Curriculum and Issues in a First Course of Computer Networking for Four-year Information Technology Programs

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Abstract

No field evolves more rapidly than computer networking technologies. However, the skills necessary to evaluate, integrate, and manage networking equipment are considered fundamental for an IT professional. This paper presents a curriculum for a first course in computer networking, the experience of two instructors in teaching similar curricula over a two-year period, and the unresolved issues revealed by the experience.

An IT professional is expected to be able to deal with vendors and stake holders in procurement processes, interpret and evaluate vendor presentations, explain technology to the uninitiated, critically evaluate and make technology recommendations, and then install and manage the network infrastructure that has been procured. In an environment where new technologies appear frequently and yet old technologies seem to live forever, how can any curriculum prepare an individual for such a responsibility?

A balanced curriculum must include fundamental concepts and real-world examples of those concepts. It must build intuition through examination of historical trends and direct experience with real networking hardware integrating diverse technologies. The curriculum must be continually evaluated in an environment where new technologies appear more rapidly than the publishing cycle for textbooks.

Introduction

BYU and several other universities have been developing a four-year degree program in Information Technology.[1,2] A key component of this program is networking. There is a requirement for a networking fundamentals course that can both serve as an introduction to networking for all IT students and also serve as a foundation for more advanced courses in networking and telecommunications. Developing and teaching such a course is complicated by several factors. Three of the most problematic are:

1. There is a large body of knowledge to cover.
2. The technology is evolving rapidly.
3. Students want to learn permanent, absolute answers where none exist.

Thus any course in networking must teach the students fundamental concepts combined with current technology in such a way that the students will be prepared for professional practice and yet be able to understand and embrace change through an attitude of life-long growth in the field. The rapid evolution of the field also requires that the instructor

Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition Copyright © 2002, American Society for Engineering Education

and students use a text as guide, but include current resources to keep the course up with the state of the industry.

The authors approach this topic from the viewpoint of a number of years of recent industrial experience along with 2 years of teaching introductory networking courses to Computer Science and IT students. The course described is currently being taught and some feedback from earlier experience is provided. The importance of hands-on experience cannot be over emphasized.

This paper is organized as follows: First, we describe the fundamental concepts that are the core of the curriculum. Second, we present our desired outcomes along with some background that guided our thinking about curriculum. Next, we present an outline of the curriculum. Following the curriculum we present an example of the teaching techniques and sequencing we are using. Finally we summarize our thinking and discuss open issues.

Fundamental Networking Concepts

In an area that is evolving as rapidly as networking, the simple teaching of facts is inadequate. Our goal must be to create a framework so that the students can integrate new technologies and concepts as they develop. Thus, the main desired outcome from a course in computer networking is to build a supplantive structure of the fundamental networking concepts that can be used to support generative learning[3] of the instances of these concepts. Our instructional approach explicitly emphasizes a foundation in the fundamental concepts that may then be adjusted to fit the evolving technology. Current technology is presented as an instance of the fundamental concept. As technology evolves in computer networking, students should recognize changes as instances of fundamental concepts and thus quickly adapt.

Fundamental concepts in networking include more than technology. The technology evolves inside of a social and industrial context. If one is to build an intuition that supports predictions relative to the future of the technology, one must include all of the variables. This is best done by teaching a fundamental concept and then following an instance through its evolution. Information about personalities and companies involved is helpful where it is available. Stories are more easily remembered and carry more information than simple presentation of models or facts.

We believe that the following are the fundamental concepts that should form the core of an introductory networking curriculum:

1. Technological evolution
2. Network modeling
3. Faults, fault isolation, and root cause
4. Standards and standards bodies
5. Distributed computing architecture
6. Cryptography and applications to security and privacy
7. Host software architecture
8. Forwarding and switching
9. Internetworking
10. Error recovery
11. Resource contention and quality of service

12. Network and service deployment and management

Desired Outcomes

Accrediting organizations have begun to focus on outcomes assessment rather than topics and hours of instruction. We believe that being explicit about what we want our IT graduates to be able to do upon completion of the course is one of the best ways to motivate our curriculum and presentation sequence.

At the completion of this course a student should:

1. Understand fundamental computer networking concepts and vocabulary.
2. Understand current networking technology in terms of fundamental concepts.
3. Understand and communicate in the vocabulary of the current networking technologies.
4. Understand, locate and apply the information in network equipment vendor product documentation.
5. Be able to configure and operate both hosts and intermediate systems.
6. Understand the relationships between standards, standards bodies, and products.
7. Understand the need for life-long learning to avoid obsolescence.

