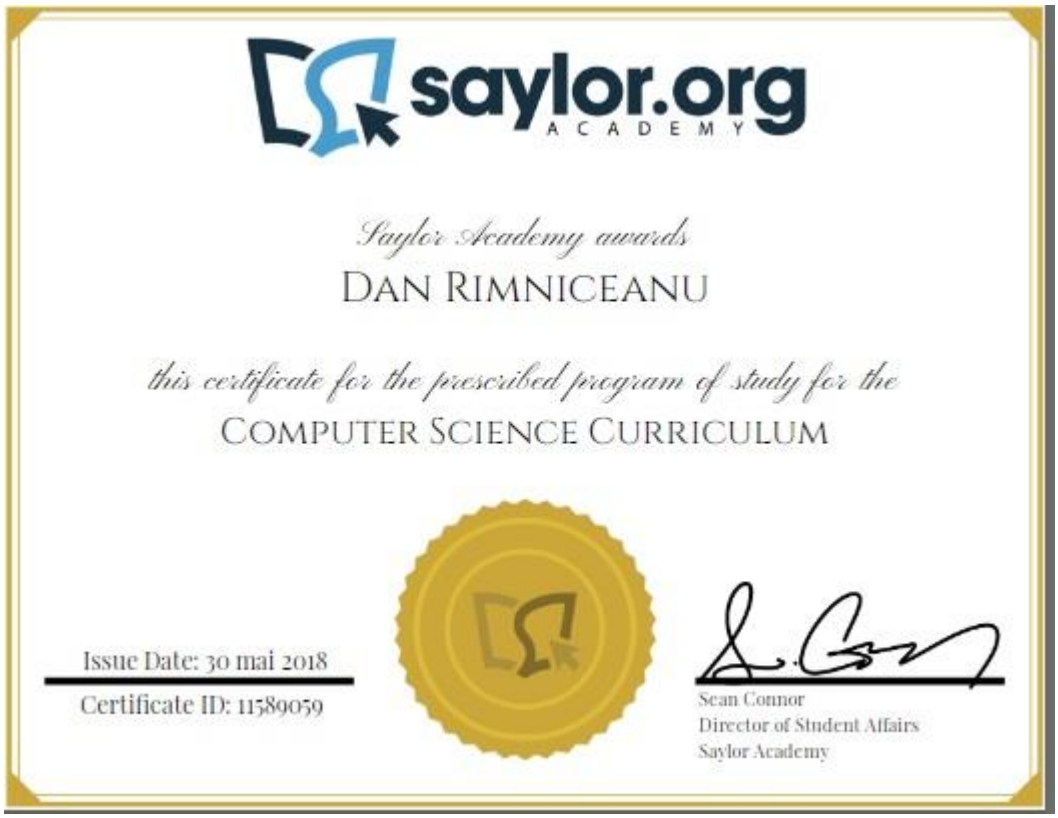

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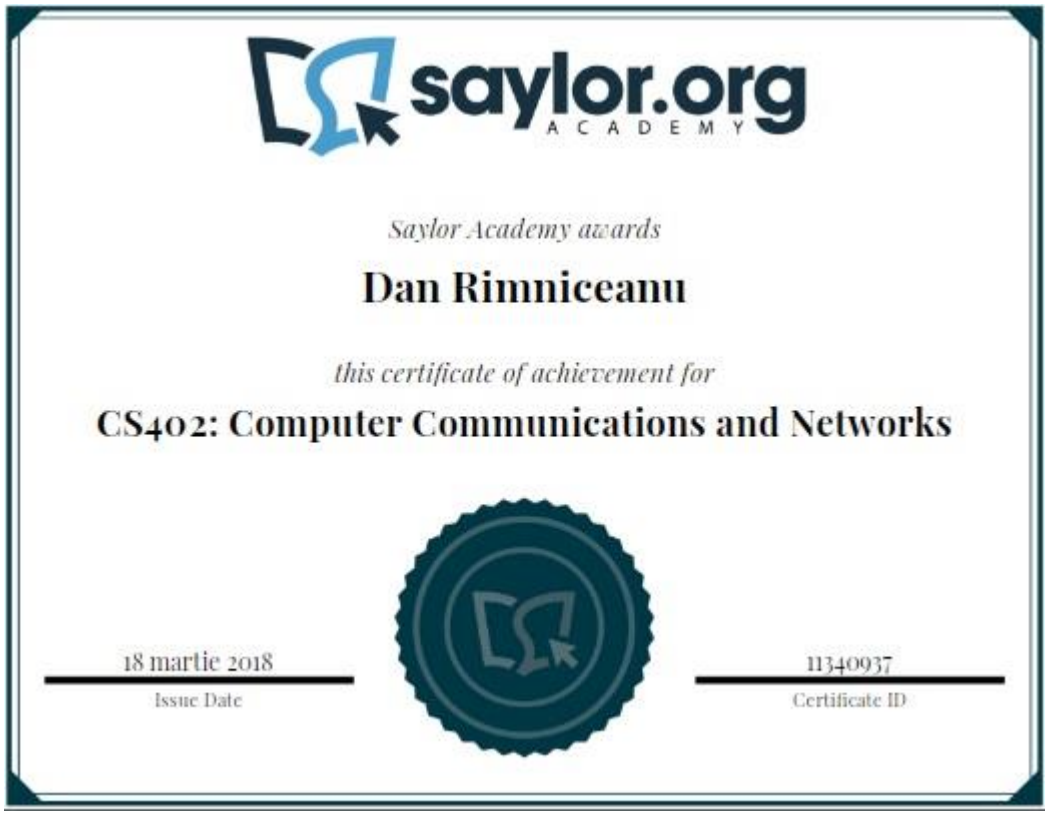

