included in the 2008 ACM and IEEE Computer Society Guidelines for Engineering Information Technology [1] as a fundamental unit in the body of knowledge belonging to the networking track. Additionally, CEP includes a course in *Routing Concepts and Protocols* as part of the program.

The *Routing* course offered at our institution is based on *Routing Protocols and Concepts* of CEP. The base text book is [12]. However, it is substantially complemented with material from [4, 5, 7]. The course covers interior gateway routing and includes both intra-domain static routing and dynamic routing protocols. Students study how routers discover remote networks and determine the best path or paths to them. They design addressing schemes and deploy WANs, LANs and inter-networks using static routing as well as RIPv1, RIPv2, EIGRP, and OSPF protocols. Based on these protocols, students identify the characteristics of distance vector and link state routing protocols. They learn fundamental tools for routing scalability and design hierarchical routing schemes with OSPF (multi-area). Students apply traffic engineering schemes using Equal Cost Multi-Path (ECMP). Table IV shows the adopted outcomes and the mapping to ABET TAC outcomes for summative assessment.

Table IV. Outcomes of *Routing* course and mapping to ABET outcomes.

Course outcome	ABET outcome 3	ABET outcome 4	ABET outcome 11	ABET outcome 16	Activities & Tools
Identify the characteristics of distance vector and link state protocols, analyze their rate convergence and advantages and disadvantages.			X		Homework assignment, quizzes, exam questions.
Designing and implementing a classless IP addressing scheme with static routing and RIPv2 protocol.			X		Hands-on lab assignment. Lab testbed. Simulation assignment. Homework assignment, quiz, exam questions.
Demonstrate comprehensive EIGRP and OSPF skills to design and deploy single and multi-area (hierarchical) classless networks.		X	X	X	Hands-on lab assignment. Lab testbed. Simulation assignment. Homework assignment, quiz, exam questions.
Demonstrate comprehensive traffic engineering skills, and implement basic schemes using equal-cost multi-path routing with OSPF and proportional traffic engineering with EIGRP.	X	X	X	X	Hands-on lab assignment. Lab testbed. Simulation assignment. Homework assignment, quiz, exam questions

Activities example

The course starts with fundamentals of routing and forwarding, followed by static (non-adaptive) routing, where routers do not base their routing decisions on measurements or estimates of the current traffic and topology but in off-line decisions set statically. The course continues with general distance vector protocols fundamentals and implementations (RIP and EIGRP). Then, link state protocols are studied and OSPF implementations in single-area and multi-area (hierarchical) settings. Multi-path traffic engineering is covered along the course as protocols are studied (EIGRP, RIP, and OSPF). The course follows the sequence of the base text book.

The course is structured in the following manner. A topic is presented in one or two lecture sessions of 75 minutes, followed by an in-class hands-on assignment, a hands-on simulation assignment, an online 20/25-question quiz, and a homework assignment with approximately 10-15 questions mostly from [4, 5, 7]. The following example illustrates some activities used to teach a topic, OSPF.

Lab assignment example

This lab assignment example covers hierarchical routing using OSPF. Students have to create an internet consisting of 2 LANs and 3 WANs interconnected by 4 routers, as shown in Figure 5. The routing scheme requires the internetwork to be divided into 3 routing areas, which are interconnected by a backbone area. Routing information is propagated using OSPF.

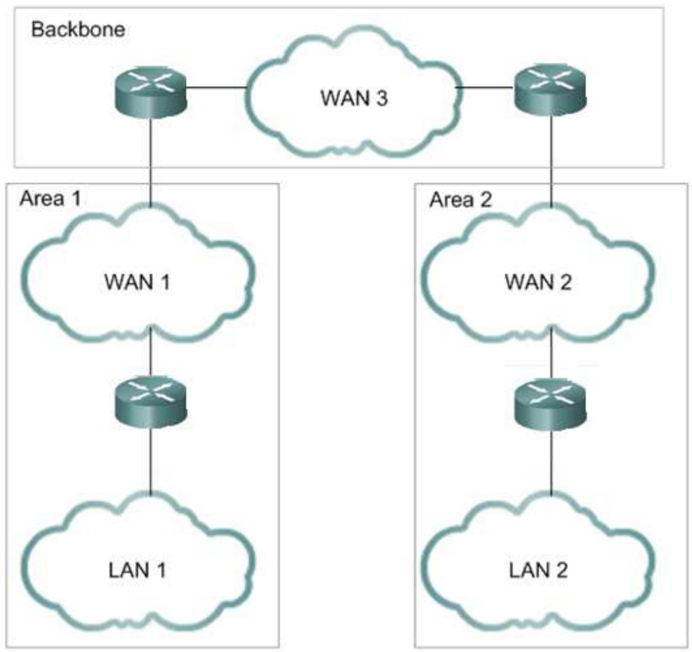


Figure 5. Hierarchical routing lab example.

We use the above lab assignment (and similar ones) to measure several student learning outcomes. Since the multi-area OSPF assignment is given after students implement single-area routing with distance vector (RIP) and link state (OSPF) protocols, students are able to analyze previous experiments and compare results in terms of rate converge (OSPF demonstrate much faster convergence rate than RIP) and scalability (multi-area routing is much more efficient for larger networks). Students are then able to measure the improvements in routing processes (ABET outcome 3); at the same time they apply creativity on how different areas advertise routing information (ABET outcome 4). Other lab assignments are also suitable for different outcomes such as ABET outcome 16 (ability to apply discrete math). We use an EIGRP lab assignment to measure ABET outcome 16; EIGRP is a routing protocol which permits proportional traffic engineering through multiple paths. The tool students apply for this purpose is graph theory, by which they have to model the network as a graph and assign precise costs to links to satisfy load balancing requirements. A quality design rubric is used to evaluate students work. For ABET outcome 11, we consider the regular 20/25-question quiz assignments (one per week) given to students. With a cycle assessment rubric, we evaluate performance, commitment to take the quizzes on time (students are given a window of time of approximately 24 hours per quiz), and continuous improvement during the semester.

Homework assignment example

Students are given approximately 8 homework assignments during the semester (one every two weeks). Homework assignments are used to reinforce main concepts, explore new routing schemes found in the literature, and further studies of issues. The following example illustrates a homework assignment exercise, which is additionally used to describe the importance of appropriate link costs adapted from [18].