We found validation of our approach in the specific requirements presented by A Study of the Needs of the Information Technology Industry by Pete Tschumi[4]. This paper presents a survey of one metropolitan area's information technology industry. *Network specialist* and *Telecommunications Specialist* were identified as two of eight job areas that are of particular interest. Focus groups were then formed for each area, using employees from industries involved in that particular interest. From the focus group, a list of knowledge, skills and abilities was built. We compared our curriculum against both lists and found good coverage of the industry requirements by our curriculum. The details can be viewed in Appendix A. Many of the items identified in the list are fundamental concepts of networking. Some, such as "Knowledge of Windows NT" are instances of the fundamental concepts that reflect technology currently used.

Certain skills are expected of any IT professional in telecommunications or enterprise networking. One example of these fundamental skills is configuration of personal workstations and their connection to the LAN. A telecommunications professional must understand how the Wide Area communications are being used in order to properly apply the technology. Similarly, much of the material taught in a first course in computer networking provides a foundation for the subjects in telecommunications. Our emphasis is on computer networking but, since there is a significant amount of overlap in the subjects of computer networking and telecommunications a student taking this course would be prepared to specialize in telecommunications through an advanced course or individual study.

The Curriculum

It should be emphasized that these fundamental concepts are threads that must be woven into the presentation of the curriculum. They permeate the presentation of many different instances. For example, the most convenient place to introduce distributed computing might be in the discussion of Web architecture which is an instance of the principle of distributed computing. Since "distributed computing" sounds esoteric and difficult, many students are better served by a lecture on Web architecture and then demonstrating that it is an example of a more general concept. As a part of the preparation of this course many textbooks were examined. Even though there is general consensus on most of these core concepts in current textbooks (see appendix B) there is no consensus on the sequence of presentation. Most texts include digital communications with the computer networking topics. The IT curriculum at BYU includes a digital communications course that is a prerequisite for this networking course. One approach would be to use a single book for the two semester sequence. However it was decided to use a more specialized digital communications text for that course to facilitate coverage of digital communications topics that are not necessarily associated with networking. Some of the more recent texts[56] do not include as much digital communications. It is not clear whether this is because other programs are taking an approach similar to ours, or the fact that the physical interfaces are all moving toward delivering a standard interface to the layers above based upon the IEEE 802 media access control service definition[7]. In any case we selected Peterson and Davie's text[8] because it uses a systems approach working from a problem to solutions and provides a review of digital communications in one chapter rather than a more in-depth treatment.

The curriculum for the networking class was developed assuming that a student has the following prerequisite background:

1. Working knowledge of C, C++ or Java programming.
2. Proficiency in the use of WWW for search and access.
3. Understanding of digital communications
    a. Media
    b. Signaling
    c. Multiplexing
    d. Telephone system
4. Ability to install Linux & Windows 2000/XP
5. Understanding of Computer Architecture.

The most common way to document a curriculum is a list of topics and expected number of lecture hours. The following view of our curriculum should contain no surprises:

List of Topics

1. Model of networks: nodes, links, protocols etc. (1)
2. OSI Model/Internet Model layers (1)
3. Introduction to encapsulation and Protocols. (TCP, HTTP)(1)
4. Data Link Layer: Framing, addressing, packets, Ethernet, 802.3, other 802 MACS, ATM, LANE, FDDI. (3)
5. Packet Switching (1)
6. Hubs, Bridges, Switches, Routers: algorithms and comparison. (2)
7. Interworking
    a. IP addressing (.5)
    b. Routing
        i. Distance Vector Protocols (1)
        ii. Link State Protocols (1)
        iii. Global Internet, Autonomous Systems (2)
8. End-to-end Protocols (2)
    a. Datagram

b. Streaming
c. RPC

9. Congestion Control and Resource Allocation (2)
   a. Issues
   b. Queuing
   c. TCP/IP Congestion control
   d. Congestion avoidance
10. Network Security (2)
    a. Cryptographic Algorithms
    b. Security Mechanisms
    c. Examples
11. Applications (5)
    a. DNS
    b. Email (SMTP, MIME)
    c. World Wide Web (HTTP)

Even though we designed the course from the perspective of fundamental concepts, the actual lecture topics are tied to specific technologies and vocabulary. In teaching the course previously, we found that we would present a concept in the context of one technology and then some members of the class would not recognize it as the same idea when it was discussed in another context. We believe that the key is to be very explicit in explaining how each technology's implementation represents the more general concepts. The brightest students make all of the connections easily; with help the more literal minded students also begin to see how things are related.