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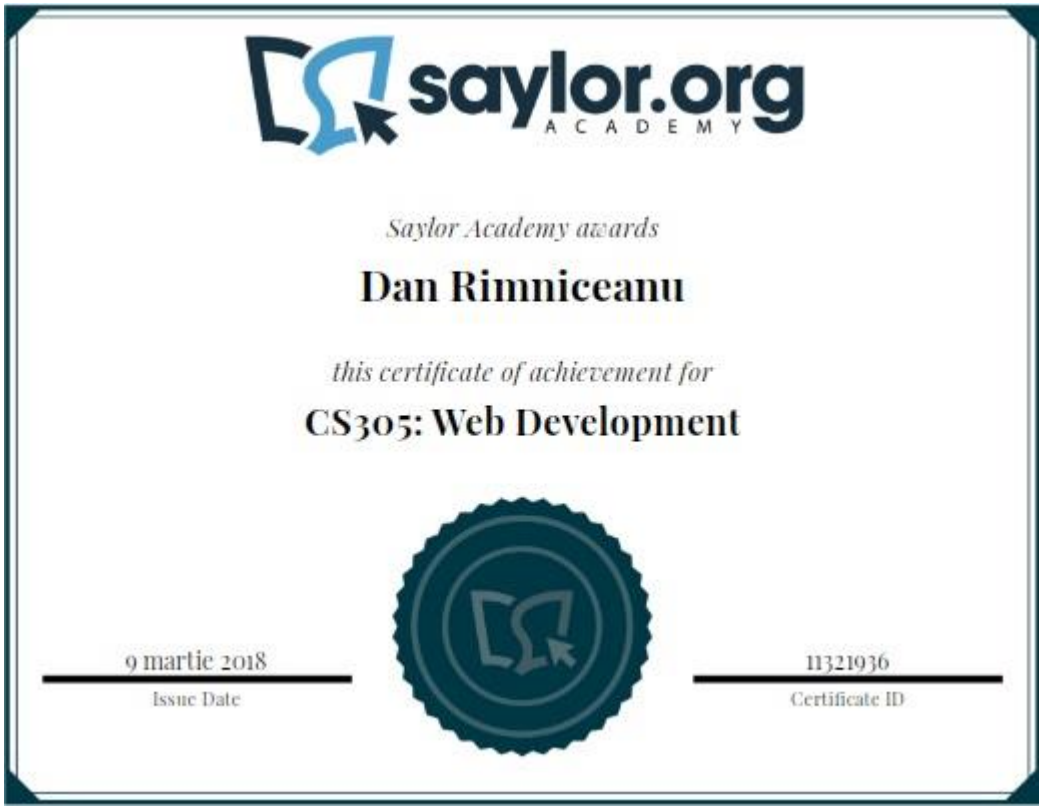
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STATEMENT OF ACCOMPLISHMENT
May 28, 2019
Dan Rimniceanu
has successfully completed a free online offering of
Introduction to Computer Networking
In order to receive a statement of accomplishment, participants were required to score 60% of the points attainable on the online quizzes.
Nick McKeown
Professor of Computer Science and Electrical Engineering
Stanford University
Philip Levis
Professor of Computer Science and Electrical Engineering
Stanford University
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- Configure Wireless Access Point
- Configure Wireless Router
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Routing Basics Course

26 July 2019

ROUTING BASICS

Paul Wilson
Director General

CS402: Computer Communications and Networks

The internet has become one of the most important components of our life. We browse the web, check e-mails, make VoIP phone calls, and have video conferences via computers. All of these applications are made possible by networking computers together, and this complex network of computers is usually referred to as the Internet. This course is designed to give you a clear understanding of how networks, from in-home local area networks, or LANs, to the massive and global Internet, are built and how they allow us to use computers to share information and communicate with one another. Unit 1 introduces you to an explanation of what computer networks are as well as to some basic terminology fundamental to understanding computer networks. You will also familiarize yourself with the concept of layers, which compose the framework around which networks are built. Next, Unit 2 explains the concept of protocols. A computer communication (or network) protocol defines rules and conventions for communication between network devices.

The rest of the course implements a top-down approach to teach you the details about each layer and the relevant protocols used in computer networks. Beginning in Unit 3, you will explore the concept of application layer protocols, which include the Domain Name System, e-mail protocols, and the Hypertext Transfer Protocol. Unit 3 ends with an

overview of how to use socket programming to develop network applications. In Unit 4, you will learn transport layer protocols, including the Transmission Control Protocol (TCP) and the User Datagram Protocol (UDP). You will go on to study the network layer Internet Protocol (IP) and packet routing protocols in Unit 5. Next is Unit 6, which is devoted to a discussion on link layer protocols, and the course concludes with an overview of voice and video protocols, network security, and cloud computing in Unit 7.

As you move through the course, take time to notice how the layers build on top of one another and work together to create the amazing tool of computer networks, which many of us depend upon daily.

Unit 1: Networking Fundamentals

When you think of networking, what is the first word that comes to mind? If you answered "Internet", you are correct. The Internet is an example of a massive computer network. Computer networks make it possible for one device to communicate with another device. Another example of a computer network is the local area network, or LAN. If you can access all of the desktops, laptops, wireless devices, and printers in your workplace, college, or home, you have a LAN.

This unit will introduce the basic concept of a computer network and arm you with the tools you will need to work through the more technical aspects of this course. You will take a look at the different types of networks that exist, with the primary focus on the LAN. The unit continues with an introduction to the concept of layers, which is central to understanding how computer networks operate. You will also become familiar with Request for Comments (RFC) documents, which are standards that define all of the Internet protocols. RFCs are created by The Internet Engineering Task Force (IETF).

The concepts presented in this course will provide you with the background information needed to develop network applications, take a network certification course, or communicate with other networks neighboring your LAN.

Completing this unit should take you approximately 4 hours.