"Consider the diamond-shaped OSPF network shown in Figure 6, where ECMP is enabled. The OSPF metric is set to 1 for each link. The link capacities are shown over each link. Assume a traffic flow of 80 from node 1 to node 4. The average packet delay on a link is given by 1/(C - F), where C is the capacity of the link, and F is the traffic over the link. (a) What is the average packet delay from source node 1 to destination node 4? (b) Suppose the network engineer decides to increase the capacity of the network by adding a new direct link, as shown in Figure 6(b). The engineer sets the OSPF cost of the new link to 1, as in the other links. (b) What is the new average packet delay from source node 1 to destination node 4? (c) What can you conclude from part (b)? (d) If there is potential improvement in term of average delay, propose an OSPF solution."

The above exercise permits students to understand that, even if the network capacity is increased, latency can increase if link costs are not properly set. In general, resources added to a network should be coordinated with proper configuration and settings. This exercise is also an application of discrete mathematics (ABET outcome 16).

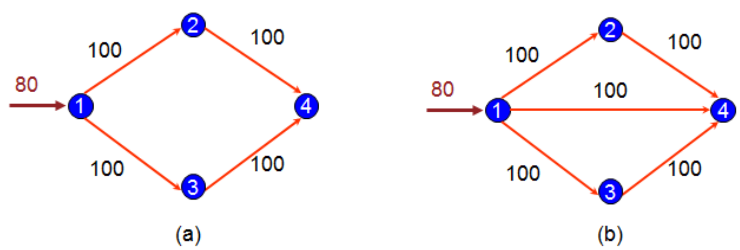


Figure 6. Network topologies for exercise example.

C. Switched and Wireless Networks

Content and outcomes

Switched networks are gaining attention because of the high bandwidth and deployment flexibility they offer (for basic functionality, switches do not require any configuration). They dominate LANs and new features and standards added to them such as virtual LANs (VLANs) permit the design of networks (campus, enterprise, etc.) based only on switches. For example, currently is possible to design an entire network without the use of a router; even routing functionality to connect different networks may now be performed by layer 3 switches. This trend is reflected in the 2008 ACM and IEEE Computer Society Guidelines for Engineering Information Technology [1], where switching is listed as a unit in the body of knowledge of networking. CEP also includes a course in *LAN Switching and Wireless* as part of the program.

The course offered at our institution is based on the book by Peterson and Davie [5] and *LAN Switching and Wireless* of CEP. The base text books are [5, 13]. As the rest of the courses, it is complemented with material from [4, 5, 6, 7]. The course provides an understanding of how switches operate and are implemented in the LAN environment for small and large networks. Beginning with a foundational overview of layer 2 functionality and Ethernet, the course gives detailed explanations of the operation of LANs based on switches, VLAN implementation, and associated protocols used to avoid loops (e.g., STP, RSTP) and disseminate VLAN information (VTP). The course also covers the approaches used for inter-network communication. The course ends with an in-depth study of 802.11 wireless networks, state-of-the art networks (mesh networks and 802.16) and routing protocols for multi-hop wireless networks extracted from the research literature; e.g., [14, 15]. Table V shows the adopted outcomes and the mapping to ABET TAC outcomes for summative assessment.

Activities example

The course starts by reviewing functions of the data link layer, Ethernet protocol, LAN devices and fundamentals concepts such as broadcast and collision domains and implications. Then, VLANs are introduced and implemented, followed by trunking, spanning tree protocols to avoid layer 2 loops, and inter-network communication. The course continues with fundamentals of wireless (e.g., wireless medium, Shannon's law, wireless links characteristics and path loss models) and 802.11 infrastructure and ad hoc networks. Finally, security and routing protocols for multi-hop wireless networks are studied. The course follows the sequence of the text book [13]. The structure of the course is similar to the courses presented in previous sections: a topic is presented in one or two lecture sessions of 75 minutes, followed by an in-class hands-on assignment, a hands-on (homework) simulation assignment, an online 20/25-question quiz, and a theoretical homework assignment with approximately 10/15 questions mostly from [4, 5, 6, 7, 14, 15]. The following example illustrates some activities used to teach the topic spanning tree protocols.

Table V. Outcomes of *Switched and Wireless Networks* and mapping to ABET outcomes.

Course outcome	ABET outcome 2	ABET outcome 6	ABET outcome 14	Activities & Tools
Describe and design hierarchical switched-LANs.		X	X	Homework assignment, quizzes, exam questions.
Use traffic analysis tools such as TTCP and TCPDump to evaluate wireless and switched networks performance.		X		Hands-on lab assignment. Lab testbed. Simulation assignment. Homework assignment, quiz, exam questions.
Describe Dijsktra's algorithm modifications to efficient routing operation in multi-hop wireless networks.	X			Hands-on lab assignment. Lab testbed. Simulation assignment. Homework assignment, quiz, exam questions.
Use 802.1Q standard for trunking on inter-switch connections.		X		Hands-on lab assignment. Lab testbed. Simulation assignment. Homework assignment, quiz, exam questions
Implement and operate 802.11 wireless networks in infrastructure (BSS, ESS) and ad hoc (multi-hop mesh) modes.	X	X	X	Hands-on lab assignment. Lab testbed. Simulation assignment. Homework assignment, quiz, exam questions

Lab assignment example

The following example tests the ability of students to identify, analyze and solve a switched network design problems using knowledge of different protocols (MSTP, VTP, 802.1Q) and techniques to balance the traffic through multiple trees (ABET outcome 6).

"High-speed LANs rely on switching capability at layer 2. A robust design of high-speed LANs includes redundancy by introducing loops in the physical network topology. However, logical loops must be avoided. Proper designs should prevent logical loops without wasting resources, by implementing load balancing schemes. Consider the network topology shown in Figure 7, and the VLANs attached to switch S2 as listed in Table VI. The four VLANs produce similar amount of traffic which must have S1 as egress switch. Provide a multi-tree solution that balances the load in the network. Automate the VLAN management with VTP protocol. Describe your design, including an introduction, problem you want to solve, your proposed approach, implementation (demonstrate your design to the instructor), performance metric, and conclusion."