In our experience of teaching networking in a classroom setting for computer science and IT as well as teaching courses to prepare programmers in industry to work on networking projects, we have found that the lectures that provide the model and vision level of learning in these settings are almost identical. The real differences in the courses are in the instances emphasized in the lectures and especially the instances selected for the labs. The labs for a computer science curriculum prepare a student to write and understand network stacks and intermediate system control software. The IT course needs to prepare a student to evaluate and integrate networking products, troubleshoot faults, and manage all of the devices involved. The concepts of technical education through a model of communicating a vision, providing a structure and then expanding through hands-on experience are influenced strongly by *Paradigms and Scope of Engineering Technology Education*[9]. This paper describes two complementary models to structure technical education so that the thinking and creative skills required of an IT professional are developed as well as implementation skills of a technologist. One contribution of our work is in the way that we have used these concepts to design the labs. Each lab is designed to reinforce the lecture topics and in addition develop the implementation skills necessary.

Laboratory assignments:

1. Set up and configure a point-to-point network.
   a. 10BaseT crossover cable.
   b. Two host network.
   c. Packet capture
      i. Physical (with scope)

            ii. Logical (with sniffer)
    d. Internet/OSI model visible through encapsulation layers.
2. Introduction to troubleshooting (Systems set up with known faults)
    a. Fault analysis and correction by layers
    b. Physical layer
    c. Data link layer
    d. Network layer
3. Client / server programming
    a. Program a web server.
    b. Prove that it works with IE and Netscape.
4. Installation and management of services.
    a. Web server installation.
    b. Browser access.
    c. Session capture and analysis.
    d. Windows Model
    e. Linux Model
    f. Evaluation and comparison
5. Introduction to network configuration
    a. Design small network
    b. Configure and test in simulator
6. Layer 2/ Layer 3 configuration and test
    a. Configure hosts
    b. Configure VLANs
    c. Configure routing subnets and VLAN bindings
    d. Test and troubleshoot connectivity
7. Network Management
    a. Programmatically access MIBs on Workstations
    b. Programmatically access MIBs on network Devices.
    c. Do simple monitoring of variables
    d. Do threshold based alarm notification.
8. Final Team Project counts as 3 Labs.

We have created a table that helps to focus our thinking on the relationships between the theoretical and the applied. The extract below includes two of the fundamental concepts with their associated instances and the experiential learning in the lab. A more complete table is included as Appendix C.

Fundamental Concept **Think / Vision**	**Instance of Concept** **Learn / Structure**	**Experience with Concept** **Do / Detail**
Foundation: Modeling Networks: Architecture Topology Protocols Layering/Abstraction	OSI model TCP/IP model and protocols	Lab 1. a. Build a point-to-point network using 10/100 BaseT Ethernet and TCP/IP. b. Capture and dissect traffic layering using a network analysis tool
Fault isolation and repair. *(This comes as the second lab as*	Failure modes at each level of model. Thinking in	Lab 2. Troubleshoot broken point-to-

the lectures proceed on the modeling to motivate paying attention to the theoretical discussions that follow – this is a problem with some students. Ourapproach allows us to motivate both the top-down and the bottom-up learners in each sequence. Show them "why they care" about the theory and the practice.)	terms of the model provides a structure within which to organize fault isolation.	point networks like the one that was built in lab 1. a. Broken wire b. Bad NIC c. Misconfigured stack

It is difficult to teach protocol layering and encapsulation without making the concepts concrete. Our experience has been similar to that of Pfile and Lin[10]. We have had significantly better success teaching these concepts using a network analysis tool, a "packet sniffer" to capture packets so that the students directly observe the encapsulation in the lab. We have the students build the simplest network possible (a crossover 10BaseT Ethernet cable between two PCs) and dissect its operation to see all of the "layers" in the Internet Model using a network analysis tool running on one of the two nodes in the network. We teach that the OSI model is another partitioning of the design space using slightly different layers.

After the student build their own two node network, we have found a second lab that uses the concepts and tools for fault isolation motivates the students to learn fault modes as we discuss technologies during the rest of the course. We create a set of several two-node point-to-point networks and intentionally introduce faults through bad connectors, faulty network interface cards, misconfigured IP stacks, and bad IP addresses. We find that the students gain appreciation for the layering model as a tool for structuring fault analysis. They also gain an appreciation for the number and type of faults that are possible even in this simple 2 PC, 1 wire network. The labs were consistently mentioned in the course evaluations as the students "favorite part" of the course. As another indication of student motivation, most choose to take the crossover 10BaseT cable that they constructed for the lab home to do their own experiments.

