INTRODUCTION TO NETWORK DESIGN AND ANALYSIS

CS206

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Topic 1: Course Introduction

This topic provides motivation to study this course.

Motivation1: Information I can receive: Now-a-days, we can get a lot of information while sitting in front of the computer. For example, we can access our bank accounts; we can receive world news, look at the weather forecast etc. This has become possible because of computer networking. This is shown next.

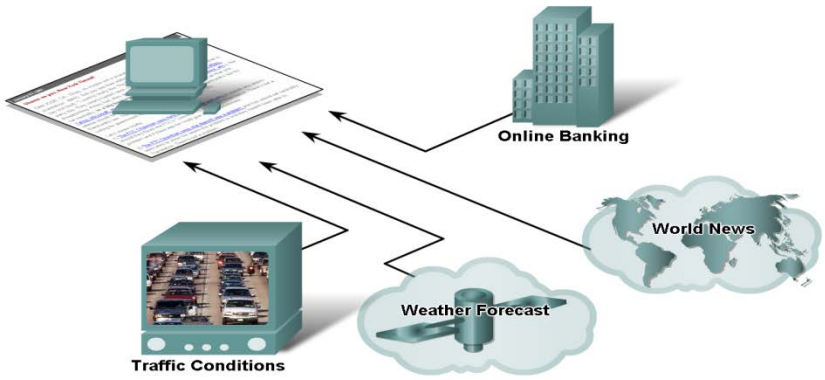


Figure taken from "CCNA Exploration Network Fundamentals" Cisco Press

Motivation 2: Daily life Applications: Email, web, instant messaging, P2P file sharing, network games, streaming videos, real-time video conferring are those applications that we use in our daily lives. We may encounter issues such as response delays, slow application at the server.

Motivation 3: Internet: The largest engineered system ever created by mankind is the Internet which consists of hundreds of millions of connected computers, communication links, and switches. There billions of users who connect via laptops, tablets, and smartphones.

In this course, we will look at how the computer networks work, how we can troubleshoot their problems using Wireshark, and how we can simulate new networks using Packet Tracer.

Course Composition: We have divided the course intro three Main Parts.

- Part 1 presents the networking fundamentals from practical point-of-view and does not delve into the theoretical nitty-gritties.
- Part 2 describes how analyzing packets with the Wireshark tool can help a student to troubleshoot his network.

- Part 3 discusses how to configure Cisco devices with practical examples and simulate networking with Packet Tracer.

Figures and Material used for Part 1(Topics 2 to 79 have been adapted from W. Odom's book with the title "*Computer Networking First-Step*", Cisco Press, 2004 unless stated otherwise.

Topic 2: What is a Network?

This topic provides the basic know how of a simple computer network.

A **computer network** is a combination of hardware, software, and cabling. This combination allows multiple computing devices to communicate with each other and thus gives computers the ability to communicate with each other. Next we show a simple network:

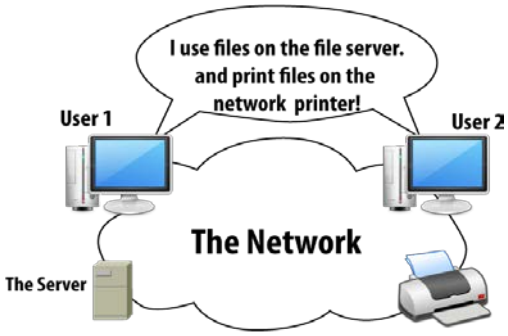


Figure 2.1: Simple Single Site Network

This is a typical small network used by a company at a single site. In a network diagram, we use a cloud to hide details such as hardware, software, and cabling. This is done, when details are not important to the current discussion. A server provides

some form of service to the users (clf

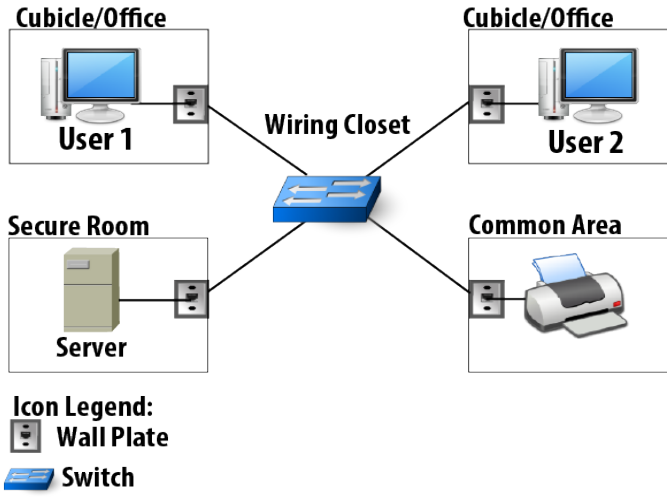


Figure 2.2: A closer Look at the simple Network

We can see that User1's PC has networking software installed, and a cable that connects his PC to a socket on the wall. That socket has a cable on the (hidden) other side of the wall plate. Cables normally run under the floor, in the ceiling, or some other hidden place, with the other end being in a wiring closet. All the cables connect to a switch inside the wiring closet. A **switch** consists of specialized hardware and software that forwards the network traffic back and forth between the various network devices on the network. There are a lots of places (called switch ports) into which you can plug in one of the networking cables.

Now, we look at the different perceptions three different people have according to their work on a different aspect of a network. First of all, we study the **Server Guy**, who is responsible for the server and needs some PC hardware skills, but more importantly, he needs strong skills with software. His perception is shown next.

The server guy views the rest of the network as a network utility i.e. he treats the rest of the network just like you think of the telephone, electrical power, and water system. There is no need to think about it unless it's not working. Next is the **Cabling Guy.** He is also known as an electrician. He runs the cables from each cubicle back to the wiring closet. His job requires physical dexterity, knowledge of how to conform to the electrical building standards. He focuses on installing, testing, and troubleshooting the cabling from each wall plate to the wiring closet. He makes sure that there's a working cable running from the wiring closet to each place in the building where a computer needs to connect to the network.

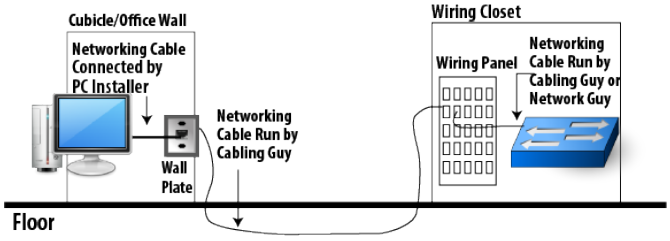


Figure 2.3: The cabling Guy's perception of the network "Elephant"

The third guy is the **Network Guy.** He is responsible for the switch, as well as any other hardware and software used to create a network utility for the computers. He installs, supports, and troubleshoots the hardware and software on the switch. He knows which computer's cable plugs into the various numbered ports on the switch. The network guy's perception is shown next.

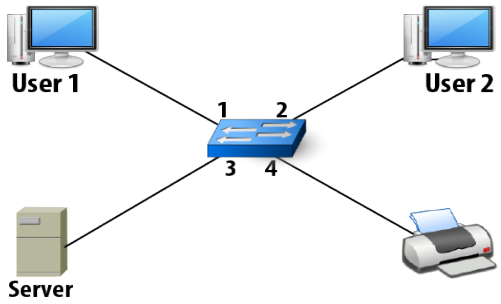


Figure 2.4: The network Guy's perception of the Network "Elephant"

Topic 3: Traditional Computer Networks

In this topic, we study different traditional computer networks.

There are two well-known examples of computer networks. They are named an **Enterprise WAN** and the **Internet.**

An Enterprise WAN is a network that should have the ability to connect all sites of a big company, located at multiple sites. You call it an enterprise network because the network is owned by and created by one company, and a company can be considered to be an enterprise.

An enterprise network is shown next.

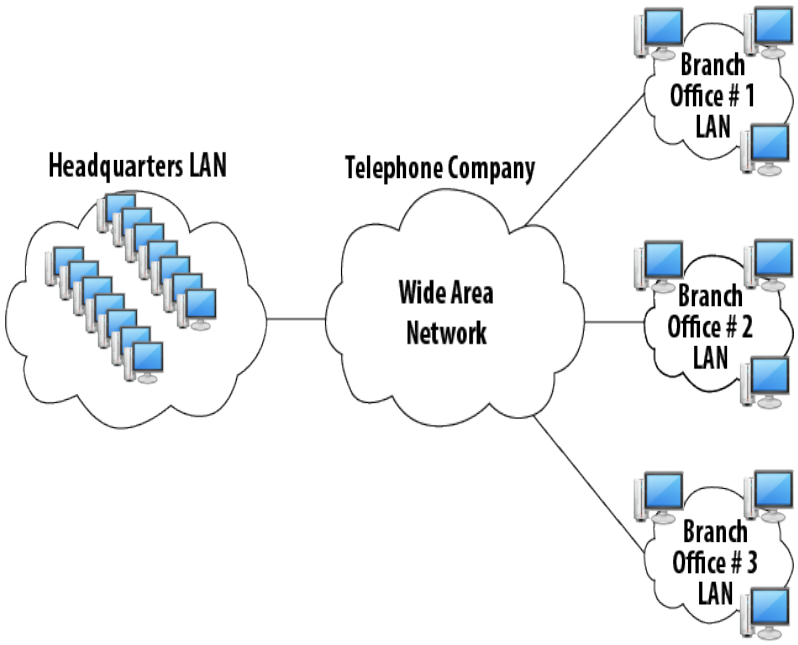


Figure 3.1: A Larger Network: AN Enterprise WAN

This typical enterprise has three remote branch offices, each with few PCs and a printer. The headquarters site has more users (hence, more PCs), as well as several servers. Each remote site consists of a simple network.

The **Internet** is a unique computer network as it connects almost all enterprise networks and individual users. We next show a part of the Internet.

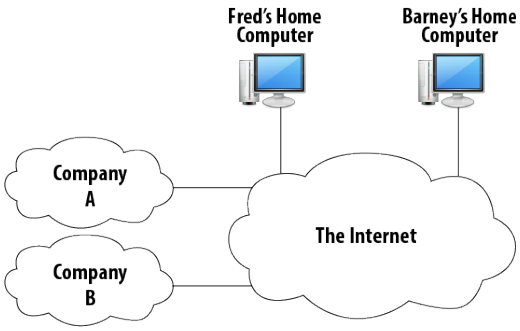


Figure 3.2: The Internet with Enterprise and individuals connected to it

The Internet works with the help of companies called Internet service providers (ISPs), which provide service to companies and individuals to connect them to the Internet. This makes almost all computers on the planet can communicate with each other.

Topic 4: Using the Network by Accident

This topic discusses the scenario when we use the network by accident.

Some of the most common network services hide the network from the end user. We call them "accidental" network services. To understand this concept, let's assume an employee named Fred working at a remote office. He is the master of his own domain; he has a PC, a printer, and he can do all his work without much interruption from the home office. Fred's daily tasks include opening a document with a word processor, changing some of the text contained in it, and printing it. He then mails the letter to the customer and saves the changes to the letter. Fred's PC is shown next.