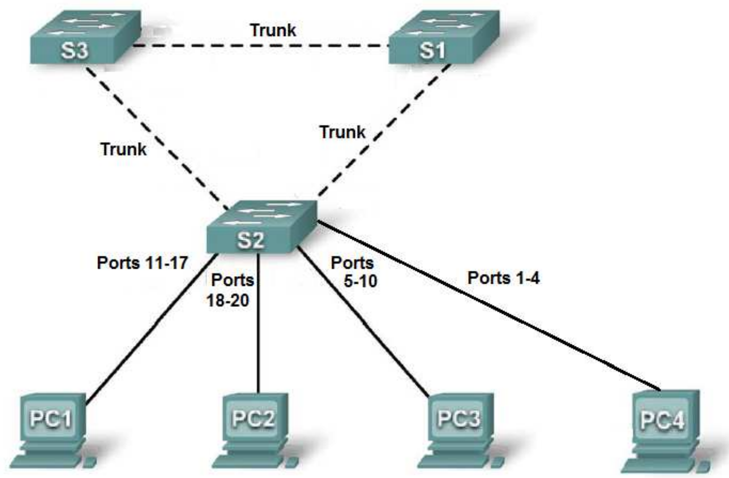


Figure 7. Network topology for lab assignment.

Table VI. VLANs in network of Figure 7.

VLAN Name	Ports
Students	1-4
Faculty	5-10
Lab	11-17
Staff	18-20

Homework assignment example

Students are given approximately 8 homework assignments during the semester (one every two weeks). The following example, extracted from [14], illustrates a homework assignment exercise, which is additionally used to test the ability of students to apply current knowledge (Dijkstra's algorithm) and adapt to emerging applications (mesh networks) (ABET outcome 2).

"Consider Figure 8, where nodes have IEEE 802.11 wireless capability and operate at the 2.4 GHz band. Nodes operate in ad hoc mode. (a) Provide the connectivity graph, showing the wireless links. (b) Assuming that all nodes are tuned to channel 11, what is the maximum throughput for a flow with source node C and destination node A? (c) If node B has two IEEE 802.11 interfaces, can you improve the throughput of the previous flow? Explain your answer."

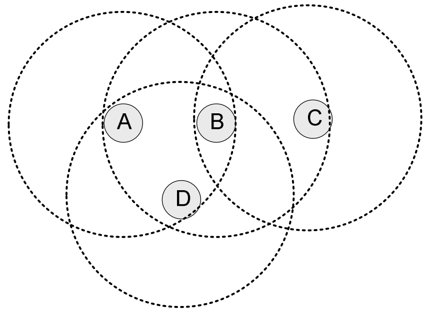


Figure 8. Wireless nodes and their respective transmission ranges.

Simulation assignment example

Figure 9 illustrates a simulation assignment example (homework). Students have to deploy the network in a network simulator and apply skills on VLANs and VTP, optimizing STP, enabling inter-network communication (VLAN routing), integrating wireless connectivity and implement security mechanism in both wireless (WPA2) and wired networks (port security at switches). This integrative assignment represents a good opportunity for multiple ABET outcomes assessment, including all outcomes listed in Table V.

D. Advanced Networking

Content and outcomes

We introduce more flexibility in this last course. The course covers several topics and includes a large project assignment. Besides the required topics, students additionally learn extra-materials based on their project assignments.

The course includes all topics from the *Accessing the WAN* from CEP, plus an extended set of topics such as MPLS, traffic engineering, and network programming. Reference textbooks are [5, 6, 8]. Wide area networks are in-depth studied. Additionally, required topics cover the following units of the knowledge area of networking considered fundamental by the 2008 ACM and IEEE Computer Society Guidelines for Engineering Information Technology [1]: Security, Network Management, and Applications.

WAN topics are: layer 2 WAN protocols, lab deployment of HDLC and PPP, virtual circuit and connection oriented technology, frame relay lab deployment.

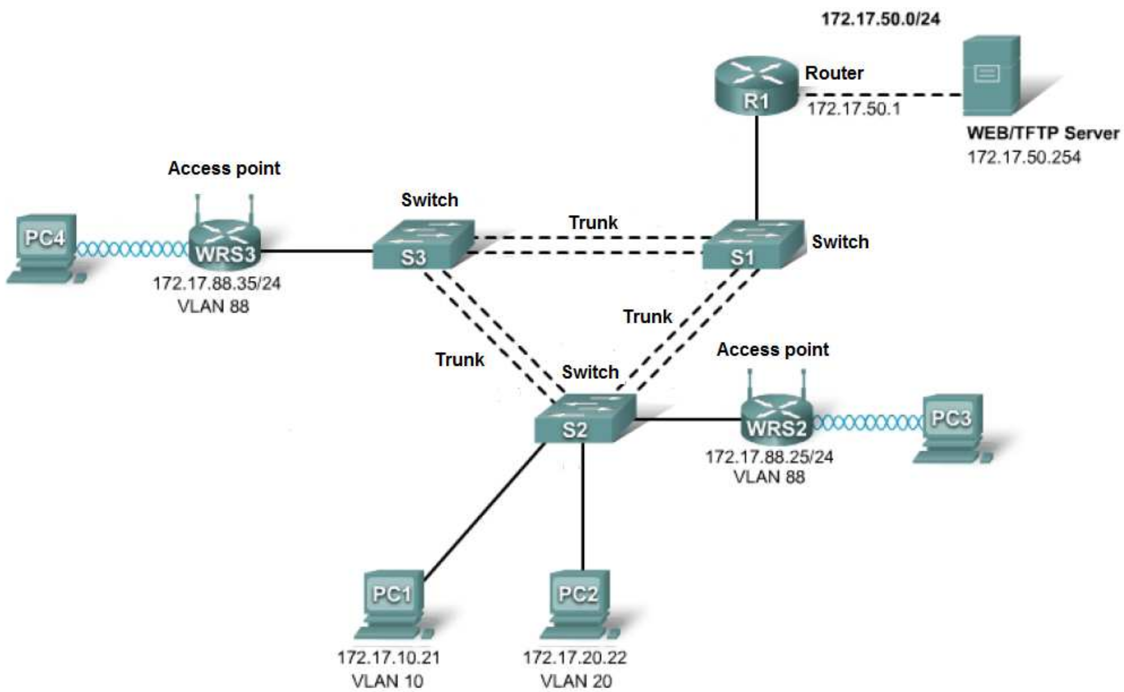


Figure 9. Simulation lab assignment.