The Challenge of Instruction in a Rapidly Evolving Discipline

Students ask why we emphasize the fundamental concepts and spend so much time discussing the evolutionary trends. We have found it helpful to explain that every development project creates a communication environment within which to work. Each project team develops a common vocabulary to describe the problem domain that includes shorthand words that encapsulate complex semantics. This vocabulary may or may not be formally placed into a model with an appropriate formal taxonomy. Network Technology progresses as development teams from different vendors develop products, marketing teams translate the development team's vocabulary into sales literature and customers buy products. The technical concepts go through at least two layers of translation before the consumer gets a chance to hear and understand them. In addition, one of the objectives of marketing is to *differentiate* products, so there is actually a disincentive to be clear and accurate in their descriptions.

This process can lead to some very difficult situations for consumers of products while the terminology and technology stabilize. For example, as people connected collision domains together with store and forward devices at layer 2 of the OSI model, the device was called a bridge. As Novell created software to allow IPX forwarding at layer 3 and provided for this service to be provided separate from a server, the PC running the software was called a bridge. Today, we all call a layer 3 forwarding device a *router*. But this term was not standard across the industry until the 90's. Tanenbaum's 1981[11] and Stallings 1985[12] texts on computer networking call these devices Gateways following the ArpaNet terminology and don't include the term "Router" at all (at least in the index), however they do discuss "routing" at length. Though we studied networks in school, each of the authors had been in industry for years when the term *Router* became *the one true name* for a layer 3 forwarding device. One of us remembers clearly being lectured and what seemed to be intentionally humiliated by a certain technical service representative for using the Novell terminology in the wrong context. How do we prepare our students to aggressively seek accurate understanding of terminology without being intimidated? How do we train them that it is the technical sales representative's job to explain what is meant by the company marketing hype, not the consumer's job to figure it out? We need to help our students realize that there is a problem of evolution of technology and terms that will be a part of their professional lives as long as network technology continues to evolve.

In addition, we have the problem that old terminology (and technology) dies a very slow death. When we configure a TCP stack today either for Windows XXXX, or any of the Unix derivatives, we give the IP address of the "Default Gateway" even though the IP address belongs to a physical port called a "Router interface" by the management software we use to configure it. It is also true that modern networking textbooks typically only mention the term "Gateway" as a synonym for router in passing[13]. Radia Perlman devotes a summary chapter to sorting out the terms bridge, router, and switch in her 1998 revision of her 1992 classic "Interconnections"[14]. In 1992 she only had to worry about bridges and routers[15]. How clear is it to typical consumers of the technology that a LAN switch is just a type of bridge? To add to the confusion, a device that translates Voice Over IP sessions into connections to the PSTN is called a "Gateway". However, we still configure the default *gateway* in our TCP/IP stacks.

This instability of terminology and concept is also a problem for textbook authors. In Appendix D we include a table that tracks changes in William Stallings six editions of Data and Computer Networking between 1985 and 1999. Mr. Stallings has revised his text every three years. It is very instructive to trace terms through the table of contents, especially specific technologies. ISDN is a core technology in the 80's and early 90's, yet it is barely mentioned in 1999. There is clear evidence of the emergence of terminology and principles that displace discussion of specific technologies. However, it was impossible to predict the evolution.

Why not just standardize the vocabulary? This is exactly what the OSI model tried to do, however, this is much harder than it seems on the surface. We know from personal experience that it took IEEE 802.1 almost a year to sort out the vocabulary and model associated with vendors views of VLANs. This work eventually became the 802.1Q VLAN[16] standard. VLANs do not fit into the OSI model. They are at "layer 2.5" more or less. The vendors overloaded the standard terms with proprietary shades of meaning. The combination of using the same words for different semantics and subtle differences in forwarding implementations of compliant 802.1D bridges had everyone confused for at least 6 bi-monthly sessions of several days each. Considering that these were the engineers that built the devices, it is not surprising that it has taken a long time for a common definition of Virtual LAN to evolve. Even now, there is confusion concerning the relationship of Spanning tree instances to forwarding databases. (Cisco does it one way, 3COM does it another and the issues were so complex, and at times contentious, that they were glossed over in the 802.1Q standard) It is impossible to describe VLANs using the standard meanings for the standard words. Words and a repartitioning of the layered models had to be invented to describe the technology.