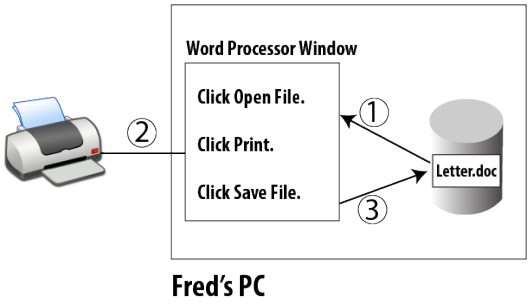


Figure 4.1: Daily task computer

As Fred's company grows, Home office sends Wilma to Fred's office to work with him and help him get all the work done. She brings her fast high-end PC with her to the new office and installs a network. She takes over Fred's old printer and connects it to her own PC. Also copies all the customer letters from Fred's PC over to her PC. The network looks like this:

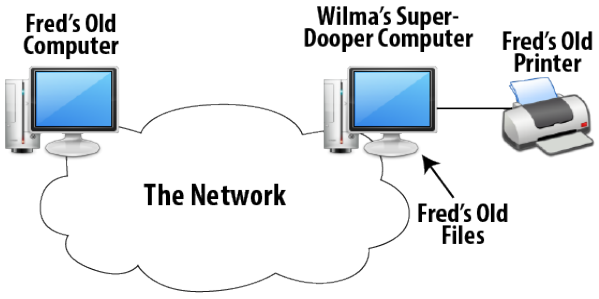


Figure 4.2: Network with Fred and Wilma's computers

As Wilma has set everything up, including the network, so she knows how it works. But Fred has no idea about the network.

To do his job on the very next day, Fred starts up his word processor, grabs a diskette, and walks over to Wilma's computer and copies a customer letter onto the diskette. He walks back to his desk, updates the letter using his old computer, and then walks back to Wilma's computer with the diskette. Then Fred copies the file

back onto Wilma's computer, replacing the old file, and brings up the word processor on Wilma's computer so that he can print a copy for mailing to the customer. This is depicted next.

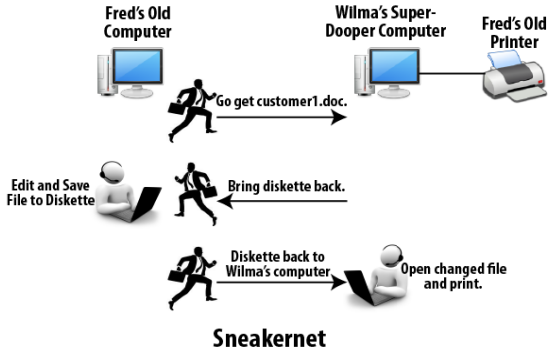


Figure 4.2: Fred's sneakernet

Fred could have done the same job in a simpler and more efficient way if he had used the network. He doesn't even need to know it's there. If Fred had just looked on his C drive in the folder called Customers, he would have seen all the same files he is used to working with. These files are on Wilma's PC - a file server but that's hidden from Fred. Also, when he clicks on the Print icon from his word processor, he'll see a printer called *same old printer*. If he prints to that printer, it will print on his same old printer, even though it's connected to Wilma's PC, which is set up as a print server.

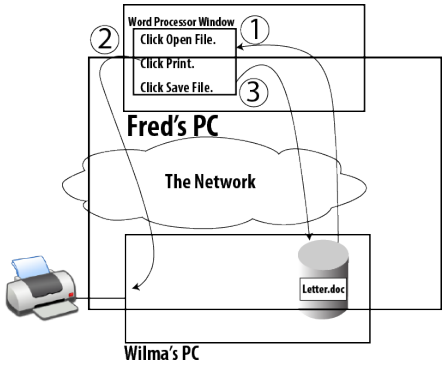


Figure 4.3: Fred's PC using the new Network

Topic 5: Using the Network on Purpose

In topic, we study the case when we use the network on purpose.

When we use the Internet, chances are high that we will be aware that we are using a network. The Internet is the global network to which almost every company and organization in the world is connected. We can make a phone call to almost anyone

on the planet because all the telephone companies in the world connect to each other. Similarly, most computers can communicate with each other over the Internet because most computer networks connect to each other through Internet Service Providers (ISPs). Networking connections among enterprises, individual home users, and other ISPs are provided by ISPs. A chunk of the Internet is shown next.

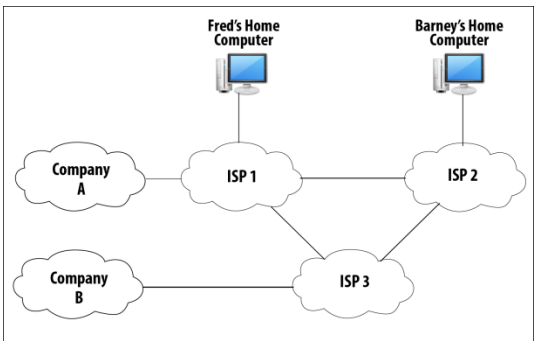


Figure 5.1: Conceptual View of the Internet

ISP1's network allows individual computers, such as Fred's, to connect to it. Fred could communicate with computers inside Company A, assuming that the security policies at Company A allowed it. Company A created its enterprise network using hardware, software, and cabling paid for by Company A. ISP1 creates its network as well using its own funds. ISP1 agrees to allow Company A's traffic to pass through ISP1 and on to other ISPs so that Company A can communicate with the rest of the world. In return, Company A pays ISP1 an ongoing fee.

Topic 6: Well-known Network Applications

This topic discusses working of the well-known network applications.

Web Browsing

A **web browser** allows you to sit at one computer and display information that resides in a **web server** somewhere on the Internet. A **web server** consists of software that resides on the computer that is accessible to the end user via the Internet. The information can be in many forms, including simple text, graphics images, animation, video streams, and audio clips. Well-known examples of web browsers are Internet Explorer, Google Chrome, Firefox Mozilla. After a browser requests a web page from a web server, the server replies by sending the contents of the web page back to the browser. Companies, organizations, and even individuals can create their own websites on the Internet. Anyone can then ask for the content in those web pages and see the results. Next, we show the working of web browsing application.

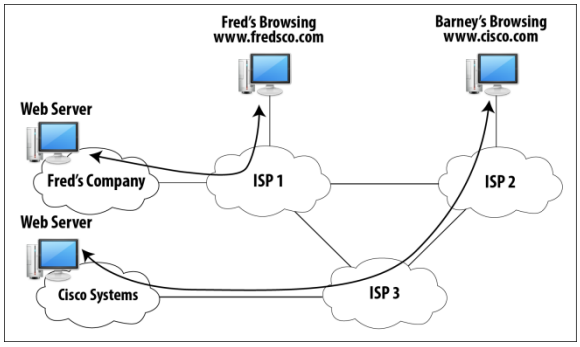


Figure 6.1: Web Browsers and Web Pages on the Internet

A client such as Fred brings up the web browser software on his computer and points to the Universal Resource Locator (URL) of the website. For example, in this case he wants to access www.fredsco.com. The URL or a web address is a string of characters that uniquely identifies a particular web page.

E-Mail

It allows a user to create, send, and receive messages electronically. E-mail is sent between one user and another user, or in some cases, to multiple other users. The person sending the mail needs to know the e-mail address of the person who needs to receive the e-mail. An e-mail address is a text string that represents the address of a person for the purposes of sending and receiving e-mail, much like a mailing address used for postal mail. Example: abc@yahoo.com. An example is shown below.

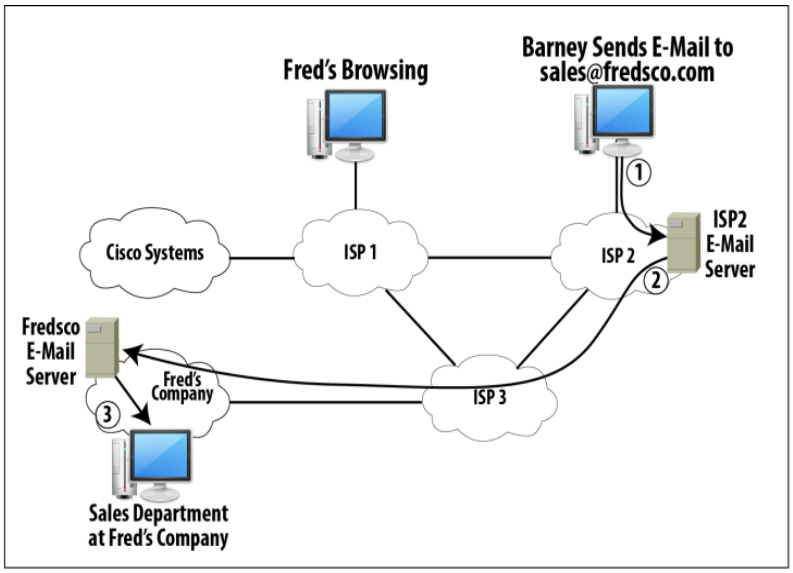


Figure 6.2: E-Mail in the Internet Using Mail Servers

In this diagram, Barney wants to e-mail the sales department at Fred's Company by sending an e-mail to the address of sales@fredsco.com. Barney does not actually

send the e-mail directly to a computer at Fred's Company. Barney sends the e-mail to his e-mail server, which for an individual Internet user like Barney, typically sits inside the ISP network to which the user is connected. An **e-mail server** is a server that receives, forwards, or holds e-mail, much like the service performed by the postal service. That e-mail server forwards the e-mail to the e-mail server at Fred's Company.

Downloading and Transferring Files

The central theme of this application is to move files into and out of your computer using a network. In most cases, the end user does not have the file, and he wants to get it. Next, we show an example where **myproject.doc** is being copied between Barney and Fred.

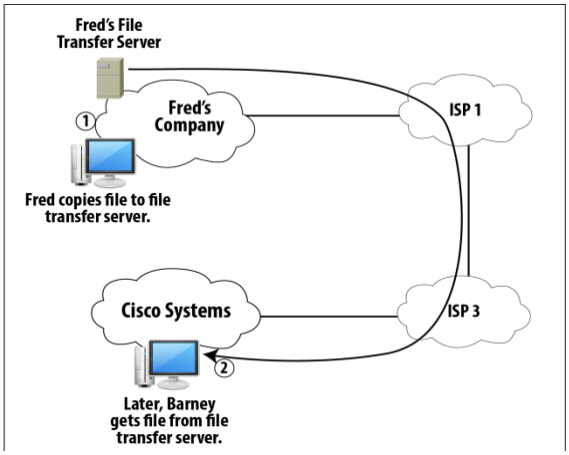


Figure 6.3: Copying myproject.doc Between Barney and Fred

File transfer is a two-step procedure:

- 1. Fred places a copy of the file onto a file transfer server, using file transfer client software.
- 2. Barney gets a copy of the file from the file transfer server, also using file transfer client software.

Topic 7: Building a Network: Starts with a Plan

In topic, we study why rules and standards are important for networking.