Security topics are: principles of cryptography, symmetric and public key encryption, authentication, integrity, principle of message digests, lab experiments using MD5 for routing protocols authentication in distributing routing tables, attacks and countermeasures, packet filtering and Access Control Lists (ACLs) implementations.

Network Management topics are: IP management and services, DHCP, ARP, and Relay ARP lab deployment, NAT, NAT overload, port forwarding and static NAT, traffic management and traffic engineering with MPLS.

Application topics refer to network programming at application level using sockets API. Experiments include multi-processes and multi-threads server implementations, protocol design experiments using emulation gateways, and implementation of a simple peer-to-peer network. Network programming is based on [8].

Table VII shows the adopted outcomes and the mapping to ABET TAC outcomes for summative assessment. Since *Advanced Networking* is a 400-level course, where students already accumulate substantial knowledge from previous courses, the course is used to assess multiple outcomes.

Table VII. Outcomes adopted for the course *Advanced Networking* and mapping to ABET outcomes. All outcomes are supported by hands-on lab assignments, quizzes, and homework assignments.

Course outcome	**ABET outcome 1**	**ABET outcome 2**	**ABET outcome 4**	**ABET outcome 6**	**ABET outcome 12**	**ABET outcome 14**	**ABET outcome 16**
Implement point-to-point WANs using HDLC and PPP.	X			X			
Describe and implement secure WANs using Challenge Handshake Authentication Protocol (CHAP) and Password Authentication Protocol (PAP).	X	X				X	
Implement a connection-oriented network – Frame Relay (FR)–, including permanent virtual circuits and reachability issues with RIP.		X		X			
Explain fundamental concepts of integrity, confidentiality, authentication, and non-repudiation.							
Deploy a network using OSPF as routing protocol and Message Digest 5 authentication for routers to exchange routing information updates.		X				X	
Implement Access Control Lists (ACLs), including defining filtering criteria, verifying, monitoring and applying them to protect networks.				X		X	
Manage and provide IP services, including DHCP and NAT.					X		
Implement traffic engineering schemes with MPLS.	X	X	X	X	X		X
Create applications (client-server and peer-to-peer) capable of handling multiple requests simultaneously.	X		X	X	X		

Activities example

Advanced Networking covers WANs fundamentals, protocols, and technologies used by this type of network. HDLC is the main point-to-point layer 2 protocol for WANs and is the basis in which newer protocols such as PPP were designed. Thus, the course covers HDLC. PPP is also studied, along with its authentication mechanisms and components. Another layer 2 technology for WANs is Frame Relay. WANs topics are extracted from [16]. Security topics include the fundamentals of confidentiality, integrity, authentication and non-repudiation, based on Chapter

8 of [3] and Chapter 5 of [16]. Innovations here include topics such as ACLs from [3] that are implemented through hands-on assignments in routers by using Cisco Internetwork Operating System (IOS). Network management topics including traffic engineering using MPLS are based on [17, 18]. Network programming material is extracted from [8].

Lab assignment example 1

The following example illustrates a network management lab assignment that must be implemented by students and integrates multiple knowledge areas.

"Consider the network shown on Figure 10. Nodes 1, 2, and 3 represent routers running OSPF as routing protocol. The capacity of links among routers is also shown in the figure. Assume that end users are attached to a LAN connected to router 3. End users generate an aggregated traffic of 100 Kbps, addressed to the Internet. As a network engineer, your goal is to minimize the maximum link utilization. The utilization of a link is defined as the ratio between the traffic flowing through the link and the capacity of that link. Thus, the objective can be stated as:

$$\text{Minimize the maximum among } \frac{f_{12}}{c_{12}}, \frac{f_{13}}{c_{13}}, \frac{f_{23}}{c_{23}}$$

where f_{ij} and c_{ij} denote the traffic and the capacity of link *ij*. Explain your solution."

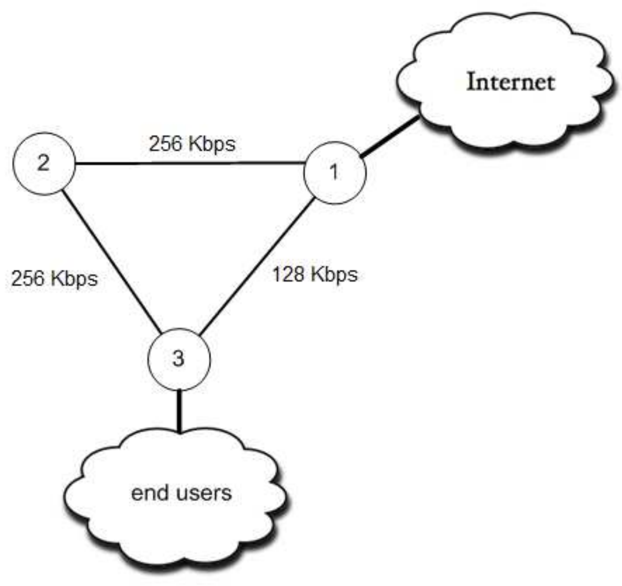


Figure 10. Hands-on lab assignment.

The above assignment integrates knowledge from applied mathematics, routing, traffic engineering and network management. The objective is to keep the link load over link capacity ratio as low as possible. To start with, students have to model the problem mathematically (ABET outcome 16) and solve it using linear programming and an appropriate tool such as LPSOLVE [19] (ABET outcome 1). Figure 11 shows a snapshot of the linear program formulation by a student and respective solution. Students, thus, need to apply math knowledge to an emerging application as traffic engineering / MPLS (ABET outcome 2). While not explicit in the specifications, students have to set dynamic routing protocol such as OSPF, which is learned in the second networking course. Then, they have to set MPLS tunnels and appropriate signaling protocol, which permit to performance traffic engineering by sending different amount of traffic through multiple paths. ABET outcomes 4, 6, and 12 can be also assessed with this lab assignment.

```
/* Objective function: minimize the maximum link
utilization */

min: a;

/* flow conservation constraints. xij is
a variable representing the amount of traffic
to be assigned through link ij. RHS equations
are given in Kbps unit. */

x31 + x32 = 100;      // source node
x21 - x32 = 0;        // intermediate node
-x31 -x21  = -100;    // sink node

/* link capacity constraint */
x31 <= 128 a;
x32 <= 256 a;
x21 <= 256 a;
```

(a)

Variables	result
	0.260...
a	0.260...
x31	33.33...
x21	66.66...
x32	66.66...