- Upon successful completion of this unit, you will be able to:
  - demonstrate an understanding of the evolution of Internet and computer networks;
  - define the use of layers in networking; and
  - explain the role of the Network Request for Comments (RFC).

- **1.1: Services and Protocols**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to Chapter 2 and section 2.1, "Services and Protocols", on pages 5–20. You may notice that some information in the textbook is not completely up-to-date. The Wikipedia article below includes some more recent

information for you to explore. Also, Figure 2.1 in the textbook shows the number of hosts on the Internet only through 2007. Updated information is available at https://www.isc.org/solutions/survey/history.

The second chapter of Computer Networking: Principles, Protocols, and Practice serves as an introduction to networking as you link across time to review the development of standards and technologies that comprise today's wired and wireless information systems entangled in the Web.

As you read this section, consider the following questions: What is the difference between a service and a protocol? What is topology and what is a transmission mode? What is the purpose of each?

- Wikipedia: "Network Topology"URL

  As noted above, this article discusses some more recent information regarding these topics.

- **1.2: The Reference Models**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to section 2.2 and section 2.2.1, "The reference models", on pages 20–23. As you read, consider how we use layers as a model for describing network processing. Layers are the foundation for studying computer networks. You must understand how to work with layers to be able to describe the flow of a data request to its destination, and how the reverse occurs when the destination sends a response.

Unit 2: Networking Protocols

In life, protocols define the way we interact with other people – for example, the way we behave in a public place. In computer science, protocols are formal sets of rules that dictate the ways in which computers communicate with one another over a network medium. Protocols constitute the backbone of networking. The standard model for networking protocols and distributed applications is the International Standard Organization's Open System Interconnect (ISO/OSI) model. The Internet protocol stack TCP/IP (Transmission Control Protocol/Internet Protocol) model presents a group of protocols optimized for inter-computer communications and in particular for communications between multiple applications that may run on one computer. This unit provides an overview of the TCP/IP stack and its different layers, identifies the function of each layer, introduces the basics of how computers talk to one another in cyberspace using TCP/IP protocols, describes the techniques for wide area networks, and discusses common transmission media for the Internet.

Completing this unit should take you approximately 6 hours.

- Upon successful completion of this unit, you will be able to:
  - differentiate between the protocols in the TCP/IP model;

- list and describe each of the layers in the OSI model and the TCP/IP model;
- use the TCP/IP model and the OSI model;
- apply network techniques to create wide area networks; and
- describe fiber and copper media.

- **2.1: TCP/IP Reference Model**
  - Massachussets Institute of Technology: Hari Balakrishnan's "The Internetworking Problem"URL

    Read these lecture notes. As you read, pay special attention to the history and different versions of internetworking structure based on TCP/IP protocols.

- **2.2: Open Systems Interconnect (OSI) Reference Model**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read Sections 2.2.3 and 2.3, "The OSI Reference Model" and "Organisation of the Book", on pages 24–25.

    As you read, consider the following questions: Which came first, the OSI model or the TCP/IP model? Which layers in the OSI model appear to be missing in the TCP/IP stack? Where are they in the TCP/IP model?

- **2.3: Wide Area Networks**
  - Wikipedia: "Wide Area Network"URL

    A Wide Area Network (WAN) is a computer network that extends over a large geographical distance. Read this article for more details about WANs. There are many different kinds of WAN, such as ATM, Cable, Dial-up, DSL, Frame Relay, ISDN, Leased line, SONET, X.25, and SD-WAN, to name a few.

- **2.4: Transmission Media**
  - Transmission MediaURL

    Read this article and take notes on the following terms and concepts: different transmission media, such as linear media, bounded media, and isotropic media; copper wire; coaxial cables; and fiber optic media.

Unit 3: The Application Layer

In this unit, we will examine the application layer of the TCP/IP stack. The application layer is where all network processes and applications run. We will explore five of this layer's prominent applications: the Domain Name System (DNS), e-mail protocols, the World Wide Web's Hypertext Transfer Protocol (HTTP), Simple Network Management Protocol (SNMP), and Secure Shell (SSH). Finally, we will discuss socket programming and how it can be used to develop network applications.

Completing this unit should take you approximately 20 hours.

- Upon successful completion of this unit, you will be able to:
  - classify network application layer protocols;
  - use the DNS protocol to map hostnames to IP addresses;
  - compare and contrast SMTP with POP3 protocols;
  - improve system reliability by using client-server and peer-to-peer models;
  - build web applications using the HTTP protocol;
  - describe SNMP protocols;
  - describe SSH-based applications; and
  - define socket programming and explain its role in application processing.

- **3.1: Principles**
  -  Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to Section 3.1, "Principles", on pages 27–30. Stop at Section 3.1.1.

    As you read, consider these questions: What is the client-server model? What is the function of the client? Where does the server reside?

    Note: On page 28, the textbook lists the binary code of A as "A : 1000011b". This is incorrect. The binary code for A should be: "A : 1000001b".

  - Wikipedia: "Endianness"URL

    Read this article. As you read, note that most languages/platforms provide libraries that convert from network order to host order in the event that the host does not agree.

  - **3.1.1: Peer-to-Peer Model**
    -  Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read Section 3.1.1, "The Peer-to-Peer Model", on page 30. This section introduces the peer-to-peer model, which will be discussed further.

    -  Massachussets Institute of Technology: Hari Balakrishnan's "Overlay Routing in the Internet"URL

      As you read, try to answer the following question: how does the peer-to-peer model change or improve the client-server model discussed in the previous section?

  - **3.1.2: Transport Services**
    -  Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read Section 3.1.2, "The Transport Services", on pages 30–31.

This section discusses how networked applications are built on top of the transport service. There are two main types of transport services: connectionless and connection-oriented. What are the similarities and differences between the two types of services?