Standards are rules that make life a lot easier. To understand this idea, let's have a look at a power socket on a nearby wall. You may find an electrical socket with three holes two that accept flat metal prongs, and one that accepts a round metal prong. The flat metal prongs are parallel to each other. If you go to a store to buy an electrical device such as a lamp, you will expect that its power cord would fit into the

wall socket of your house. In case, does not fit into the power socket, you will get very confused.

Let's now imagine that you bought a new lamp. You plug it in, and the light bulb instantly is broken. You put in a new bulb, and it doesn't light up. You decide that there is some problem with the lamp. So you bring it back to the store and replace it with an identical lamp. When you get it home, the same thing happens to this lamp too. What to do next? Let's call the customer service to inquire from about the problem. This is our special 'We light up your life' model of lamp. It uses the same kind of power cord you are used to using but requires less electrical voltage, saving you money. If you read the instructions for the lamp, you will see that it directs you to rewire and change the voltage coming out of the sockets you want to use for the lamp. 'If you plug this lamp into a normal wall socket, the extra voltage will fry the lamp, and it will no longer light up your life.' So contact an electrician and get your socket changed.

A standard therefore tends to define a particular thing, such as the shape of the wall socket and connector used by an electrical socket and electrical power cable. Another standard might dictate how much voltage flows through the wall socket, whether it is AC or DC, how much current, and the like. Both standards are important and must be followed to prevent exploding lamps. Similarly, networking has standards. First, the PCs in the network need some form of physical connectivity. Physical connectivity refers to the combination of cabling, networking devices, and network interface cards (NICs) in the computers, which together provide the physical capability to transmit and receive data across a network. Next, we show this idea.

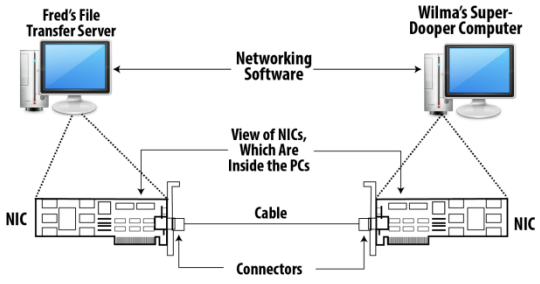


Figure 7.1: Components of a Simple Network

Both PCs have an NIC installed, and each card has a receptacle into which a cable can be connected. To emphasize their existence, the NICs are shown outside the PCs. The two computers must implement the same standards for how the networking software on each computer tells the other what it wants to do.

Topic 8: Examples of Good Rules for Networking

This topic presents examples for implementing networking.

Example 1

When two humans communicate one person says something and the other person listens. The two people need to understand the same language. Similarly, when computers communicate with each other over a network, the sending application needs to send some information to an application on the receiving side. Let's assume Fred's computer is using Wilma's computer, which is configured as a file server.

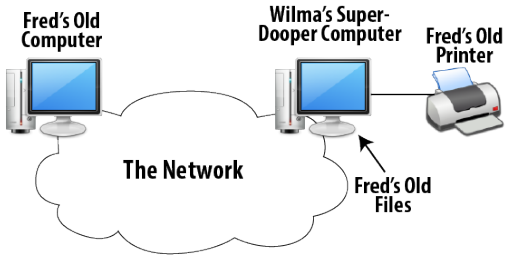


Figure 7.2: Data Transmission Using Packets

Over the network, the file will be transmitted in the form of binary digits (bits). The file server reads the file from the disk. A networking standard will define the encoding rules so that data can be transmitted. For example, it can ask the sender to change the voltage to one level to mean a binary 0, and another to mean a binary 1. In our example shown above, the NIC inside Wilma's computer sends some electrical signal over the cable. The device on the other end of the cable Fred's PC NIC interprets the incoming electrical signal. This will work if both NICs agree to some standard means of transmission. For instance, imagine that Wilma's NIC sends a +5 volts to transmit a binary 0 and +10 volts to send a binary 1. If Fred's NIC expects to receive a +2 volt signal for binary 0 and +4 volts for binary 1, the network will not work because Fred will not understand what Wilma is sending him.

Example 2

Devices in a network send bits in groups, generally called packets. Assume Wilma wants to send a file to Fred. She sends the data bits in the form of three packets as shown next.

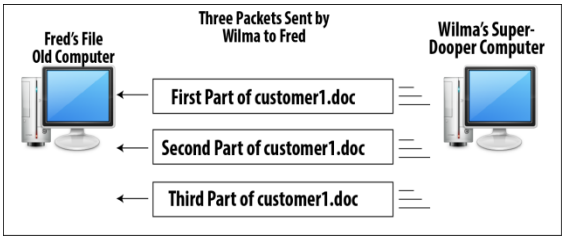


Figure 7.3: A Simple protocol for Error Recovery

We assume that Fred received all the three packets. The second packet has some bits that he is unable to understand. This may have occurred due to electrical interference (one electrical signal changes because of some other nearby electrical signal). If both NICs have agreed upon +5 volts to be a binary 0, and +10 volts to be a 1, then the receiving NIC will get confused upon receiving let's say +7.5 volts. A standard needs to be defined to address this issue. Both Wilma and Fred's computer software must agree to use the same networking protocol that provides a method to recognize and recover from errors. In the diagram below, we have shown such as error recovery mechanism:

1- The sender of the packet numbers the packets.
2- When the receiver (Fred) notices the error, he can send a message back to the sender (Wilma) asking her to send the specific packet again.
3- Wilma replies to Fred's request by resending packet 2.

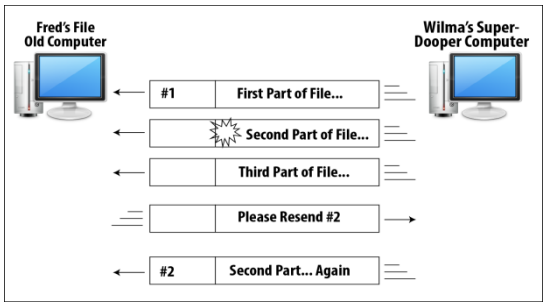


Figure 7.4: Error Recovery

Topic 9: Proprietary and Public Models

In this topic, we describe Proprietary and Public Models.

Networks began to be developed as part of each computer vendor's offerings by the late 1960s, and they became popular by the late 1970s. Each computer vendor created its own networking model, which helped computers from that one vendor communicate easily. At the advent of networking, the two largest computer vendors in the world were: International Business Machines (IBM) and Digital Equipment Corporation (DEC). IBM created its own networking model called Systems Network

Architecture (SNA), and DEC created its own DECnet. Each of these vendor-proprietary networking models allowed networks to be created and implemented and they worked but they were issues. Proprietary networks cannot communicate with other networks. IBM computers could not communicate with DEC computers.

Let's assume a company that owns some IBM computers and some DEC computers. How the company can form a network? The company should have two separate networks?

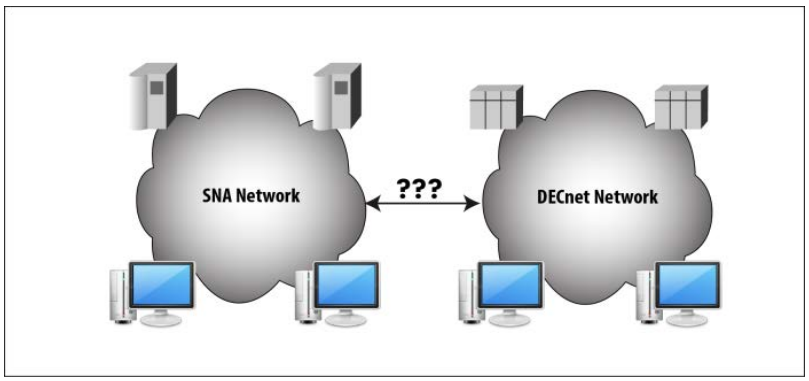


Figure 9.1: Non-Networking of IBM and DEC Networks in a Single company

Two solutions emerged: one short term, and one long term.

Short term solution

DEC made its computers conform to the IBM SNA model as IBM was roughly 10 times larger at the time in terms of gross revenues. So, DEC created software that converted between DECnet standards and SNA standards. DEC created a DEC-to-SNA gateway, which allowed the DEC and IBM SNA devices to talk.

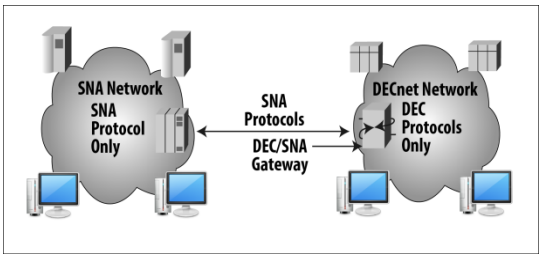


Figure 9.2: DECnet Emulating SNA Using a Gateway

Long term solution

The second, better, and long-term solution was to get IBM and DEC to stop using their proprietary networking models and use a public, open networking model. Due to this, all computers can communicate easily. Public network models provide pervasively popular networks. Today, we live in a world in which practically every computer uses the same public network model, called Transmission Control Protocol/Internet Protocol, or TCP/IP. No one vendor dictates the standards and protocols for it. Individuals from many companies and organizations have participated in the standards definition process. The Internet Engineering Task Force (IETF) manages the process of creating TCP/IP standards. IETF is open to any interested individual and its URL is http://www.ietf.org.

Topic 10: How TCP/IP Standard Grows?

This topic describes how TCP/IP standard grows.

The Internet Engineering Task Force (IETF) manages the creation and approval of TCP/IP standards and protocols. Each standard or protocol of the TCP/IP model is defined in a document. It is posted on the Internet so that anyone can look at it and comment before it becomes a Requests for Comments (RFC). TCP/IP is composed of a lot of individual protocols. The name TCP/IP is a combination of the two most popular protocols inside the TCP/IP model.

Transmission Control protocol (TCP)

TCP is described in RFC 793. TCP appends a TCP header in front of the user data. A header is a bunch of overhead bits added to the user data so that a protocol can do its job. Acknowledgment number is a field in the TCP header. TCP uses it for error recovery. On the receiver, TCP uses it to inform the sender which packet he expects to receive next and can thus be used to inform about erroneous packets.