(b)

Figure 11. (a) Linear program to solve the problem given in Figure 10 (LPSOLVE [19] software package), and (b) respective solution.

Lab assignment example 2

The second example shows a network programming assignment integrated in a NAT scenario, which imposes limitations to a peer to peer application to be developed. The example can be used as a final project of the course *Advanced Networking*.

"Construct a peer-to-peer file transfer network. The network has a well-known server (with a fixed public IP address) which indexes files and locations of them. Files are stored in end users. Make sure to test your solution with a case where an end user wants to request a file located in another end user behind NAT. Specifically, you must deploy the following scenario in the lab: Antonio, a user of the network, discovers through querying to the index server that a peer user named Bob has a file it wants to download. Bob is behind a NAT whereas Antonio isn't. Bob's network performs NAT overload (i.e., Antonio cannot initiate a TCP connection to Bob). Your solution may allow, for this type of scenario, to have the index server to acts as relay. The server should spawn a different process or thread to handle the file transfer."

The above assignment represents another integrative lab assignment, where students have to master multiple knowledge areas, such as programming, operating systems concepts, and networking. Beyond the programming assignment, students have to deploy a NAT system, inter-network with respective IP addressing schemes. The assignment can be used to assess ABET outcomes 1, 4, 6, and 12.

IV. Infrastructure Support

Lab rooms

The four courses in computer networks are supported by 2 Networking Lab rooms in the Department of Engineering at our institution. Lab rooms are composed of 20 dual-booting (Windows 7 and Linux Fedora Core 15) Desktops. Figure 12 illustrates the setting of the lab rooms (left) and a picture of one of the rooms (right). Labs are composed of a work area, where students work on a Desktop. The work area is connected to a telecommunications rack, which simulates an industrial telecommunications room. The work area and telecommunications rack are connected by horizontal cables, which run from a patch panel next to the telecommunications rack to a wall jack in each work area. Connections to the devices are made with patch cables. The lab arrangement complies with the ANSI/TIA/EIA-568-B standard.

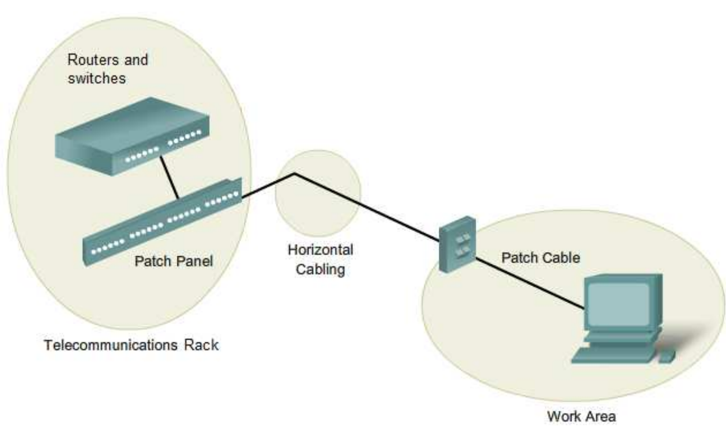


Figure 12. Networking Lab. The figure to the left shows the arrangement of the lab. The work area represents the Desktop used by students. The telecommunications rack (which simulates an industrial telecommunications room) is where students connect intermediary devices according to given specifications. The figure on the right shows a student working on a Desktop in the work area, next to the telecommunications rack.

At our institution, there are two telecommunications rack per lab room. Each telecommunications rack is composed of 9 routers and 9 switches from Cisco.

Software packages and online support

Table VIII lists the main activities of networking courses and tools to support them. Hands-on lab assignments are done with lab equipment such as routers and switches endowed with Cisco IOS. IOS is the system software in Cisco devices, which permits the user to configure the network device as needed. For simulation assignments, we use Cisco Packet Tracer, which is a network simulation program that allows students to experiment with network behavior. It provides simulation, visualization, authoring, assessment, and collaboration capabilities. Since devices used in simulations have to be configured with IOS, the simulator provides realistic environment, exactly as students would do on real-life. This permits us to enrich networking courses that otherwise are very abstract. As an example, Access Control List (ACL) or packet filtering is included in any comprehensive book in networking [4, 5, 6, 7]. However, none of these books include hands-on (either lab-based or simulation-based) examples. With Packet Tracer, we complement theoretical concepts on ACL by having Packet Tracer assignments where students implement security mechanism with ACL, exactly as they would do in real-life. Figure 13 shows a snapshot of Packet Tracer, with a network topology built on the left and a command line interface used to implement an ACL on a router (R1) on the right. The command line shows the implementation of an ACL from [3], Chapter 8.

Table VIII. List of activities of networking courses and tools to support them.

Activity	Tools	Course
Hands-on lab assignment	Lab equipment with Cisco Internetwork Operating system (IOS), Desktops with application software such as LPSOLVE, Putty, TFTP client.	All
Hands-on simulation assignment	Packet Tracer network simulator including IOS	All
Quizzes	Online Cisco website	All
Homework assignments	Theoretical questions, Packet Tracer Network Simulator	All
Hands-on network programming assignments	Linux OS with GCC C compiler, Socket API	Advanced Networking
Hands-on network programming simulation assignments	CNET network simulator	Advanced Networking

Referring back to Table VIII, quizzes are given by including CEP material into the courses. In each course, there is approximately one online quiz of 20/25 questions every 7-10 days. Quizzes reinforce theoretical knowledge presented in class hours and prepare for the Cisco CCNA certification. As part of the Cisco Network Academy, our institution has Cisco IOS software with free updates and advanced capabilities (e.g., MPLS), Packet Tracer, and quizzes and exams belonging to the CEP.