- **3.2: Application-Level Protocols**
  - There are a number of application protocols available, but only three have been included in your textbook: Domain Name System (DNS), Electronic Mail (SMTP and POP3), and HyperText Transfer Protocol (HTTP). The DNS protocol allows you to easily reference resources outside of your network. E-mail protocols allow you to reach out and communicate with friends and family, and HTTP is the popular protocol for accessing webpages on other systems.

In addition to the three application protocols covered in your textbook you will also take a look at the SNMP and SSH protocols. These two protocols are being used more and more in Internet applications. In particular, the SNMP protocol allows the administrators to manage a large network in a more efficient way, and the SSH protocol allows us to design virtual private networks over public networks.

As you read through these subunits, think about your own social networking activities. How does each of these protocols allow you to communicate using a variety of media, equipment, and file types/software?

- **3.2.1: Domain Name System (DNS)**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 3.2.1, "The Domain Name System", on pages 32–37.

    In order to access a website, you need to know the website's IP address. IP addresses can be somewhat cumbersome and difficult to remember, since they are simply four numbers separated by periods (e.g., 120.755.3.9). The Domain Name System (DNS) is the application that has solved this problem by allowing us to use "human readable" names for websites. What is the domain name for your home page on your work, school, or home LAN? What is the IP address for each one? Which would you rather use, the IP address or the domain name?

  - Wikipedia: "Domain Name System"URL

    Read this article. The Domain Name System is a networking protocol. It converts domain names to the IP addresses, which are needed to locate and identify computer services and devices with the underlying network protocols.

- **3.2.2: Electronic Mail (SMTP and POP3)**

- Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

  Read Section 3.2.2, "Electronic mail", on pages 37–46. In this section you will look at the e-mail application and explore two of the more popular protocols: SMTP and POP3. How does e-mail work? How long does it take for a message to reach its destination? Then what happens?

- **3.2.3: HyperText Transfer Protocol (HTTP)**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read Section 3.2.3, "HyperText Transfer Protocol", on pages 46–55. HTTP is a text-based protocol, in which the client sends a request and the server returns a response. In this section link across the World Wide Web via your textbook to see how this is accomplished.

- **3.2.4: Simple Network Management Protocol (SNMP)**
  - Wikipedia: "Simple Network Management Protocol"URL

    Read this article. As you read, pay special attention to the definitions of managed devices, agent, and network management system (NMS). At the same time, try to explain what kind of message flows are defined in NMS.

- **3.2.5: The Secure Shell (SSH) Protocol Architecture**
  - *OpenSSH*: "SSH Protocols"URL

    Read this article. As you read, pay attention to how SSH protocol is defined and the difference between FTP and SSH-based Secure FTP.

- **3.3: Writing Simple Networked Applications**
  - Doug Hellmann's "SocketServer – Creating Network Servers"URL

    Read this tutorial on how to make a simple network application program with Python socket. It is recommended that you download and install Python from the Python official website (http://www.python.org/) and run the sample program.

- **3.4: Summary**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read Section 3.4, "Summary", on page 61.

    This unit discusses the evolution of the Internet from IPv4 to IPv6 in application processing. Why was the change from 32-bit IPv4 to128-bit IPv6 critical for the application layer?

- **3.5: Practice Exercises**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read from Section 3.5, "Exercises", to the end of Chapter 3, on pages 61–65. These exercises further expand the key principles in this chapter. If you are a computer professional, you will enjoy the challenges and higher-level discussions in this section. For the novice, just wander through the presentations and spend more time on the topics that are meaningful to you.

    It will take a significant amount of time for you to finish these exercises. We recommend that you schedule 4 hours and attempt a few challenging exercises.
  - Enabling Remote DesktopsURL

    Follow these steps in order to control your computer from a mobile device.
  - Virtual Network Computing (VNC)URL

    Follow these steps to control your computer from a mobile device via Virtual Network Computing. Virtual Network Computing is a graphical desktop sharing system. It uses Remote Frame Butter Protocol to control another computer remotely. Even if you choose not to download the above apps, reading this article is still valuable as it provides an explanation of the difference between RDP and VNC.

Unit 4: The Transport Layer (TCP/UDP)

When we talk about networks, we are talking about data transport. The TCP/IP stack provides a TCP/UDP layer that handles the data transport between machines across networks. In this unit, you will learn the TCP and UDP protocols by examining the structure of TCP and UDP segments and identifying how this layer serves as the application layer in the TCP/IP stack.

Each application relies on the transport layer that is described in this unit. It is a key layer in today's networks as it contains all the mechanisms necessary to provide a reliable delivery of data over any unreliable network. First, we will develop a simple reliable transport layer protocol. Then, your textbook links you through the details of the TCP and UDP protocols used in TCP/IP networks. We will also study Stream Control Transmission Protocol (SCTP) and Real Time Transport Protocol (RTP), which are not covered by the textbook. These protocols are the fundamental protocols for modern multimedia applications over the Internet.

Completing this unit should take you approximately 18 hours.

- Upon successful completion of this unit, you will be able to:
  - select the correct transport layer protocol, such as TCP and UDP, to transfer data segments;

- describe the SCTP and RTP protocols and the applications based on these protocols; and
- analyze network activity at the transport layer.

- **4.1: The Transport Layer**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to Chapter 4 and Section 4.1, "Principles of a Reliable Transport Protocol", on pages 67–87.

    This section discusses the transport protocol in perfect and imperfect network service environments in terms of interactions with the Service Data Unit (SDU) at various stages of the transmission between sending and receiving nodes. What happens to your transmission when the environment is perfect? If your data gets corrupted by transmission errors, lost, reordered, or duplicated, then what happens? Explore the links in your textbook for a better understanding of what goes wrong in cyberspace and the mechanisms used to repair impacted activity.

- **4.2: User Datagram Protocol (UDP)**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 4.2, "The User Datagram Protocol", on pages 87–89.