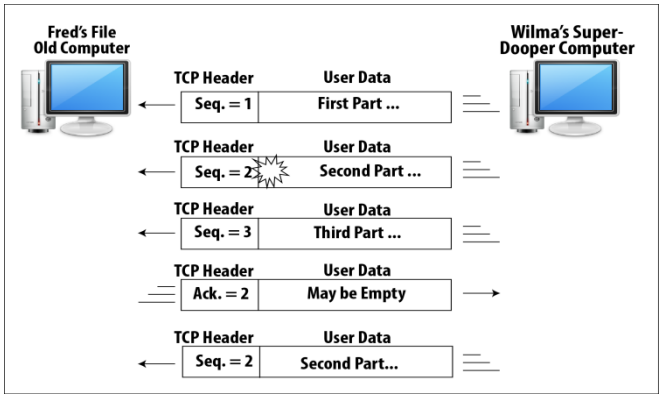
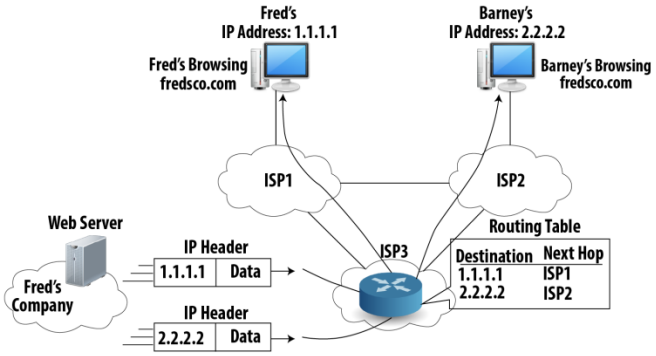


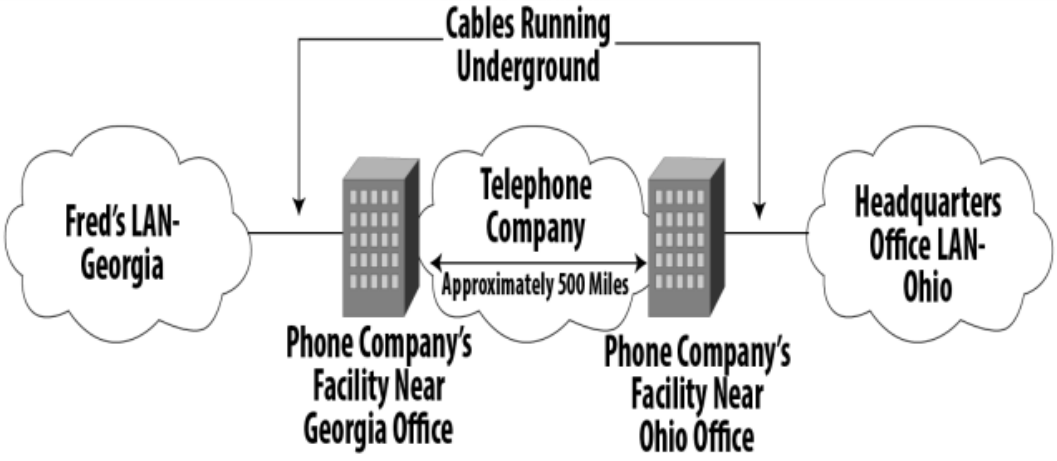
Figure 10.1: TCP Error Recovery

The Internet Protocol (IP)

IP is another TCP/IP standard protocol. It defines logical addressing and routing for the TCP/IP model and is explained in RFC 791. The best analogy for understanding IP's working relates to the postal service. Before you put a letter in the mailbox, you put an address on the front. Similarly, a computer sends a packet over the physical network by putting an address in front of the packet. In addition to TCP header, IP adds its own header. IP address is used for identifying a computer. Besides names, NTN/CNIC numbers are identifiers for different purposes. www.fredsco.com is a string for a computer which humans can remember easily. A number such as 3.3.3.3 is computer-friendly. Computers are identified by IP addresses. When packets are received by a router, the router looks at the IP address and decides where to forward the packet. A router uses a table, called a routing table. This is shown next.



There are other standards bodies who have already defined standards that TCP/IP can easily use. IETF happily references other well-known standards created by other standards organizations. For example, The Institute of Electrical and Electronic Engineers (IEEE) defines standards for LANs, which defines a type of network, or a part of a larger network, in which the devices are relatively close together. By "close", we mean in the same building or in the same small campus of buildings. Like any other network, a LAN includes computers, hardware, software, and cabling that allow communications to happen. TCP/IP standards simply say "Use IEEE LAN standards if you want to use a LAN." Another example is the International Telecommunications Union (ITU), which defines standards for WANs. A wide-area network (WAN) defines a type of network, or part of a network, in which the devices are relatively far apart. A WAN is a network, or part of a network, for which the cabling must pass outside the property of one company. The distance might only be a few miles, or it might be thousands of miles!



Topic 11: Two-Well Known Networking Models

In this topic, we study TCP/IP and OSI networking models.

Systems can be implemented more efficiently and more effectively if the activities are broken down into layers. Layering helps in product development, and it helps in keeping each protocol simple. The reduced complexity makes for better products and more stable networks.

The TCP/IP Style

TCP/IP really is a set of protocols and standards, some not even defined directly by TCP/IP, that allow you to create networks. Some people segment the TCP/IP network model into the four layers. Others consider it to be a five-layer model. From a practical perspective, it does not matter.

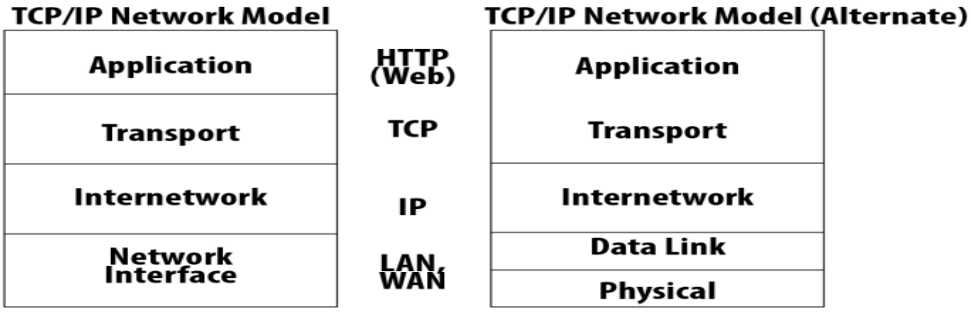


Figure 11.1: TCP/IP Model

Each layer represents a general function that must be accomplished.

The OSI Style

While TCP/IP was being evolved into a legitimate networking model, a competing public networking model, called Open Systems Interconnect (OSI), was being

developed. The OSI model was developed by an organization called the International Organization for Standardization (ISO). The aim was to build the end-all networking model i.e. once implemented by all computers on the planet; it would allow pervasive communications among all computers from all vendors in all countries everywhere! OSI uses a seven-layer model, instead of the four (or five) layers in the TCP/IP model.

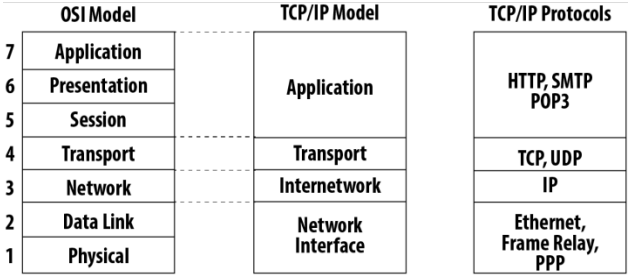


Figure 11.2: OSI & TCP/IP Models

TCP/IP versus OSI:

OSI was developed much more slowly than TCP/IP. TCP/IP took over the marketplace before OSI could be finished. ISO plays an active role in standards development even today, working with the IETF, ITU, and other standards bodies.

Topic 12: What is a Local Area Network?

This topic describes the basics of local area network.

A LAN is a network in which the devices are relatively close together i.e. in the same building or in the same small campus of buildings. The simplest LAN consists of at least 2 computers, networking software, a cable and network interface cards (NICs). It is shown next.

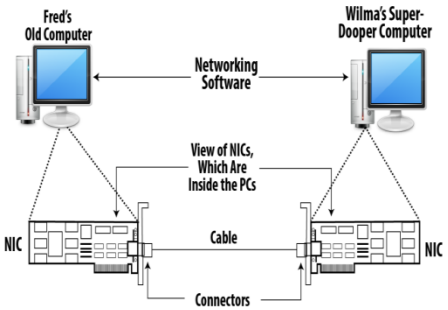


Figure 12.1: Components of a simple Network

Assume Fred opens a file on his computer that resides on Wilma's disk drive. Then, prints the file on the printer connected to Wilma's computer, and finally, saves the file back on Wilma's disk drive. This sequence is shown

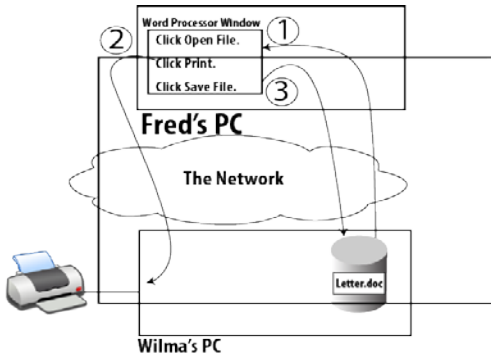


Figure 12.2: Basic Flow with Fred Using a file/ print server

A file is just a bunch of bits. In the previous example, the network needs to be able to transfer a bunch of bits from one computer to another. To send a binary code from one device to another, the sending device puts some electricity on the wire. An NIC can vary the voltage level of an electrical signal to different values. One value represents a binary 1 while the other means binary 0. Assume that a company employs an encoding standard that makes the NICs to define a binary 0 with a voltage of ±5 volts, and a binary 1 with ±10 volts. This is shown next.

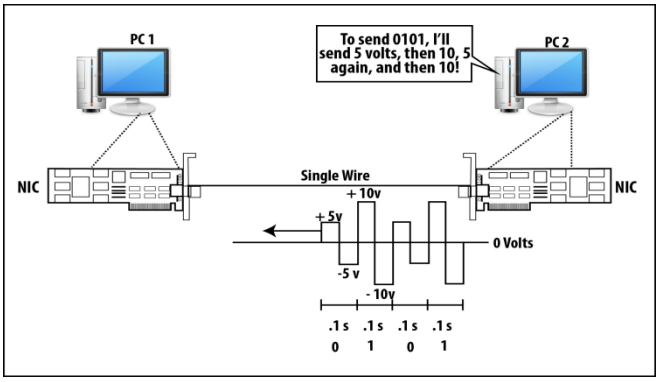


Figure 12.3: Basics Data of Transmission across a wire

PC2 wants to send a binary value 0101. It generates some electricity on the wire according to the encoding scheme. PC1, on the other end of the wire, senses the incoming electrical signal. It interprets the electricity, using the same set of encoding rules to mean 0101, exactly as PC2 intended. **Digital Transmission** is the use of discrete, constant values, which are then instantly changed to other possible discrete values. When both sender and receiver agree to encoding scheme, and the

rate at which the bits are transmitted over the wire. The receiver (PC1) must think about the electrical signal at different points in time, on a regular interval. The sender (PC2) must use the same regular time interval to decide when it should change signal.

An Example

Assume PC2 varies the voltage to mean either 0 or 1 every .1 seconds, and PC1 samples the incoming electrical signal every .1 seconds. The speed of this connection is 10 bits per second (bps). Digital Transmission does not work correctly if the two PCs do not agree on the transmission speed. For example, if we assume that PC2 thought the speed was 10 bits per second, meaning it should encode a new bit every 1/10 of a second. If PC1 thought that it should be receiving a bit 20 times per second, it would sample the incoming electrical signal every 1/20 of a second. PC1 would think it was sending 10 bits each second, and PC2 would think it received 20 bits. In real life, LANs typically run at much higher speeds, with a slow LAN transmitting at 10 million bits per second (Mbps, also called megabits per second). Can PC1 and PC2 talk simultaneously in both directions over the same wire? The electrical signals would overlap, and neither PC1 nor PC2 could understand what was sent. This is shown next.