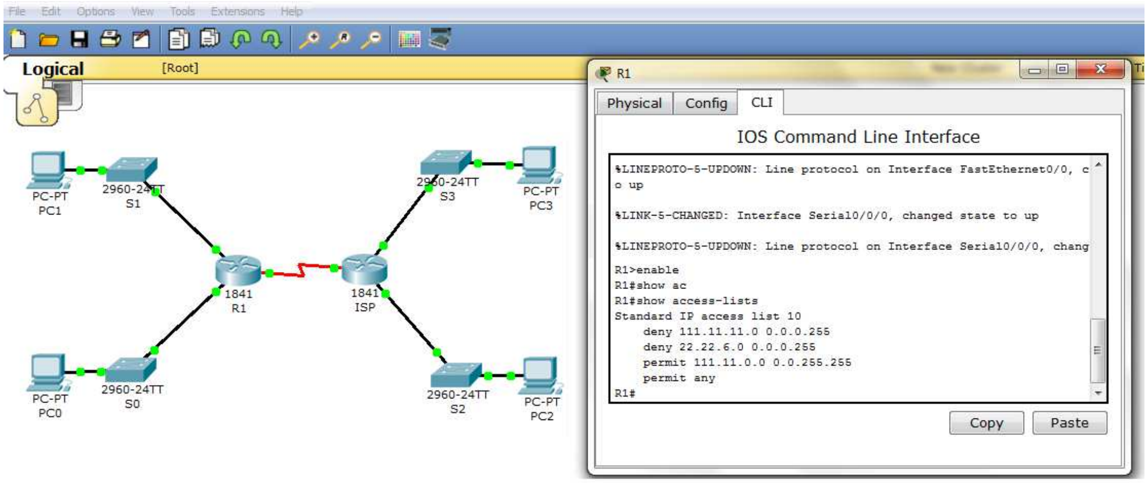


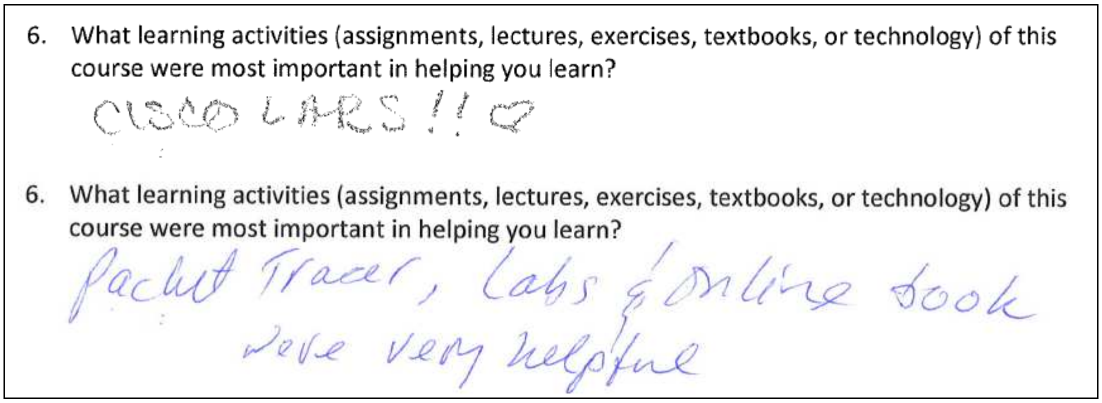
Figure 13. Snapshot of Packet Tracer network simulator.

The online component is becoming essential for the success of students and quality of the courses. With online components, students spend more time studying and reinforcing their knowledge by using their time outside regular hours (e.g., using weekend days for online quizzes and online hands-on lab sessions). Table IX shows the approximate time requirements.

Table IX. Per week activities and respective approximate time requirements for computer networks course.

Weekly activities	**Minutes**
Weekly lecture (in-class)	75
Hands-on lab session (in-class)	75
Hands-on lab session using Packet Tracer (online)	90
Online quiz (online)	60
Overall	**300 minutes**

A course including activities for 300 minutes per week is implemented much more efficiently using distance education components. Otherwise, on a face-to-face offering of 75-minute sessions, students would have to come to class 4 times per week. Clearly intensive courses like these are strongly benefited with online components. Moreover, since online activities (150 minutes per week) have strong hands-on components, students are very motivated in performing these activities. Figure 14 shows feedback samples illustrating how attractive Packet Tracer, lab and online components are for students. These types of answers were unanimous.


6. What learning activities (assignments, lectures, exercises, textbooks, or technology) of this course were most important in helping you learn?

CISCO LABS !! ♡

6. What learning activities (assignments, lectures, exercises, textbooks, or technology) of this course were most important in helping you learn?

Packet Tracer, Labs & Online book were very helpful

Figure 14. Feedback from students regarding how attractive they consider lab components, Packet Tracer, and online components.

To support network programming assignments included in the course *Advanced Networking*, Desktop computers have Linux Fedora Core 15 with GCC C compiler. As listed in Table VIII, hands-on network programming assignments use socket API, where students implement network applications that are tested in the networking lab. As alternative final projects for the Course *Advanced Networking*, we plan to include also protocols development at lower layers (data-link, wireless routing protocol, etc.) For this task, we have already experimented with CNET network simulator [20].

V. Preliminary results and impact on enrollment and retention

Introduction to Computer Networks was offered by first time in the new format during the Spring semester of 2011. Because of the high demand, it was again offered in Fall 2011.

Figure 15 shows the enrollment of this course since 2008. In the past, the course was offered approximately once per year, with an enrollment of less than 15 students. During the 2 offerings with the new model, the enrollment in consecutive semesters were 42 (Spring 2011) and 37 (Fall 2011) students.

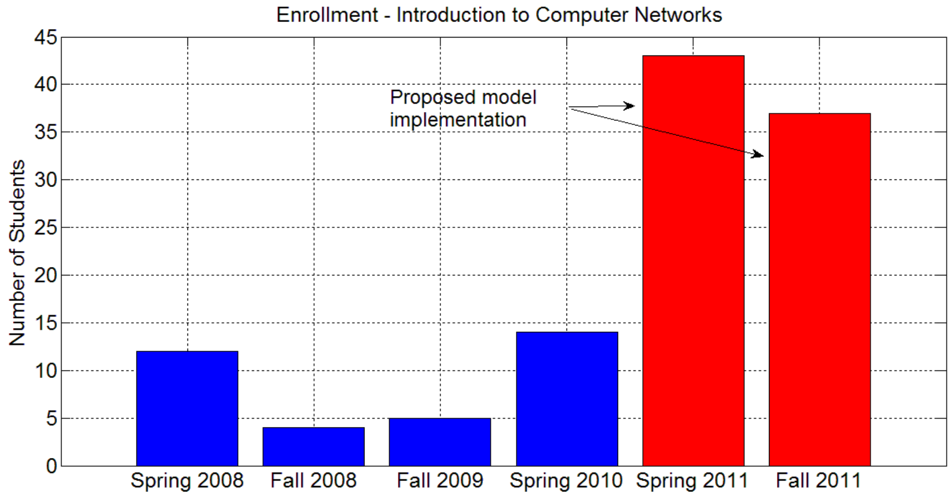


Figure 15. Enrollment of the course *Introduction to Computer Networks*.