This is the world that we must prepare our students to enter. A world where vendors use the same name for different things, where useful technology is available years before there is a standard way to describe it. A world where the details change daily and you must study continuously to have any hope of understanding what is going on. We believe that the approach taken in this curriculum will help prepare IT students for their professional lives better than any approach that we have used in the past. However, there are several open issues.

Open Issues

Sequencing of topics and labs is problematic. We want to motivate students to listen and understand in class through giving them an intellectual incentive before lectures with experience. However, sometimes the student needs information from the lecture to facilitate the lab. We will continue to experiment with difference sequences of topics and labs. It is also unclear how much networking hardware is required for this introductory course. Indeed we have found that 4 PCs with 3 NICs in one of them can be used to demonstrate most of the concepts directly. Every TCP stack is a static router, and there is free software available for Linux that implements routing and bridging. However, playing with 4 PCs does not prepare a student for the complexity of a real network with thousands of nodes from tens of vendors. We have used a layer 3 Alcatel switch, a simple Cisco VLAN bridge, and this semester we will try the 4 PC approach with one lab accessing a larger routed network. The use of this cluster of inexpensive PC-based hardware is attractive because of the applicability of the platform to other situations. It is an ideal platform for a web system development course and a set of these units can be aggregated to form a much larger network. As the course evolves, we think that a virtual lab approach as described in Liu, Marti and Zhao's paper[17] may be viable approach when used in combination with more direct experience in a physical lab.

We are continually challenged to design and implement labs such that the equipment fits into our available space. One approach that we are prototyping is the creation of a 4 node network in a small portable configuration using standard motherboards with custom external packaging. The success of our program is forcing us to deal with the challenge of teaching many more students using the existing physical facility.

Conclusion

We have developed a strong curriculum for an introductory networking class tailored to the needs of a 4 year Information Technology program. The curriculum focuses on revealing the evolution of network technology to students so that they are better prepared to expect and manage changes as they occur. This is accomplished through a combination of coordinated lectures and laboratory experiences. There is a focus demonstrating how specific technologies represent more general principles. Initial experience with the approach has been very positive.

Networking professionals will continue to be challenged to understand the reality behind each new technology as it is deployed. Terminology and technology evolve rapidly. We must do our best to equip our students with the tools and the attitudes necessary to understand and embrace the changes they will face.

The curriculum must evolve with the terminology and technology. Instructors must be aware of innovations in the space so that they can make students aware of the evolution occurring during the course. The best way to build students intuition about change is to guide their thinking through the evolution they are facing.

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Appendix A (Source: Tschumi, Pete, A Study of the Needs of the Information Technology Industry, ASEE 2000 Session 2793**)**

Original Networking List	**Included in our Networking Course**
Knowledge of Network Protocols	Yes
Knowledge of Networking Hardware	Yes
Ability to Troubleshoot	Yes
Knowledge of Communication Fundamentals	Yes
Knowledge of Connectivity Methods	Yes
Knowledge of Network Security Issues	Yes -- also in advanced course
Knowledge of Operating Systems	No -- different course
Ability to Manage/Schedule Time	No
Ability to Analyze Network Needs	Overview -- also in advanced course
Ability to Configure Network Components	Yes
Ability to Optimize Network Performance	Overview -- also in advanced course
Knowledge of Networking/Product Relationships	Yes
Ability to Monitor Networks	Overview – also in advanced course
Knowledge of Basic Communication Debugging	Yes
Knowledge of Windows NT	No -- some is prerequisite
Ability to Design LAN	Overview -- depth in advanced course
Ability to Manage the Network	Overview – depth in advanced course
Ability to Use Test Equipment	Yes
Knowledge of Communication Media	Prerequisite
Original Telecommunications List	**Included in our networking course**
Knowledge of Basics of Communications	Yes
Knowledge of Telecommunications Protocol	Yes
Ability to understand Telcom system flow	No
Knowledge of Signal Analysis	Prerequisite
Knowledge of Telecommunication Hardware	No
Knowledge of Computing Fundamentals	Yes -- prerequisite
Knowledge of Signal Encoding	Prerequisite
Knowledge of Telecommunications Software	No
Ability to Research new technologies	Yes -- project oriented
Knowledge of Evolving Telecommunication Technologies	Overview
Knowledge of Fundamentals of Electronics	Prerequisite
Ability to Design cost effective communication networks	Overview
Knowledge of Telco Operations and Networks	No
Ability to interface OS and Communication Devices	No
Knowledge of Signal Noise Analysis and Bit Rate Errors	Prerequisite
Ability to Deal with Telcos and Vendors	No
Ability to Design Communication Network Using a variety of Technologies	Overview