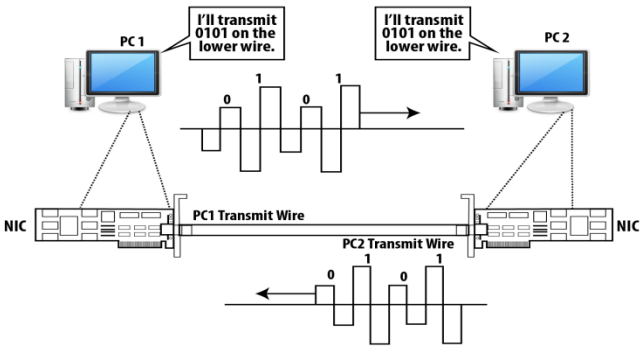


Figure 12.4: Concurrent Data Transmission across Two Different Wires

Topic 13: LAN Cables and Connectors

In this topic, we study LAN cables and connectors.

Cabling and connectors are used to manage the wires.

Cables

The copper wires that networking cards use are encased inside a cable which is made from plastic. A thin plastic coating painted onto each wire helps prevent it from breaking. Different colors of plastic coating for each wire helps in looking at each end of the cable and figuring out which wire is which.

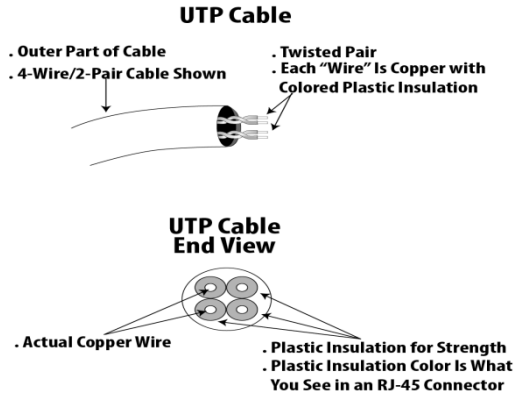


Figure 13.1: Typical LAN Cable

The electrical currents on the wire can change when electrical signals that exist in the air caused by other wires or other nearby electrically powered devices – Electromagnetic interference (EMI). A computer might misinterpret a 0 as a 1 or a 1 as a 0, or might not understand what the sender really sent. To reduce electrical interference, the wires are twisted together in pairs. Such a pair is called a twisted pair. Shielding can be added to the cable to reduce EMI. The cable becomes less bendable but more expensive. Such a cable is called shielded twisted pair (STP). This is shown next.

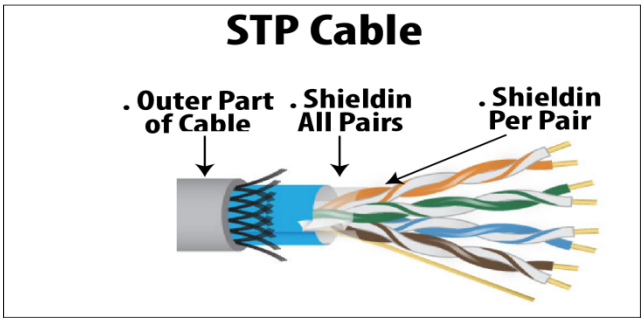


Figure 13.2: Shielded Twisted Pair (STP) cabling

Unshielded cables are called unshielded twisted pair (UTP). Mostly, the LAN technology employs less expensive UTP cabling. STP cabling is preferred in environments where significant EMI exists.

Connectors

They line up the wires on the end of a cable. Each colored wire has a specific reserved place inside the connector. A pin is a physical position in the end of the connector in which the copper part of the wire sits.

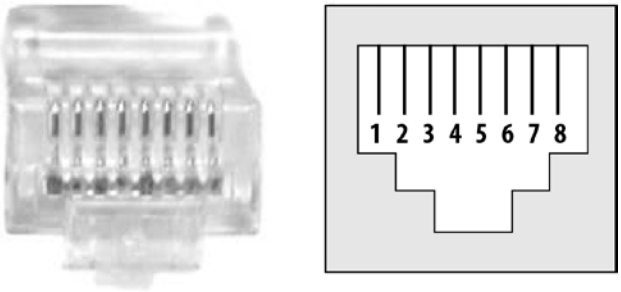


Figure 13.3: Typical Networking connector (RJ 45)

The Telecommunications Industry Association (TIA) and Electrical Industries Alliance (EIA) define standards for which wires fit into which pins when you make a cable for use with LAN. Eight wires can fit into an RJ-45 connector. EIA/TIA standards suggest numbering schemes for the eight pin locations and the pairs of wires. Two of them are shown next.

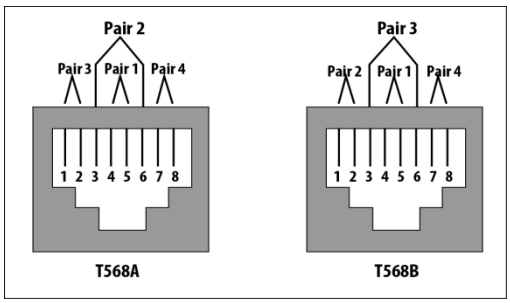
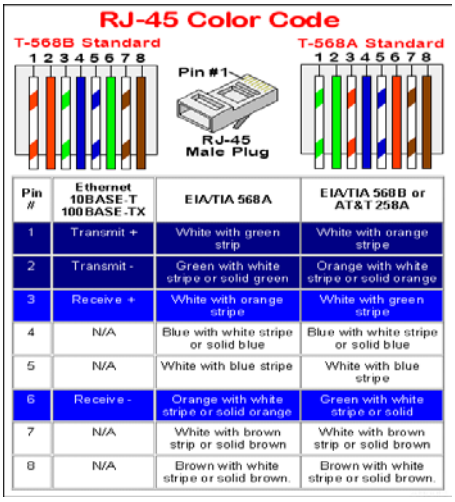


Figure 13.4: Pinout options for (RJ 45) Connectors

The standard also specifies which color of wire goes into pin position 1, 2, and so on. The **RJ-45 Color Code** scheme is shown next.



Pin #	Ethernet 10BASE-T 100BASE-TX	EIA/TIA 568A	EIA/TIA 568B or AT&T 258A
1	Transmit +	White with green strip	White with orange stripe
2	Transmit -	Green with white stripe or solid green	Orange with white stripe or solid orange
3	Receive +	White with orange stripe	White with green stripe
4	N/A	Blue with white stripe or solid blue	Blue with white stripe or solid blue
5	N/A	White with blue stripe	White with blue stripe
6	Receive -	Orange with white stripe or solid orange	Green with white stripe or solid
7	N/A	White with brown strip or solid brown	White with brown strip or solid brown
8	N/A	Brown with white stripe or solid brown.	Brown with white stripe or solid brown.

Figure 13.5: Color code scheme of RJ45 Connector

NICs send data over the twisted pair that uses pins 1 and 2 of an RJ-45 connector and receive data on the twisted pair that uses pins 3 and 6. Let's cable one end of a wire in pin 1 of one connector, and the other end into pin1 of the other connector. Pin 2 on one end of the cable connects to pin 2 on the other side and so on. This arrangement is called a straight-through cable. This is shown next.

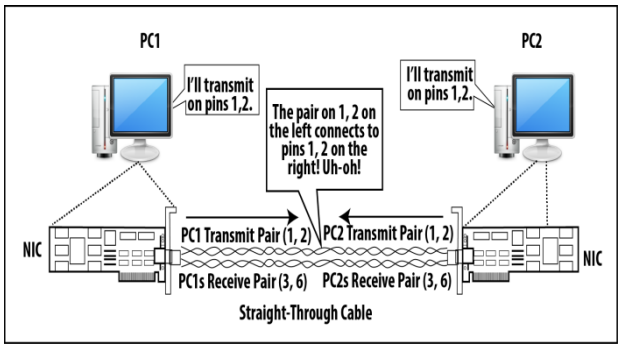


Figure 13.6: Both PCs Using the Same Pair (Lane) to send data

NICs of both PCs send data at pins 1 and 2. That electricity goes over the wires and enters the other NIC on pins 1 and 2. But, the NICs aren't receiving data on pins 1 and 2! Hence, both PCs send, but neither receives data. If we connect the wire at pin 1 on one end of the cable with pin 3 on the other end; the wire at pin 2 with pin 6 on the other end; the wire at pin 3 with pin 1 at the other side; and the wire at pin 6 with pin 2 at the other side. This arrangement is called cross-over cables. The NICs of the two PCs can receive the data sent by the other device! This is shown next.

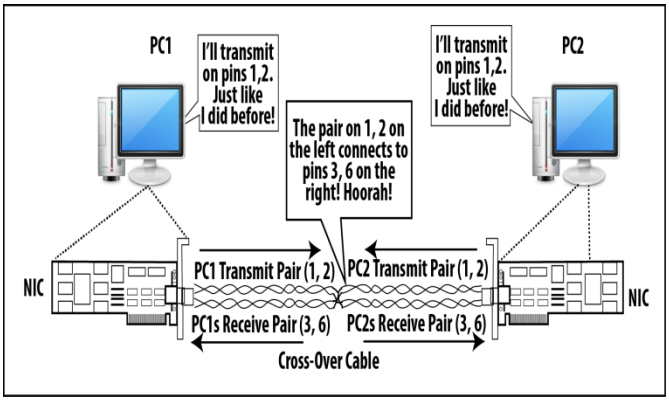


Figure 13.7: Both PCs Using Different Pair (Lane) to send data

Topic 14: Ethernet Hubs

This topic explains the basics of Ethernet hubs.

Ethernet is by far the most popular type of LAN today. Ethernet LANs are highly used at work and school. To connect to other PCs, you would need more LAN NICs, and your PC probably does not have enough room for all the cards. Also, you would need to run cables between your PC and all the other PCs. If you tried to do this for 100 PCs on the same floor of the building, and every PC wanted to connect to every other, you would have 99 cables connected to 99 NICs inside each PC!

The alternative to running a cable to every other PC is to run a cable from each PC to a wiring closet and connect the cables to a networking device, called an Ethernet hub. An Ethernet hub allows the electrician to cable each device to the hub using only a single NIC and single cable. It eliminates the cabling problem. This is shown next.