    The UDP allows several applications running on a host to exchange SDUs with several other applications running on remote hosts. This section explores the checksum process and how the UDP accomplishes this multiprocessing.

- **4.3: Transmission Control Protocol (TCP)**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to Section 4.3, "The Transmission Control Protocol", on pages 89–90. Stop at Section 4.3.1.

    Almost every Internet application relies on the TCP in the transport layer. In this section you will discover how your favorite Internet activity exchanges data around the world. Then in the following subunits, you can travel with your data as it streams to its destination and back.

  - **4.3.1: TCP Connection Establishment**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 4.3.1, "TCP Connection Establishment", on pages 90–95. As you read, be able to describe the three-way handshake used by TCP to establish a connection.

- **4.3.2: TCP Connection Release**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 4.3.2, "TCP Connection Release", on pages 95–97. As you read, make sure you are able to identify and explain the two types of connection release.

- **4.3.3: TCP: A Reliable Data Transport Mechanism**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the beginning of section 4.3.3, "TCP Reliable Data Transfer", on pages 97–98. Stop when you get to "Segment Transmission Strategies".

- **4.3.3.1: TCP Segment Transmission Strategies**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "Segment Transmission Strategies" on pages 98–99. Stop at the "TCP Windows" section.

    This section of your textbook presents the Nagle Algorithm. What is it, and what two strategies does it provide for data transmission?

- **4.3.3.2: TCP Windows**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "TCP Windows" on pages 99–100. Stop at "TCP's Retransmission Timeout". As you read, consider the following questions: What is a TCP window according to the information provided in this section of your textbook? How does a TCP window improve processing in the transport layer?

- **4.3.3.3: TCP Retransmission Timeout**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 4.3.3, "TCP's Retransmission Timeout", on pages 100–102. Stop at "Advanced Retransmission Strategies".

    Follow the path in this section of your textbook to see how the TCP retransmission timeout improves transport performance.

- **4.3.3.4: Advanced Retransmission Strategies**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

Read "Advanced Retransmission Strategies" on pages 102–105. Stop at "TCP Congestion Control".

As you read, consider the following questions: What is the exponential back off and how does TCP use it? What is the delayed acknowledgement strategy in TCP? What is the fast retransmit heuristic as utilized by TCP? What is the SACK option?

- **4.3.3.5: TCP Congestion Control**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "TCP Congestion Control" on pages 105–113. Stop at the summary.

    TCP's congestion control is one of its best performance control features. This section explains this feature and how it improves performance in the transport layer.

- **4.4: Stream Control Transmission Protocol (SCTP)**
  - Wikipedia: "Stream Control Transmission Protocol"URL

    Read this article, which explains why we need the new SCTP protocol and how it works.

- **4.5: Real Time Transport Protocol (RTP)**
  - Wikipedia: "Real-time Transport Protocol"URL

    Read this webpage to understand how RTP is used for streaming multimedia data. As you read, pay special attention to how RTP protocol is different from TCP protocols and how it is used for multimedia data transport.

- **4.6: Summary**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the summary of chapter 4 on pages 113–114.

    The transport layer relies on TCP mechanisms to recover from the errors of the network layer. The chapter 4 summary reviews the strategies at each stage of the transmission.

- **4.7: Practice Exercises**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read through the practice exercises on pages 113–126. These exercises further expand the key principles in this chapter. If you are a computer professional, you will enjoy the challenges and higher-level discussions in this section. If you are a

novice, explore the presentations and spend more time on the topics that are meaningful to you.

Unit 5: The Network Layer

In this unit, we will learn how packets (groupings of data) travel on a network and how each machine can be addressed uniquely so that data transport between two nodes is reliable. We will learn that networks can run out of space, meaning that unique addresses for different machines are no longer available. In these situations, computer scientists must manage IP addressing using CIDR and subnetting – techniques we will learn about in this unit.

The network layer is responsible for the delivery of packets from any source to any destination through intermediate routers. Follow the links to explore in detail the IPv4, IPv6, RIP, OSPF, and BGP protocols used in today's Internet.

Completing this unit should take you approximately 31 hours.

- Upon successful completion of this unit, you will be able to:
  - choose the correct network layer protocol to perform packet forwarding;
  - compare and contrast CIDR with subnetting activities within the network layer;
  - describe IP addressing and explain its purpose; and
  - define a packet and explain its role in transporting data.

- **5.1: Principles**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to chapter 5 and the beginning of section 5.1, "Principles", on pages 127–129. Stop at section 5.1.1, "Organisation of the Network Layer".

    The network layer includes the datagram and virtual circuit modes, the separation between the data plane and the control plane, and the algorithms used by routing protocols.

    As you read this section, it is important to understand the purpose of the router and the use of the packet in enabling you to send data and receive the response. How does the packet interact with the router?

  - **5.1.1: Organization of the Network Layer**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 5.1.1, "Organisation of the Network Layer", on pages 129–132.

      What are the two internal organizations used in the network layer? When are each used? What is a datagram? Explore this section of your textbook to see how a

datagram is used in the network level. Compare and contrast the datagram organization with the virtual circuit discussed in this section.

The concept of hop-by-hop forwarding is this section. What does this concept have to do with the routing table? What is the difference between the data and control planes?

- **5.1.2: The Control Plane**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the beginning of section 5.1.2, "The control plane", on page 132. Stop at "Static routing".

    In this section, the textbook explains how the control plane maintains the routing table. The three techniques to accomplish this are static routing, distance vector routing, and link state routing. As you explore the next three subunits describing each one in detail, note the advantages and disadvantages of each technique. How does each method deal with link and router failures?

- **5.1.2.1: Static Routing**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "Static Routing" on pages 132–133. Stop at "Distance Vector Routing", which you will read below. As you read, consider the following questions: What is static routing? What are its advantages and disadvantages?