Appendix B: Textbooks

Name	Title	Reference	Year
Stallings, William	High-Speed Networks: TCP/IP and ATM Design Principles	New Jersey, Prentice Hall	1998
Stallings, William	Data & Computer Communications, 6th Ed.	New Jersey, Prentice Hall	1999
Stallings, William	Data & Computer Communications, 2nd Ed.	New Jersey, Prentice Hall	1988
Stallings, William	Data & Computer Communications, 3rd Ed.	New Jersey, Prentice Hall	1991
Stallings, William	Data & Computer Communications, 4th Ed.	New Jersey, Prentice Hall	1994
Stallings, William	Data & Computer Communications, 5th Ed.	New Jersey, Prentice Hall	1997
Stallings, William	Data & Computer Communications	New Jersey, Prentice Hall	1985
Ramteke, Timothy S.	Networks, 2nd Ed.	New Jersey, Prentice Hall	2001
Shinder, Debra L.	Computer Networking Essentials	Indianapolis, IN, Cisco Press	2001
Comer, Douglas E.	Computer Networks and Internets, 3rd Ed.	New Jersey, Prentice Hall	2001
Peterson, L. & Davie B.	Computer Networks: A systems Approach, 2nd Ed	San Francisco, CA, Morgan Caufmann	2000
Huitema, Christian	Routing in the Internet, 2nd Ed.	New Jersey, Prentice Hall	1999
Perlman, Radia	Interconnections: Bridges & Routers	Reading, MA, Addison-Wesley	1992
Perlman, Radia	Interconnections 2nd Ed.: Bridges, Routers, Switches and Internetworking Protocols	Reading, MA, Addison-Wesley	1999
Kurose, J. & Ross K.	Computer Networking: A Top-Down Approach Featuring the Internet	Reading, MA, Addison-Wesley	2001
Forouzan, Behrouz A.	Data Communications and Networking	Boston, MA, McGraw-Hill	2001
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Tanenbaum, Andrew S.	Computer Networks 3rd Ed.	New Jersey, Prentice Hall	1996
Abrams, A.,Blanc, R, Cotton, I.	Computer Networks: A Tutorial, Revised 1980	Long Beach, CA. IEEE Computer Society	1980
Bertsekas, D & Gallager, R.	Data Networks 2nd Ed	New Jersey, Prentice Hall	1992
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Martin, James	Systems Analysis for Data Transmission	New Jersey, Prentice Hall	1972
Halsall, Fred	Data Communications , Computer Networks and Open Systems	Reading, MA, Addison-Wesley	1996

Appendix C: Integrated Curriculum Chart

Fundamental Concept **Think / Vision**	**Instance of Concept** **Learn / Structure**	**Experience with Concept** **Do / Detail**
Foundation: Modeling Networks: Architecture Topology Protocols Layering/Abstraction	OSI model TCP/IP model	Lab 1. a. Build a point-to-point network using 10/100 BaseT Ethernet and TCP/IP. b. Capture and dissect traffic layering using a network analysis tool
Fault isolation and repair *(This comes as the second lab as the lectures proceed on the modeling to motivate paying attention to the theoretical discussions that follow – this is a problem with some students. This approach allows us to motivate both the top-down and the bottom-up learners in each sequence. Show them "why they care" no matter which direction they question.*)	Failure modes at each level of model. Thinking in terms of the model provides a structure within which to organize fault isolation.	Lab 2. Troubleshoot broken point-to-point networks like the one that was built in lab 1. a. Broken wire b. Bad NIC c. Misconfigured stack
Distributed Computing	Web Architecture HTTP FTP	Lab 3: Socket Programming Implement minimal Web server
Direct connection of hosts: Local Area Networks Framing and addressing Collision Domains	Ethernet, FDDI, Token Ring, 802.11,	Ethernet/802.3 Lab 1
Switching and Forwarding: Virtual Circuit Switching Cell Switching Frame Switching Datagrams Bridging Broadcast Domains	802.1D Learning Bridges Virtual LANs ATM cell switches Hardware IP Switches	Lab 4: Connection and configuration of 802.1D compliant bridge
Internetworking Services and Interfaces Address Management Address space portioning Density of use	IP networking Addressing Classes/Subnetting DHCP ARP ICMP Interface configuration	Lab 1: Exposure & Intro. Lab 2: Exposure & Intro. Lab 5: Host configuration of Windows and Linux IP stacks DHCP Static addresses and subneting