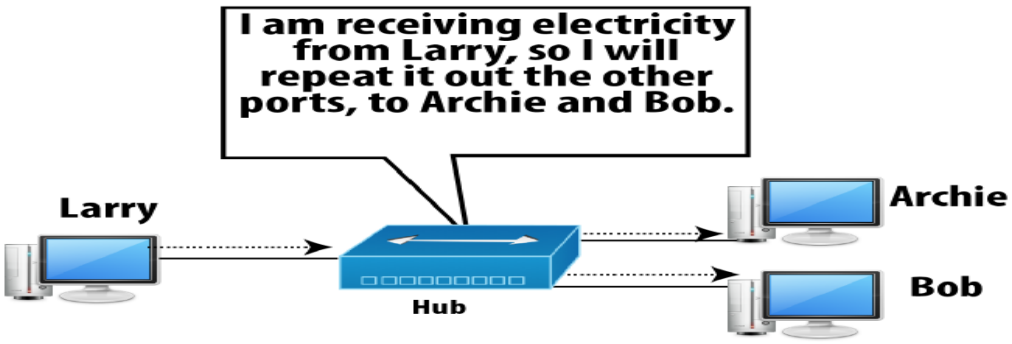
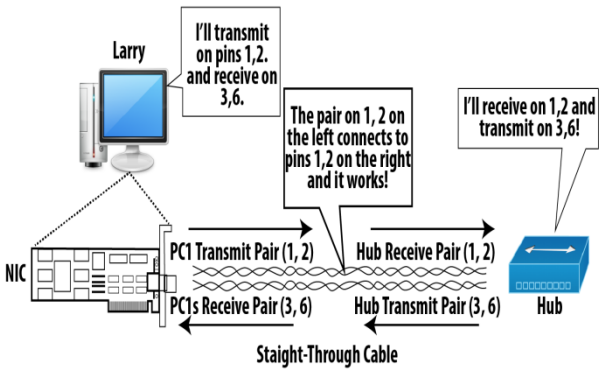


Figure 13.6: Ethernet Hub repeats everything it hears

The hub simply listens for incoming electrical signals, and when received, the hub repeats the same electrical signal to every other device that's connected to the hub. The hub expects straight-though Ethernet cabling between itself and the PCs. This is

opposite of Ethernet's pin configuration. A straight-through cable works between a PC NIC and a hub. This is shown next.



Hubs Logic:

1- Receive traffic on pins 1 and 2 on each physical interface.

2-When received, repeat the same electrical signal out all other ports, except the one in which the data was received.

3-When repeating out other ports, repeat the traffic out pins 3 and 6 so that the PCs will be listening.

Topic 15: Ethernet Frames and Collisions

In this topic, we study Ethernet frames and learn why collisions occur.

Ethernet is world's most popular LAN standard. It consists of a set of standards and protocols for LAN communication, as defined by the IEEE. For instance, Ethernet standards define how a network interface card (NIC) should encode binary 0s and 1s on a wire by varying the voltage. Before a PC could ask an NIC to send data, the PC must encapsulate the user data inside an Ethernet frame. i.e. take the data and add a header and trailer to it. Ethernet standard defines the formats of headers and trailers. The resulting bunch of bits created including the Ethernet header and trailer is called an Ethernet frame. This is shown next.

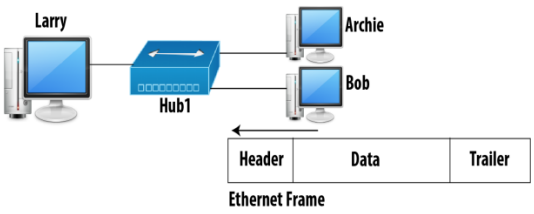


Figure 15.1: Ethernet Frame sent from Bobs to Larry

The information in header and trailer are used by the computers, NICs, and networking devices to make the Ethernet work smoothly. The first 8 bytes in an Ethernet header are called the preamble. The preamble contains alternating 1s and 0s so that the NICs receiving the data know that a new frame is being sent across the LAN. A collision occurs when two or more frames are sent over a single twisted pair at the same point in time. The result is that none of the frames is intelligible. Even when all devices follow Ethernet rules, collisions can happen. Let's focus on two key facts. **Fact1:** When two or more electrical signals travel over the same pair, both electrical signals are distorted and become a single signal. The receiving device cannot interpret the signal as 0s and 1s. **Fact2:** A hub repeats received electrical signals out on all other physical ports on the hub, except the one over which the signal was received, even if other electrical signals are already being repeated. This is shown next.

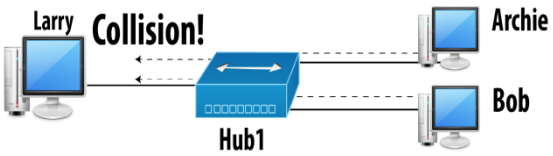


Figure 15.2: Collision between Bob's and Archie's Frames

What happens when both Bob and Archie send an Ethernet frame to Larry at the same time? The hub blindly repeats each of the frames sent by Bob and Archie out all other ports, including the one connected to Larry. Larry cannot understand either frame because the hub is trying to send both electrical signals over the cable to Larry at the same time.

Topic 16: How to avoid Collisions over Ethernet?

This topic discusses how to avoid collisions over Ethernet.

Imagine that you are connected to a hub, and you are currently receiving a frame. What would happen if you sent a frame at that time? This will cause a collision. Ethernet standards define a basic algorithm that helps reduce collisions, as well as defining what to do when collisions occur. The algorithm is called the carrier sense multiple access collision detect (CSMA/CD) algorithm

The CSMA/CD Algorithm

It is based on a simple concept: Listen before sending, and wait until you are not receiving a frame before you try to send your frame. Well, that's exactly what the algorithm calls for. Why not just wait a moment? This is shown next.

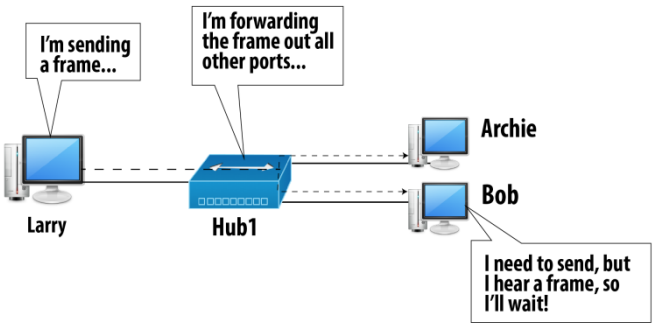
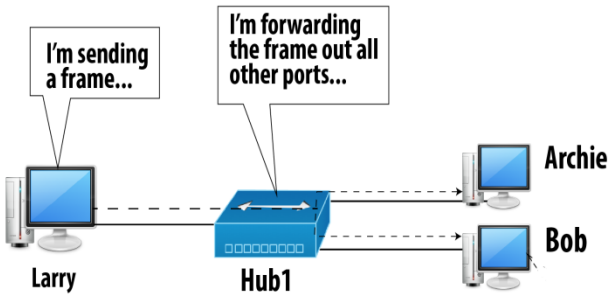


Figure 16.1: Collision Avoidance by Listening before sending

Even when you are using CSMA/CD, collisions can still occur. Why? Let's imagine Larry Bob and Archie are connected via an Ethernet. Currently Larry is sending a frame. Bob and Archie want to send frames over the LAN. Possible after Larry finishes. This is shown next.



When no one is sending anything, there is no electricity flowing over the wires and we say that LAN is silent. As soon as both Bob and Archie stop receiving an electrical signal, both try to send their frames at roughly the same time. This is shown next.

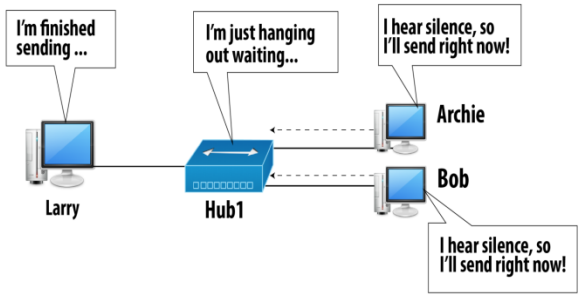


Figure 16.2: An imminent and Unavoidable Collision

The hub will repeat both frames out to Larry, so Larry will know about the collision. The hub won't forward Bob's frame back to Bob, Bob receives one frame. The same happens with Archie. Bob and Archie do not know there's a collision! When an NIC transmits a frame, it receives its own frame as well. This is called a loopback circuit. By using loopback, while Bob is sending a frame and if Archie also sends a frame at

the same time, the hub forwards Archie's frame to Bob and now Bob knows there is a collision.

CSMA/CD: what to Do When a Collision Happens

1. The senders of the collided frames send a jamming signal to make sure everyone knows a collision has occurred.

2. The senders of the collided frames independently pick a random timer value.

3. Each sender waits until his own random timer has expired and then tries to send his frames again.

Topic 17: Importance of Ethernet Addresses

In this topic, we learn the importance of Ethernet Addresses.

In an Ethernet LAN with a hub, a computer receives a lot of Ethernet frames due to the hub logic. Only some of them contain data that is meant for that computer. Consider Larry, Archie and Bob are connected over an Ethernet LAN with a hub. A frame sent by Larry to Bob will be received by Bob and Archie.

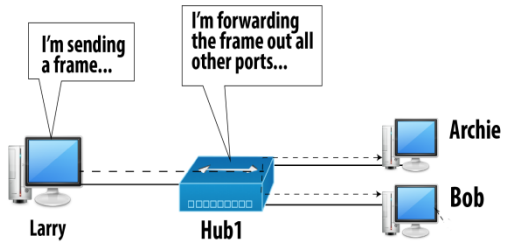


Figure 17.1: Collision Avoidance by Listening Before Sending

Archie should simply ignore the frame, and Bob should examine the data and process it. Practically, this becomes possible with the help of Ethernet Addresses. Before Larry sends the frame, he puts Bob's Ethernet address into a field in the Ethernet header called the destination address field. Next, we show working of this concept:

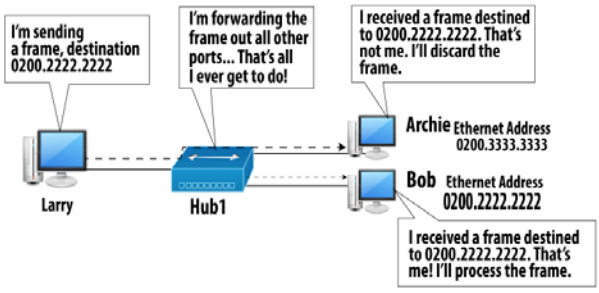


Figure 17.2: How Bobs Decides the frame was sent to Him

Each NIC has a unique Ethernet address, which is put onto the NIC by the NIC manufacturer. Ethernet standards specify that addresses be 48 bits long (6 bytes). The Ethernet header includes both a source address field and a destination address field. The source address identifies the Ethernet address of the NIC that sent the frame. When an NIC receives a frame, it uses the destination address to decide whether to process it or ignore it.

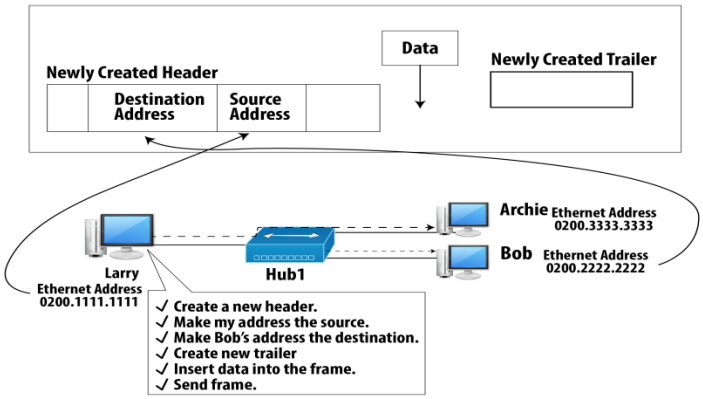


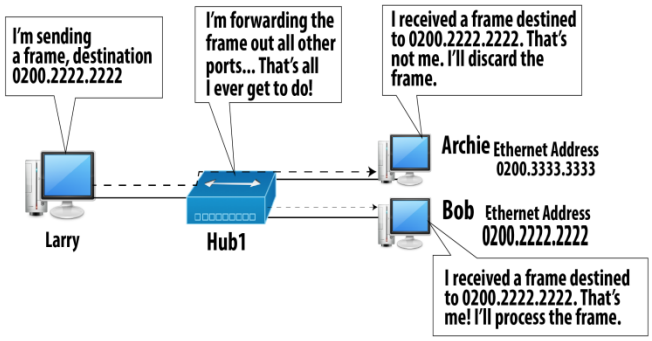
Figure 17.3: Ethernet Source and Destination Addresses

After Larry assembles the frame, he can use CSMA/CD logic to determine when he can send the frame.