- **5.1.2.2: Distance Vendor Routing**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "Distance Vector Routing" on pages 133–137. Stop at "Link State Routing", which you will read below. As you read, consider the following questions: What is distance vector routing? What are its advantages and disadvantages?

- **5.1.2.3: Link State Routing**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "Link State Routing" on pages 137–140. Stop at section 5.2, "Internet Protocol". As you read, consider the following questions: What is link state routing? What are its advantages and disadvantages? How does link state routing handle link and routing failures?

  - Wikipedia: "Bellman-Ford Algorithm"URL

Read this article for more details about the Bellman-Ford routing algorithm. This routing protocol is used in RIP, OSPF, and BGP.

- Wikipedia: "Dijkstra's Algorithm"URL

  Read this article for more details about the Dijkstra routing algorithm. What is the Dijkstra Algorithm? How is the Dijkstra Algorithm used in link state routing? Like the Bellman-Ford algorithm, this routing protocol is used in RIP, OSPF, and BGP.

- Geographic Information Technology Training Alliance: "Djikstra's Algorithm, Step by Step"URL

  Review this demonstration, which discusses how Djikstra's algorithm is implemented step-by-step.

- **5.2: Internet Protocol**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to section 5.2, "Internet Protocol", on pages 140–141. Stop at section 5.2.1 "IP Version 4", which you will read below.

    In this section we will explore the Internet Protocol (IP) to discover how IP enables the applications running above the transport layer (UDP/TCP) to utilize any of the different datalink layers available.

  - **5.2.1: IP version 4 (IPv4)**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 5.2.1, "IP version 4", on pages 141–150.

      This section starts with a discussion of IP version 4 before exploring network addressing in more detail. As you read, consider the following questions: What are two of the problems with IP version 4 that led to the development of the Classless Interdomain Routing (CIDR) architecture? How does CIDR improve the scalability of the IP routing system?

  - **5.2.2: Internet Control Message Protocol (ICMP) Version 4**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 5.2.2, "ICMP version 4", on pages 151–157. Sometimes a router or the destination host has to inform the sender of the packet of a problem that occurred while processing that packet. In the TCP/IP protocol suite, this reporting is done by the Internet Control Message Protocol (ICMP). How are these messages generated by the ICMP?

- **5.2.3: IP version 6 (IPv6)**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 5.2.3, "IP version 6", on pages 157–164. As the popularity of the Internet grew exponentially, it became necessary for an expanded addressing architecture, IP version 6 (IPv6). This section discusses how IPv6 has resolved a number of routing issues while becoming the new standard.

- **5.2.4: ICMP Version 6 (ICMPv6)**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 5.2.4, "ICMP version 6", on pages 164–166. ICMPv6 is the companion protocol for IPv6, just as ICMPv4 is the companion protocol for IPv4. ICMPv6 is used by routers and hosts to report problems when processing IPv6 packets. In addition, ICMPv6 is used when auto-configuring addresses. This section discusses messaging for IPv6.

- **5.2.5: Middleboxes**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to section 5.2.5, "Middleboxes" on page 166. Stop at "Firewalls", which you will read below. As you read, consider the following questions: What is a Middlebox? Why do we need them?

- **5.2.5.1: Firewalls**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "Firewalls" on pages 166–168. Stop at "NAT", which you will read below. As you read, consider the following questions: When you first used your computer to access the Internet, what was the first security technique you heard about? How does a firewall protect your system from the "evil-doers" lurking on the Internet?

- **5.2.5.2: Network Address Translation (NAT)**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "NAT" on pages 168–169. Stop at section 5.3 "Routing in IP networks".

    Large corporations and government agencies prefer their networks to be private (that is, not seen on the Internet). In this section, explore the concept of private networks to learn how their need to communicate with the outside world and with specific machines under certain conditions has resulted in NAT; the mechanism

that allows private networks to communicate openly with the outside world. How does NAT work?

- **5.3: Routing in IP Networks**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to section 5.3, "Routing in IP Networks", on page 170. Stop at section 5.3.1, "Intradomain Routing", which you will read below. Routing protocols will be discussed in terms of two classifications: intradomain and interdomain. What are the differences between these classifications?

  - **5.3.1: Intradomain Routing**
    - **5.3.1.1: Routing Information Protocol (RIP)**
      - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

        Read "RIP" on pages 171–172. Stop at "OSPF", which you will read below. As you read, consider the following questions: What is RIP? What are the features of the RIP protocol? How does RIP meet the objectives of intradomain routing? What are its weaknesses?

    - **5.3.1.2: Open Shortest Path First (OSPF)**
      - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

        Read "OSPF" on pages 172–175. Stop at section 5.3.2 "Interdomain routing", which you will read below. As you read, consider the following questions: What is OSPF? What are the features of the OSPF protocol? How does OSPF meet the objectives of intradomain routing? What are its weaknesses? How is OSPF different from RIP?

  - **5.3.2: Interdomain Routing**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 5.3.2, "Interdomain Routing", on pages 175–194. As you read, consider the following questions: What are the objectives of interdomain routing? What is the difference between transit and stub domains? What are some of the relationships you can expect to find in an interdomain routing policy?

      Describe the BGP. How does BGP differ from the intradomain protocols RIP and OSPF that you've studied? What messages might the BGP generate? What is router convergence? Why is router convergence necessary? How is router convergence handled by the BGP?

- **5.4: Resource Management**

- Massachusetts Institute of Technology: Hari Balakrishnan's "End-to-End Congestion Control"URL

  Read this tutorial to understand congestion management at different levels: end-to-end, router assisted, and pricing based.

- **5.5: Practice Exercises**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read from section 5.5, "Exercises", through the end of chapter 5, on pages 195–209. These exercises expand the key principles in this chapter. If you are a computer professional, you will enjoy the challenges and higher-level discussions in this section. If you are a novice, explore the presentations and spend more time on the topics that are meaningful to you.