Internetworking: Static Routing Dynamic Routing Distance Vector Link-State	IP static routing Forwarding, Time to Live, Interface configuration Multihomeing IP Dynamic routing: OSPF – Link State RIP	Lab 5: Multihome forwarding, A host can be a static router
Global issues Route Scaling Address Space utilization Multiple protocol routing	The INTERNET CIDR Autonomous Systems Management domains Tiers of Providers Backbones and Peering BGP-4 INTERNET 2 IPv6 IPv6 as a carrier of IPv4 and IPX	
Processes inside of machines need to be addressed.	IP packet arrival demuxing UDP TCP	Lab 3.
Error Recovery and Congestion Control End to End Hop by Hop	TCP (all on the host) Sliding Window Adaptive retransmission Random Early Detection	
Resource contention	Space in the router: Queuing FIFO Fair Dropping Packets	
Quality of service	RSVP DiffServ ATM CBR,ABR…	
Services Management Tools are needed to manage services in server hardware	Linux service management: INETD, XINETD Windows 2000 Service Manager	Lab 6: Services management analysis and comparison of Linux and Windows 2000 paradigms of service management. After configuring and testing web services on both platforms.
Name Services	Internet DNS, Microsoft WINS	
E-mail	SMTP, MIME, MS Exchange	

Network Management	SNMP	Lab 7: SNMP access to real routers and hosts. Configuration of SNMP agents on hosts. Reading and writing data using SNMP.
Multimedia Requirements on QOS	H.323 Videoconferencing.	
Network Security Cryptographic concepts Symmetric and Asymmetric encryption. Public Key Infrastructure Confidentiality Non-Repudiation Authentication	SSL on the Web IPSec VPNs	
Virtual Networks Using another network as one of your layers.	802.1D VLAN, multiple broadcast domains on a single physical network. IPSec VPN – virtual wires over the public Internet	

Appendix D: Evolution of Stallings Table of contents.

Note: An empty entry indicates that there was no change from the previous revision. Empty entries from the beginning of the chart indicate the introduction of a new chapter.

1985	1988	1991	1994	1997	1999
Introduction 1 Computer Communications Revolution 2 A communications Model 3 Data Communications 4 Data Communications Networking 5Computer Communications Architecture 5 Standards Making Organizations		A. Standards Organizations * Enhances discussion of OSI model		**Introduction** 1 A Communications Model 2 Data Communications 3 Data Communications Networking 4 Protocols and Protocol Architecture 5 Standards A.Standards Organizations B.Internet Resources	
					Protocols and Architecture 1 Protocols 2 OSI 3 TCP/IP
Data Transmission 1 Concepts and Terminology 2 Analog and Digital Technology 3 Transmission impairments 4 Transmission Media A. Fourier Analysis				+B: Decibels and Signal Strength	**Data Transmission** 1 Concepts and Terminology 2 Analog and Digital Technology 3 Transmission impairments A. Fourier Analysis B. Decibels and Signal Strength
				Transmission Media 1 Guided Transmission Media 2 Wireless Transmission	

Data Encoding 1Digital Data, Digital Signals 2Digital Data, Analog Signals 3 Analog Data, digital Signals 4 Analog Data, Analog Signals A. Proof of the sampling Theorem					+5 Spread Spectrum
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Data Link Control 1 Line Configurations 2 Flow Control 3 Error Control 4 Bit-Oriented Link Control			**Data Link Control** 1 Line Configurations 2 Flow Control 3 Error Control 4 Data Link Control Protocols	**Data Link Control** 1 Flow Control 2 Error Detection 3 Error Control 4 High-Level Data Link Control (HDLC) 5 Other Data Link Control Protocols A. Performance Issues	
Multiplexing 1FDM 2 Synchronous TDM 3 Statistical TDM					+4 Asymmetric Digital Subscriber Line +5 xDSL
Communication Networking Techniques 1 Communication Networks 2 Circuit Switching 3 Message Switching 4 Packet Switching 5 Comparison of Switched Techniques 6 Broadcast Networks			**Chapter is Deleted**		