Topic 18: Frame Check Sequence

This topic describes the usage of Frame Check Sequence.

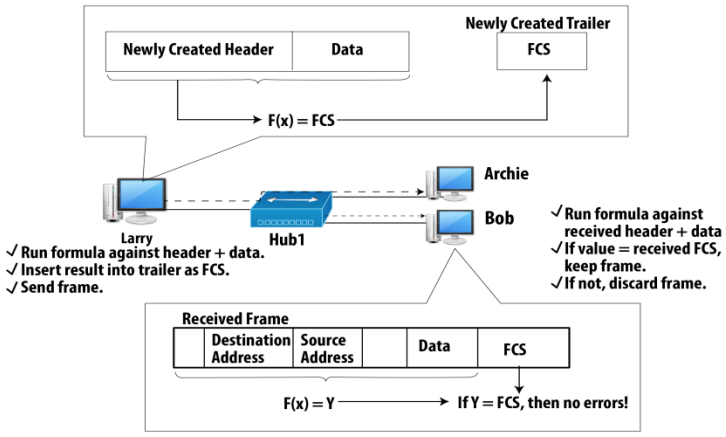
Consider Larry, Archie and Bob are connected over an Ethernet LAN with a hub. Larry sends a frame to Bob. This is shown next.



When Bob's NIC interprets the incoming electrical signal as meaning some string of binary 0s and 1s, it might misinterpret the meaning. Electrical signal has changed as it passed over the wire, affected by resistance in the wire, EMI, collisions, and other factors. Sender might send a 1 and the receiver might think it was a 0, or vice versa. Ethernet uses a field in the Ethernet trailer called the frame check sequence (FCS)

field. It holds a 4-byte number that is set by a sender and allows a receiver to determine whether a frame contains bit errors.

A sender runs a mathematical formula, with the input being the contents of the Ethernet frame to be sent, up to the Ethernet trailer. The sender places the results of the formula into the trailer FCS field. On the receiver's side, the receiver applies the same formula to the same part of the Ethernet frame (everything up to the trailer). If the result of the formula as calculated by the receiving NIC is the same as the value in the transmitted FCS, then no errors occurred. Otherwise an error has occurred.



Ethernet standards specify that the receiver should simply discard frames that have errors. The receiver does not request that the frame be re-sent, and the sender does not know that the frame was in error. This simple process is called error detection. Error recovery refers to the process whereby the receiver requests that the sender retransmit the frames that did not pass the FCS check. Transmission Control Protocol (TCP) performs error recovery, but Ethernet does not.

Topic 19: Two Ethernet Standards

This topic describes two different standards of Ethernet.

Ethernet was originally created in the 1970s by Robert Metcalfe and some others working for Xerox corporation. Later Intel got involved, and convinced them to put Ethernet logic on a computer chip, making the mass production of Ethernet cards less expensive. Also Digital Equipment Corporation (DEC), the second-largest computer maker at the time, got involved to support Ethernet. The original standard, as defined by those three companies, came to be called DIX Ethernet. The final version created by these three companies is known as Ethernet Version 2. In the 1980s, the IEEE while standardizing several LAN standards, created a committee to define the Ethernet standards and protocols. The committee was named the 802.3 committee. Another committee was created by the IEEE to define the common LAN features and was known as the 802.2 committee. The 802.3 standard is also called

Media Access Control (MAC), and the 802.2 standard is also called Logical Link Control (LLC). Next we show the header defined by 802.3 and 802.2, as well as the trailer, as defined by 802.3.

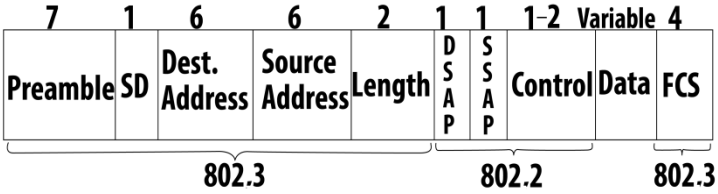


Figure 19.1: IEEE Ethernet Headers and Trailers

The preamble with starting delimiter (SD) serves to "wake up" the receiving adapters and to synchronize their clocks to that of the sender's clock. The original DIX Ethernet specifications used an 8-byte preamble field. IEEE renamed the eighth byte of the preamble to starting delimiter, with no change in the value of the field. Ethernet addresses are often called MAC addresses and are 6 bytes in length.

IEEE Ethernet Technologies

The early 10BASE-2 and 10BASE-5 standards specify 10 Mbps Ethernet over two types of coaxial cable, each limited in length to 500 meters. In mid-1990s, Ethernet was standardized at 100 Mbps, which is 10 times faster than 10 Mbps Ethernet. 100BASE-T was defined for twisted pair copper wires and 100BASE-FX was defined over fiber. 100 Mbps Ethernet is limited to a 100 meter distance over twisted pair and to several kilometers over fiber. Gigabit Ethernet offers a raw data rate of 1,000 Mbps. 10 Gbps Ethernet was initially operating over optical fiber, but is now able to run over category UTP cabling.

Topic 20: Working of a LAN Switch

In this topic, we learn how a LAN switch works.

Only one device can transmit data at a time over a LAN connected via a hub. A switch allows multiple devices to transmit at the same time, increasing the amount of data that can be sent over the LAN. Let's assume PCs of Fred, Barney, Betty and Wilma are connected over a LAN via a hub. Fred wants to send a frame to Barney while Betty wants to send a frame to Wilma. **Hub's logic:** When I receive an electrical signal, I repeat it out on all ports, except the port over which the signal was received. **CSMA/CD logic:** A PC needs to listen before sending i.e. if you're currently receiving a frame, wait until it is finished before you try to send your frame. Otherwise a collision can occur.

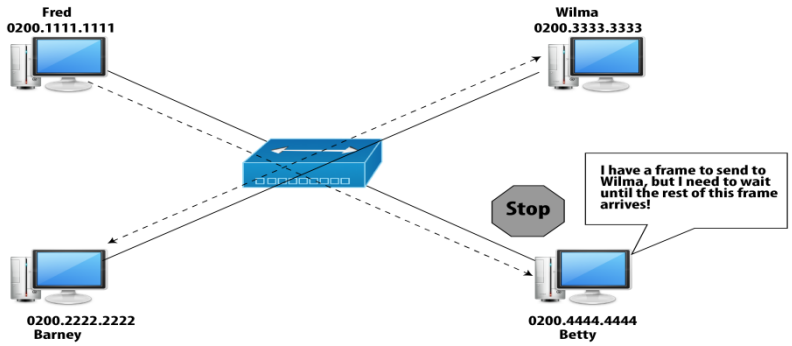


Figure 20.1: Betty Waiting on Fred's Frame that was sent to Barney

It's like paving a beautiful wide road and only having one lane, so everyone must wait until one car finishes driving past before the next car can use the road.

Switch

A LAN switch provides the same cabling advantage that a hub does, while providing significant performance improvements. **Switch's logic:** When receiving a frame, examine the destination Ethernet address. Forward the frame out on the one port and only that port through which that address can be reached. In comparison to a hub, a switch does not simply repeat the electrical signal out on all other ports. A switch forwards frames selectively only forwarding the frame where it really needs to go.

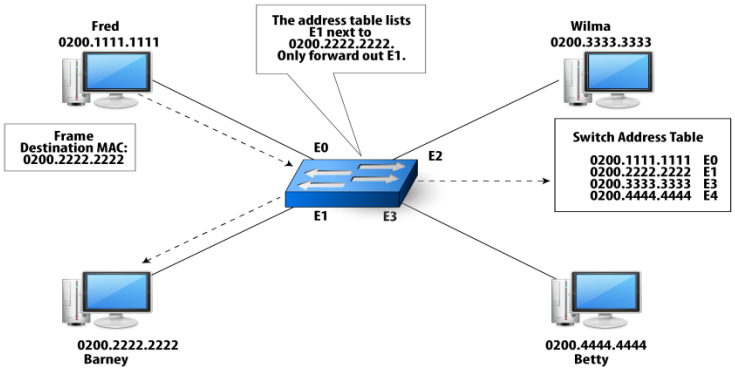


Figure 20.2: Switch logic

In real life, we can simply replace a hub with a switch, and use the same cables. The switch still uses a twisted pair for transmission and another for receiving traffic in each cable. It uses the same pin outs in the RJ-45 connector. The switch receives on pins 1 and 2 and transmits on pins 3 and 6 just like a hub i.e. you need a straight-through cable between the switch and each computer. The physical details can remain the same. To make a forwarding decision, a switch uses a table that lists the MAC addresses in the network. We can refer to it as either the switching table or the MAC address table.

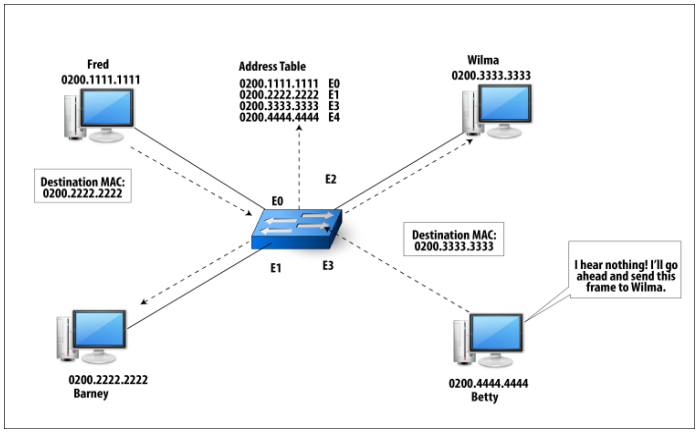


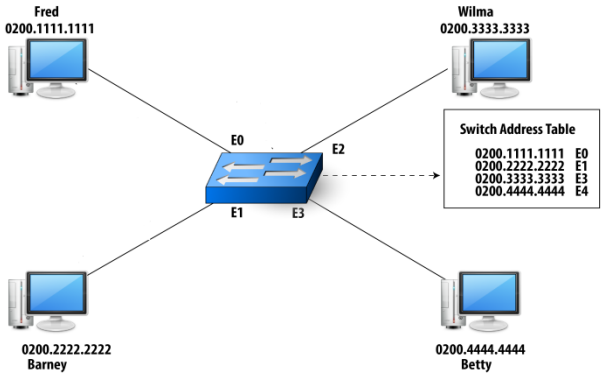
Figure 20.3: Fred Sending to Barney, While Betty send to Wilma

LAN switching logic improves LAN performance because the frame is not repeated to every computer that is attached to the switch. Betty still uses CSMA/CD logic. With two devices sending at the same time, the capacity of the LAN to forward frames doubles! If we are using a 10 Mbps Ethernet, separate transmissions occur, each at 10 Mbps. This LAN has 20 Mbps of capacity. Now imagine a switch with 24 ports, with the device on port 1 sending to the device on port 2; the device on port 3 sending to the device on port 4; and so on. This switch supports 12 x 10 Mbps, or 120 Mbps, of capacity.