  - The Network Simulator: ns-2URL

    This is a software tool that helps you perform networking experiments on your computer. Download and try it with a few simple examples, such as exercise 5 (page 196) and 6 (page 197) in the textbook.

  - Network Device ScanningURL

    Follow the steps detailed in this document. You will learn how to scan for network devices in your local area network using a mobile device, in this case, the "LAN Scan HD" app.

Unit 6: The Link Layer

The final layer of the TCP/IP protocol stack that you will learn in this course is known as the link layer. This unit will explain how you can address machines on a network from that layer, use IP addresses to determine physical addresses, and identify the different mechanisms in the link layer that can correct packet collisions when data is transferred over the wire.

This unit guides you through the principles of the link layer. Then the textbook will direct your focus to computer networks with a discussion of how multiple hosts share one transmission medium. The chapter ends with a detailed discussion of the two types of computer networks that are important today from a deployment perspective: Ethernet and Wi-Fi.

Completing this unit should take you approximately 17 hours.

- Upon successful completion of this unit, you will be able to:
  - demonstrate an understanding of the link layer;
  - resolve IP addresses with physical addressing in the link layer;
  - reduce packet collisions in a network using CSMA; and

- define CSMA and describe its use in the link layer.

- **6.1: Principles**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the introduction to chapter 6 and the beginning of section 6.1, "Principles", on pages 211–212. Stop at section 6.1.1 "Framing", which you will read below.

    The datalink layer uses the service provided by each of the different technologies found in the physical layer to send and receive bits between directly connected devices. The datalink layer receives packets from the network layer. What are the two main services provided by the datalink layer? Why are these services necessary?

  - **6.1.1: Framing**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 6.1.1, "Framing", on pages 212–213. As you read, consider the following questions: What is the framing problem? What service does the datalink layer provide to resolve this problem?

  - **6.1.2: Error Detection**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 6.1.2, "Error Detection", on pages 213–214. Datalink mechanisms also help solve problems related to detecting transmission error.

- **6.2: Medium Access Control**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the beginning of section 6.2, "Medium Access Control", on pages 214–215. Stop at section 6.2.1, "Static Allocation Methods", which you will read below.

    A computer network environment faces additional problems beyond the framing and error detection issues that are resolved in the datalink layer. What are these problems? How does the Medium Access Control algorithm(s) function in any of the computer network topologies?

  - **6.2.1: Static Allocation Methods**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 6.2.1, "Static Allocation Methods", on pages 215–216. As you read, consider the following questions: What is static allocation? What are some of the

static allocation methods utilized in the datalink layer to share resources in a computer network? Describe each method and how each handles the available resources.

- **6.2.2: ALOHA**
  - Wikipedia: "ALOHAnet"URL

    Read this article, which provides a more detailed examination of the ALOHAnet structure.
  -  Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 6.2.2, "ALOHA", on pages 216–217. The University of Hawaii addressed the problem of sharing resources with its network of remote island campuses in a unique way. This description of the ALOHAnet explores their solution.
- **6.2.3: Carrier Sense Multiple Access (CSMA)**
  -  Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 6.2.3, "Carrier Sense Multiple Access", on pages 217–218. The ALOHA solution has been enhanced by CSMA. As you read, be able to describe CSMA and how it works to share computer network resources.
- **6.2.4: CSMA With Collision Detection**
  -  Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 6.2.4, "Carrier Sense Multiple Access with Collision Detection", on pages 218–222. In a wired environment, both ALOHA and CSMA performance are better able to detect collision. Can you explain why that is?
- **6.2.5: CSMA with Collision Avoidance (CSMA/CA)**
  -  Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 6.2.5, "Carrier Sense Multiple Access with Collision Avoidance", on pages 222–225. CSMA/CA is found in the Wi-Fi environment. How are collisions avoided?
- **6.2.6: Deterministic Medium Access Control Algorithms**
  -  Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

Read section 6.2.6, "Deterministic Medium Access Control algorithms", on pages 226–228. Some applications are sensitive to the time delay of transmissions. Deterministic Medium Access Control algorithms have been used to resolve this problem. Explore this section to see some of the deterministic algorithms.

- **6.3: Technologies**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read the beginning of section 6.3, "Datalink Layer Technologies", on page 229. Stop at section 6.3.1, "The Point-to-Point Protocol", which you will read below.

    It would take a library full of volumes to discuss all of the technologies used on the Internet. Your textbook has condensed this information into a discussion of six major categories. The following subunits address the datalink services of these technologies.

  - **6.3.1: Point-to-Point Protocol**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read section 6.3.1, "The Point-to-Point Protocol", on pages 228–230.

  - **6.3.2: Ethernet**
    - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

      Read the beginning of section 6.3.2, "Ethernet", on pages 230–234. Stop at "Ethernet switches", which you will read below. MAC addresses are the datalink services found in an Ethernet environment.

    - **6.3.2.1: Ethernet Switches**
      - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

        Read "Ethernet Switches" on pages 234–237. Stop at "The Spanning Tree Protocol (802.1d)", which you will read below. As you read, consider the following questions: What is an Ethernet switch? How does it function in the datalink layer? How does it utilize Medium Access Control mechanisms?

    - **6.3.2.2: The Spanning Tree Protocol (802.1d)**
      - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

        Read "The Spanning Tree Protocol (802.1d)" on pages 237–240. Stop at the "Virtual LANs" section, which you will read below. The spanning tree protocol is a distributed standard that is used by switches to reduce the network topology to a

spanning tree by eliminating all cycles. Explore the examples in your textbook to see how this technology processes frames in the datalink layer.

- **6.3.2.3: Virtual LANs**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read "Virtual LANs" on pages 240–241. Stop at section 6.3.3, "802.11 wireless networks", which you will read below. As you read, consider the following question: How do Ethernet switches create virtual LANs?