The following two courses, *Routing* and *Switched and Wireless Networks*, were offered once each since the Spring of 2011: during the Fall and Summer of 2011 respectively. Table X shows the courses offered after implementing the model. As part of the courses, students have to take an Industrial Certification exam, which is issued by Cisco. A certified student is recognized to be very well prepared and on track for the CCNA certification [2]. A student receives a certificate if he/she has a performance of 75% or better on this exam. While the percentage of students certified in the first course (*Introduction to Computer Networks*) were only 38% on Spring 2011 and 26% on Fall 2011, those students who continue to the next courses are likely to have a very good performance; note that 6 students out of 7 student were certified on the course *Switched and Wireless Networks*, and 10 out of 14 on the course *Routing*.

Table X. Networking courses offered since Spring 2011 and students's performance.

Course	**Enrollment**	**Industrially Certified Students**
Introduction to Computer Networks Spring 2011	42	16 (38%)
Switched and Wireless Networks Summer 2011	7	6 (86%)
Introduction to Computer Networks Fall 2011	38	10 (26%)
Routing Fall 2011	14	10 (71%)

Table XI shows a performance comparison for the course *Introduction to Computer Networks* offered during the Spring semester of 2011. As part of the activities, students have 10 quizzes during the semester. The quizzes are prepared by Cisco Network Academy, and consist of 20/25 questions that have to be answered within 60 minutes. The second column presents the performance of students at our institution, and the third column the aggregate performance of the Cisco Academy students around the world. Our institution's students performance may be considered slightly higher than Cisco's students performance. To further investigate our students performance, Table XII shows a similar results but for the second course (*Routing*). Unfortunately, Cisco has no statistics available for the entire Cisco Network Academy for this course. However, Table XII shows interesting results when compared with Table XI, second column. *Routing* is considered a more advanced course. Despite this, note the better performance of students of *Routing* than that of students of *Introduction to Computer Network*. We believe that the second course is taken by highly motivated students. E.g., while the course *Introduction to Computer Networks* had an enrollment of 42 with an average quiz performance of 87.6%, *Routing* had an enrollment of 14 with an average quiz performance of 91.34. This result also supports the fact that 71% of students were certified in *Routing* while only 38% in *Introduction to Computer Networks*. Certainly only 14 students out 42 that took *Introduction to Computer Networks* enrolled in *Routing*. However, it is important to highlight that more students from this group of 42 students are just enrolling to the second offering of *Routing*, scheduled for Spring 2012. In this regard, an indicator of retention is given in Figure 16.

Table XI. Students's performance on quizzes for the course *Introduction to Computer Networks* at our (second column) and at Cisco Network Academy (third column).

Quiz	Our institution's Spring 2011 performance (%) (42 students)	Cisco Academy performance (%) (415,000 students)
Chapter 2	78.25	78.3
Chapter 3	84.3	88.4
Chapter 4	84.15	85.4
Chapter 5	84.45	84.4
Chapter 6	83.5	87.2
Chapter 7	92.05	88.6
Chapter 8	92.85	91.4
Chapter 9	91.3	86
Chapter 10	92.65	90.2
Chapter 11	92.5	80
Average per Chapter	**87.6**	**85.99**

Table XII. Students's performance on quizzes for the course *Routing* at our institution.

Quiz	Fall 2011 Performance (%) (14 students)
Chapter 1	91.3
Chapter 2	88.6
Chapter 3	90
Chapter 4	97.6
Chapter 5	89.7
Chapter 6	92.7
Chapter 7	81.3
Chapter 8	94.4
Chapter 9	92.9
Chapter 10	94.9
Average per Chapter	**91.34**

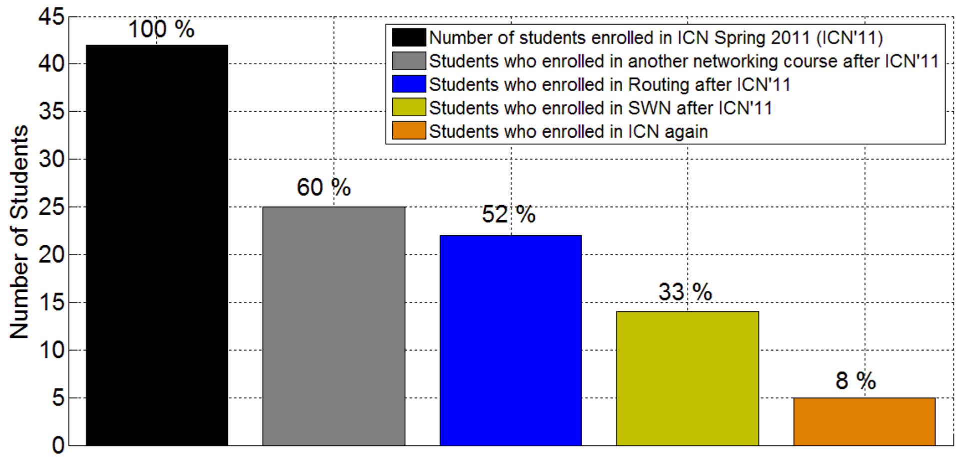


Figure 16. Retention indicators for the cohort of students who enrolled in the course *Introduction to Computer Networks* (ICN) during the Spring semester of 2011 (ICN'11). SWN refers to Switched and Wireless Networks.