Circuit Switching 1 One-node networks 2 Digital Switching Concepts 3 Digital Data Switching Devices 4 Computerized Branch Exchange 5 Public Telecommunications Nework	4 Digital Private Branch Exchange	**Circuit Switching** 1 One-node networks 2 Digital Switching Concepts 3 Digital Data Switching Devices 4 Digital Private Branch Exchange 5 Routing 6 Control Signalling	**Circuit Switching** 1 Communication Networks 2 Circuit Switching 3 Single-Node Networks 4 Digital Switching Concepts 5 The Digital Private Branch Exchange 6 Control Signaling	**Circuit Switching** 1 Switched Networks 2 Circuit Switched Networks 3 Switching Concepts 4 Routing in Circuit Switched Networks 5 Control Signaling	**Circuit Switching** 1 Switching Networks 2 Circuit Switching Networks 3 Circuit Switching Concepts 4 Routing in Circuit Switching Networks 5 Control Signaling
Packet Switching 1Examples 2Virtual Circuits and Datagrams 3 Routing 4 Traffic Control 5 Error Control			**Packet Switching** 1 Packet Switching Principles 2 Example Systems 3 Virtual Circuits and Datagrams 4 Routing 5 Traffic Control 6 X.25	**Packet Switching** 1 Packet Switching Principles 2 Routing 3 Congestion Control 4 X.25 A. Least Cost Algorithms	
Radio and Satellite Networks 1 Packet Radio Architecture 2 Packet Radio Access Protocols 3 Satellite Network Architecture 4 Satellite Channel Access Protocols A. Performance Considerations for Broadcast Networks			**Chapter Deleted**		
				Frame Relay 1 Background 2 Frame Relay Control Architecture 3 Frame Relay Call Control 4 User Data Transfer 5 Network Function 6 Congestion Control	**ATM & Frame Relay** 1 Protocol Architecture 2 ATM Logical Connections 3 ATM Cells 4 Transmission of ATM Cells 5 ATM Service Categories 6 ATM Adaptation Layer 7 Frame Relay

					Congestion Control in Data Networks 1 Effects of Congestion 2 Congestion Control 3 Traffic Management 4 Congestion Control in Packet-Switching Networks 5 ATM Traffic Management 6 ATM-ABR Traffic Management 7 Frame Relay Congestion Control
				Asynchronous Transfer Mode (ATM) 1 Protocol Architecture 2 ATM Logical Connections 3 ATM Cells 4 Transmission of ATM Cells 5 ATM Adaptation Layer 6 Traffic Congestion and Control	**Chapter Deleted**

Local Networks 1 Local Network Technology 2 Bus/Tree Topology 3 Ring Topology 4 Medium access Control protocols 5 LAN protocol Performance A. Standards			**Local and Metropolitan Area Networks** 1 LAN/MAN Technology 2 Bus/Tree and Star Topologies Using Metallic Media 3 Optical Fiber Bus 4 The Ring Topology 5 Medium Access Control Protocols 6 MAC Performance 7 LAN/MAN Standatds	**LAN Technology** 1 LAN Architecture 2 Bus/Tree LANs 3 Ring LANs 4 Star LANs 5 Wireless LANs	**LAN Technology** 1 LAN Applications 2 LAN Architecture 3 Bus/Tree LANs 4 Ring LANs 5 Star LANs 6 Wireless LANs 7 Bridges A: The IEEE 802 Standards
				LAN Systems 1 Ethernet and Fast Ethernet (CSMA/CD) 2 Token Ring and FDDI 3 100VG AnyLAN 4 ATM LANs 5 Fibre Channel 6 Wireless LANs	**LAN Systems** 1 Ethernet and Fast Ethernet (CSMA/CD) 2 Token Ring and FDDI 3 ATM LANs 4 Fibre Channel 5 Wireless LANs A: Digital Signal Encoding for LANs B: Performance Issues
				Bridges 1 Bridge Operation 2 Routing with Bridges 3 ATM LAN Emulation	**Chapter Deleted**
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					Internetwork Operation 1 Routing Protocols 2 Integrated Services Architecture 3 Resource Reservation (RSVP) 4 Differentiated Services
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			Distributed Applications 2 File Transfer: FTAM 3 Electronic Mail: X.400	**Distributed Applications** 1 Abstract Syntax Notation One (ASN.1) 2 Network Management: SNMPv2 3 Electronic Mail: SMTP and MIME 4 Uniform Resource Locators (URL) and Universal Resource Identifiers (URI) 5 Hypertext Transfer Protocol (HTTP)	**Distributed Applications** 1 Abstract Syntax Notation One (ASN.1) 2 Network Management: SNMPv2 3 Electronic Mail: SMTP and MIME 4 Hypertext Transfer Protocol (HTTP)
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				Appendix B: RFCs Cited in this Book	
					Appendix C: 1 Simulation Projects 2 Performance Modeling 3 Research Projects 4 Reading/Report Assignments