- **6.3.3: 802.11 Wireless Networks**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 6.3.3, "802.11 Wireless Networks", on pages 241–246. Wi-Fi is a very popular wireless networking technology. There are hundreds of millions of Wi-Fi devices, resulting in multiple wireless networking standards that use different frequency ranges and different physical layers. Explore the wireless revolution into the datalink layer in this section.

- **6.4: Summary and a Review of Hub, Switch, and Network Router**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

    Read section 6.4, "Summary", on page 246. In chapter 6, you explored how Local Area Networks pose a problem for transporting frames since several devices share the same transmission channel. A variety of Medium Access Control algorithms have been necessary to regulate the access to the transmission channel by reducing collisions: ALOHA, CSMA, CSMA/CD, and CSMA/CA. Review the key technologies discussed in this section.

  - S. Saurabh's "Repeaters, Hubs, Bridge Switches, and Routers"Page

    Watch this video for more details about networking devices such as switch,hub and routers. A network switch is a multiport network bridge that uses hardware addresses to process and forward data at the data link layer (layer 2) of the OSI model. A router is a networking device that forwards data packets between computer networks. An Ethernet hub, active hub, network hub, repeater hub, multiport repeater, or simply "hub", is a network hardware device for connecting multiple Ethernet devices together and making them act as a single network segment.

- **6.5: Practice Exercises**
  - Université Catholique de Louvain: Olivier Bonaventure's "Computer Networking: Principles, Protocols, and Practice"URL

Read section 6.5, "Exercises", through the end of chapter 6, on pages 246–247. These exercises expand the key principles in this chapter. If you are a computer professional, you will enjoy the challenges and higher-level discussions in this section. If you are a novice, explore the presentations and spend more time on the topics that are meaningful to you.

-  Local Area Network Service Scan and Wake on LANURL

  Follow the steps detailed in this document in order to control your computer from a mobile device.

Unit 7: Multimedia, Security, and Cloud Computation over the Internet

Multimedia over the Internet becomes more and more popular. This unit guides you through the protocols for transmitting multimedia content, such as voice and video, over the Internet, and discusses security, reliability, and fault tolerance issues related to Internet applications. You will also be introduced to one of the most recent Internet-based technologies: cloud computation, and we will briefly discuss network remote access and directory services.

Completing this unit should take you approximately 13 hours.

- Upon successful completion of this unit, you will be able to:
  - describe and compare application protocols, such as VoIP and IPTV;
  - use cloud computing;
  - describe challenges and solutions for TCP/IP security;
  - improve TCP/IP security by using security protocols;
  - evaluate remote access and directory services; and
  - apply fault tolerance techniques to improve network reliability.

- **7.1: Voice over Internet Protocol (VoIP)**

  - Linuxwall: "SIP and RTP: Overview of a VoIP Communication"URL

    Read this article, which discusses one of the most popular network applications: Voice over IP. There are quite a few industry protocols for Voice over IP; one of the most popular and widely accepted is IETF protocol SIP. As you read, pay special attention to the registering and calling process.

- **7.2: Internet Protocol Television (IPTV)**

  - Wikipedia: "IPTV"URL

    Read this article, which discusses another popular network application: Video over IP. This protocol enables us to have videoconferences over the Internet. As you read, pay special attention to the different IPTV techniques, such as video on demand (VOD), live television, and time-shifted television.

- **7.3: TCP/IP Security**

- Massachusetts Institute of Technology: Hari Balakrishnan's "Security Problems with Internet Architecture"URL

  Read this lecture. As you read, pay special attention to DoS attacks, intrusion, hijacking, Web authentication attacks, and weakness in Internet architecture.

- **7.4: Cloud Computing**
  - Wikipedia: "Cloud Computing"URL

    Read this article and take notes on the following popular terms: IaaS (Infrastructure as a Service), PaaS (Platform as a Service), SaaS (Software as a service), MaaS (Monitoring as a Service), CaaS (Communication as a Service), and XaaS (anything as a Service).

  - WAC Consulting Group: "Cloud Computing vs. On-Premise Solutions"Page

    Watch this video, which discusses the advantages and disadvantages of cloud computing and when it makes sense for companies to move to the cloud.

- **7.5: AAA Protocol, Network Remote Access, and Directory Services**
  - AAA ProtocolURL

    Read this article and take notes on the following: authentication, authorization, and accounting (AAA) and where they are used.

  - **7.5.1: Remote Authentication Dial In User Service (RADIUS)**
    - Wikipedia: "RADIUS"URL

      Read this article and take notes on the following popular terms: Remote Authentication Dial In User Service (RADIUS), roaming, realms, and proxy operations.

  - **7.5.2: Terminal Access Controller Access-Control System Plus (TACACS+)**
    - Wikipedia: "TACACS and TACACS+"URL

      Read these articles and take notes on the following: Terminal Access Controller Access-Control System (TACACS), Terminal Access Controller Access-Control System Plus (TACACS+), and how they are used in AAA Protocols.

  - **7.5.3: Lightweight Directory Access Protocol (LDAP) and Directory Services**
    - Wikipedia: "Lightweight Directory Access Protocol"URL

      Read this article and note the following terms: directory service, X.500, distinguished name (DN), and LDAP operations.

- Wikipedia: "Directory Service"URL

  Read this article and note the following terms: directory service, X.500, distinguished name (DN), and LDAP operations.

- **7.6: Network Reliability and Fault Tolerance**
  - Wikipedia: "Network Reliability"URL

    Read this article and take notes on the following popular terms: reliable network, reliable multicast, unicast protocols, and reliability properties.

- **7.7: Practice Exercises**
  -  Network Security Scanner NmapURL

    Follow the steps detailed in this document, which will instruct you how to use port-scanning techniques to administrate a large network.