The black bar in Figure 16 indicates the total number of students enrolled in the course *Introduction to Computer Networks* (ICN) during the Spring semester of 2011 (ICN'11). 60% of those students enrolled in one or more computer networks course in subsequent semesters (Summer 2011, Fall 2011, or Spring 2012). 52% of students enrolled in the *Routing* course while

33 % enrolled in the *Switched and Wireless Networks* (SWN) course. 8 % of students repeated *ICN*. Note that *Routing* had a better enrollment than SWN. The reason of this is the fact that *Routing* was offered during the Fall semester of 2011 and will be offered again during the Spring semester of 2012. On the other hand, SWN was offered in the Summer of 2011, and will be offered again during the Spring semester of 2012. At our institution, the enrollment in courses during Summer semesters is lower than the enrollment in either Fall or Spring semesters. An important result from Figure 16 is the retention rate. Retention is measured as the number of students who continued enrolling in courses in a window of time of one year. If we measure the retention of students who enrolled in ICN during the Spring 2012, then we obtain a retention of 60% (second bar in Figure 16) on the number of students who continued taking networking courses. This number is much higher than the retention rate of the whole college, which is lower than 40% for freshman students. For us, this result is of great importance, since it represents an increment of more than 50%. While a retention rate of 60% on freshman students may not appear to be a significant figure for a large institution, we should highlight that our institution is located in a high-poverty underserved region, where many students drop out or do not continue their studies because of several reasons.

VI. Conclusion

We presented a model for computer networks education in computing disciplines that seeks to increase motivation and engagement of engineering students. The model includes an innovative mix of industrial and academic components and consists of 4 courses, starting at freshman year. It provides a strong foundation of computer networks where topics are systematically reinforced through hands-on activities directly applied to what the job market requests. In contrast to traditional programs that expose students to computer networks in their graduating semesters at a relatively abstract level, our model uses an industrial application-oriented, hands-on approach, to address computer networks concepts that are traditionally taught theoretically. The resulting model shifts traditional emphasis on *pre-requisite requirements* to an emphasis on engineering motivation for those pre-requisites, with a just-in-time structuring of them. By exposing students to hands-on networking topics starting during their freshman year, the model helps in attracting students to this field and in improving recruitment and retention, engaging them on the second fastest predicted growing occupation among more than 1,000 occupations in the U.S. for the years 2008-2018. Preliminary results of the implementation of the model in a Hispanic serving institution and feedback from students have surpassed any expectation.

References

1. Curriculum Guidelines for Undergraduate Degree Programs in Information Technology, Association for Computing Machinery (ACM) and IEEE Computer Society, 2008.

2. CCNA Cisco Exploration Program. Information available online at: http://cisco.netacad.net.

3. J. Kurose, K. Ross, *Computer Networking, a Top Down Approach*, Prentice Hall, 5th Edition, 2010.

4. A. Tanenbaum, D. Wetherall, *Computer Networks*, Prentice Hall, 5th Edition, 2011.

5. L. Peterson, B. Davie, *Computer Networks, A Systems Approach*, Morgan Kaufmann, 5th Edition, 2011.

6. D. Comer, *Computer Networks and Internets*, Prentice Hall, 5th Edition, 2010.

7. B. Forouzan, *Data Communications and Networking*, McGraw Hill, 4th Edition, 2007.

8. D. Comer, *Hands-on Networking with Internet Technologies* (Lab Manual), Prentice Hall, 2nd Edition, 2005.

9. United States Department of Labor, Bureau of Labor Statistics. Information available online at: http://www.bls.gov/emp/ep_table_102.htm.

10. N. Klingbeil, K. Rattan, M. Raymer, D. Reynolds, R. Mercer, *The Wright State Model for Engineering Mathematics Education: A Nationwide Adoption, Assessment and Evaluation*, ASEE Annual Conference & Exposition, Austin, TX, June, 2009.

11. *Network Fundamentals* – CCNA Exploration V 4.0, Cisco Network Academy, Cisco Press, 2010.

12. *Routing Protocols and Concepts* – CCNA Exploration V 4.0, Cisco Network Academy, Cisco Press, 2010.

13. *LAN Switching and Wireless* – CCNA Exploration V 4.0, Cisco Network Academy, Cisco Press, 2010.

14. J. Crichigno, M. Y. Wu, W. Shu, *Protocols and Architectures for Channel Assignment in Wireless Mesh Networks*, Ad Hoc Networks, Vol. 6, Issue 7, September 2008.

15. I. Akyildiz, X. Wang, W. Wang, *Wireless mesh networks: A survey*, Computer Networks, Vol. 4, Issue 47, 2005.

16. *Accessing the WAN* – CCNA Exploration V 4.0, Cisco Network Academy, Cisco Press, 2010.

17. L. de Ghein, *MPLS Fundamentals*, Cisco Press, 2006.

18. M. Pioro, D. Medhi, *Routing, Flow, and Capacity Design in Communication and Computer Networks*, Morgan Kauffman, 2004.

19. M. Berkelaar Lp-Solve, A Public Domain Milp Solver, http://lpsolve.sourceforge.net/5.5/, 2011.

20. www.csse.uwa.edu.au/cnet

Appendix. ABET Technology Accreditation Commission Outcomes

1. An appropriate mastery of the knowledge, techniques, skills, and modern tools of their disciplines.
2. An ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering, and technology.
3. An ability to conduct, analyze and interpret experiments, and apply experimental results to improve processes.
4. An ability to apply creativity in the design of systems, components, or processes appropriate to program educational objectives.
5. An ability to function effectively on teams.
6. An ability to identify, analyze and solve technical problems.
7. An ability to communicate effectively.
8. A recognition of the need for, and an ability to engage in lifelong learning.
9. An ability to understand professional, ethical and social responsibilities.
10. A respect for diversity and a knowledge of contemporary professional, societal and global issues.
11. A commitment to quality, timeliness, and continuous improvement.
12. The application of Computer and network hardware, operating systems, system and network administration, programming languages, applications software, and databases in the building, testing, operation, and maintenance of hardware and software systems.
13. The application of electrical, electronic, telecommunications, and digital signal propagation fundamentals in the building, testing, operation and maintenance of hardware and software systems.
14. The ability to design, implement, maintain and provide for the security of facilities involved with the processing and transfer of information.
15. The ability to apply project management techniques to facilities that process and transfer information.
16. The ability to apply discrete mathematics, and probability and statistics in the support of facilities that process and transfer information.