Topic 21: Switch: Collision Avoidance

In this topic, we study how a switch avoids collisions.

Let's assume PCs of Fred, Barney, Betty and Wilma are connected over a LAN via a switch. When a switch receives a frame, it examines the destination Ethernet address. It forwards the frame out on the one port and only that port through which that address can be reached.



Let's discuss the scenario: what happens if everyone wanted to talk (send) to Fred at the same time? Keeping the logic of a switch in mind, the switch would try to

forward all three frames, which would cause a collision. A switch receives on pins 1 and 2 and transmits on pins 3 and 6.

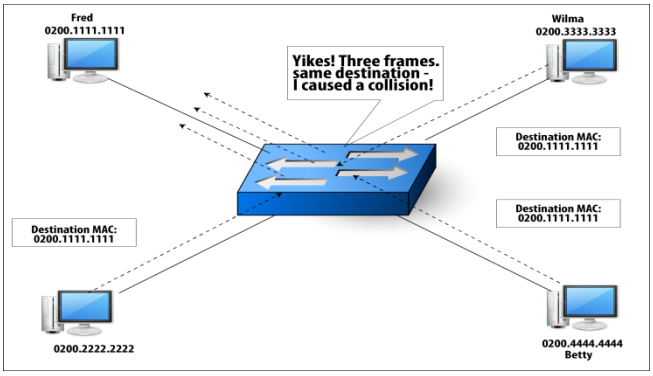


Figure 21.1: Potential collision when forwarding multiple frames

Buffers

To avoid sending all three frames at the same time, the switch uses buffers. Buffers consist of memory inside the switch that is used to store frames temporarily. The switch sends one frame, and it keeps the other two frames in buffers. After the switch finishes sending the first frame, it gets one of the frames from the buffers and sends it. Finally, the switch grabs the third frame from the buffer and sends it. By doing so, the switch usually avoids causing a collision.

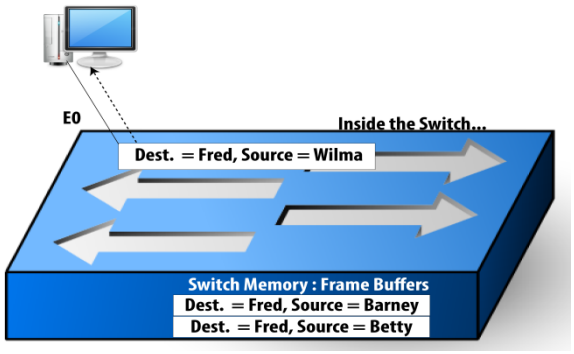


Figure 21.3: Switch Avoids Collisions by Buffering the Frames

Switch Logic Updated

When receiving a frame, examine the destination Ethernet address. Forward the frame out the one port and only that port through which that address can be reached. If multiple frames need to be sent out to the same port, send one frame and buffer the rest. As soon as the port becomes available, send the other frames. By buffering frames, delay will be introduced called buffering delay. How much? For instance, if those three frames were each 1250 bytes long, it would only take 3 milliseconds (.003 seconds) for all three to be sent over the cable with a 10 Mbps rate from the switch to Fred. If collisions had occurred, each frame would have taken

longer to reach Fred, and, both the collision and the time taken to resend the frames could have prevented other user traffic from crossing the LAN. Buffering of frames definitely improves LAN performance.

Topic 22: Full Duplex and Full Switching

This topic presents concepts of full duplex and full switching.

Let's assume PCs of Fred, Barney, Betty and Wilma are connected over a LAN via a switch. With carrier sense multiple access/collision detect (CSMA/CD), if an NIC is not receiving a frame, it can send. The switch avoids collisions by buffering the frame if the output port is busy.

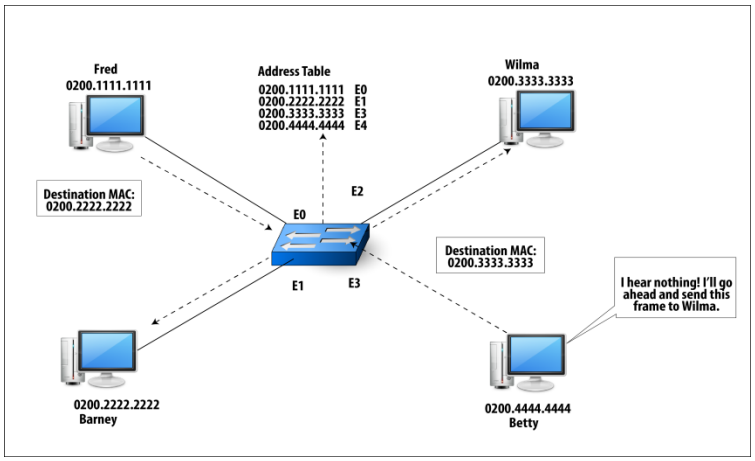


Figure 22.1: Potential Collision When Forwarding Multiple Frames

A computer NIC, using CSMA/CD, believes it should not send a frame: when the NIC is actually receiving a frame. Imagine that Fred is sending a frame to Barney. Barney wants to send a frame. (In this case, Barney wants to send a frame to Fred, but the destination does not really matter in this scenario.)

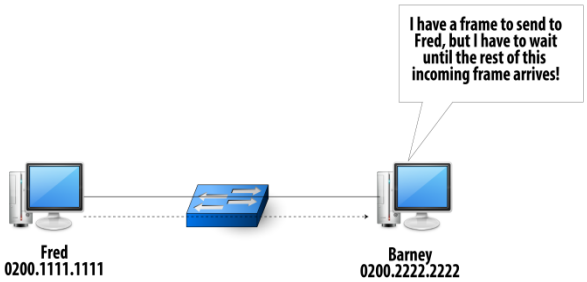


Figure 22.2: Barney Waiting to Send, When Fred Sends to Barney

With Barney's CSMA/CD logic enabled, he must wait before sending a frame. But can a collision really occur? Physically, there is a single cable between Barney and the switch. Barney sends on the pair using pins 1 and 2, and the switch sends to Barney on the pair using pins 3 and 6. The switch will buffer any frames if pins 3 and 6 are busy. There is truly no danger of a collision. Barney would not cause a collision, if he sends the frame. Barney can send and receive at the same instant in time as receiving the frame from Fred. This ability is called full duplex. The CSMA/CD imposes restriction of only sending or only receiving at one point in time. This is called half duplex. This is shown next.

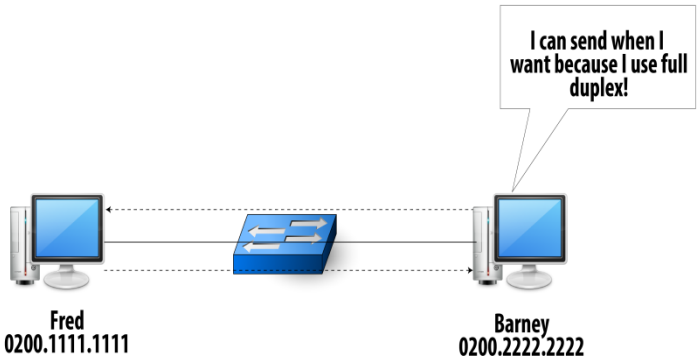


Figure 22.3: Barney and Fred Sending and Receiving at the Same Time Full Duplex

With switches and full duplex enabled, the LAN works like you have a two-lane road between the switch and each device, plus another two-lane road between each port on the switch. This is shown next.

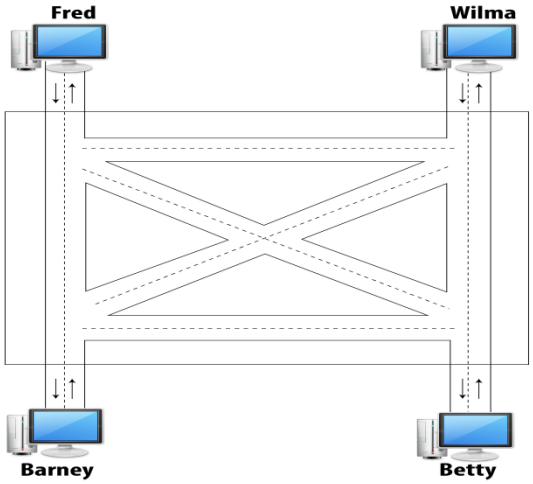


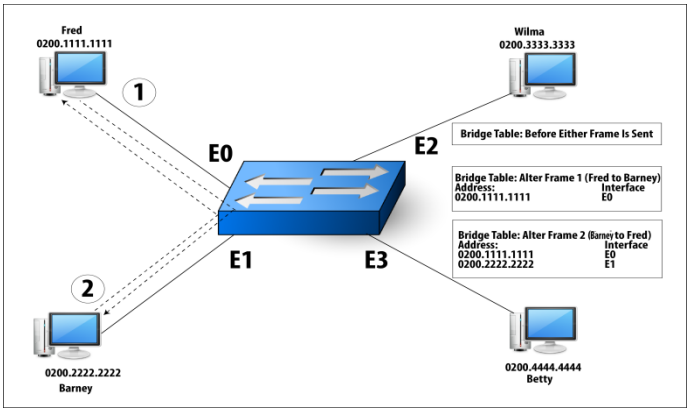
Figure 22.4: **Full Duplex and Full Switching**

Topic 23: Learning Ethernet addresses

In this topic, we study how Ethernet addresses are learnt.

A switch maintains a switching table or Media Access Control (MAC) address table. It makes its decisions about where to forward the frames based on that table. How does the switch figure out what should be in the MAC address table in the first place? The switch has no entries in the MAC address table when the switch first powers up. A switch dynamically learns MAC addresses and the corresponding ports. This process of learning MAC addresses is called learning.

Whenever an NIC sends an Ethernet frame, the NIC places its own MAC address into the frame as the source MAC address. The switch learns the MAC address of the sender of each frame by examining the source MAC address.



When a switch receives a frame, it sends the frame out on one port, based on a comparison of the destination MAC address and the MAC address table – forwarding decision. Conversely, by not sending the frame out on other ports, the switch has simply filtered the frame from exiting those ports, which is a filtering decision. What should a switch do with a frame that is sent before the switch has learned the MAC address table? The switch performs flooding.

Flooding

When a switch receives a frame whose destination address is not in the MAC address table, the switch forwards the frame out on all ports except the one over which the frame was received.

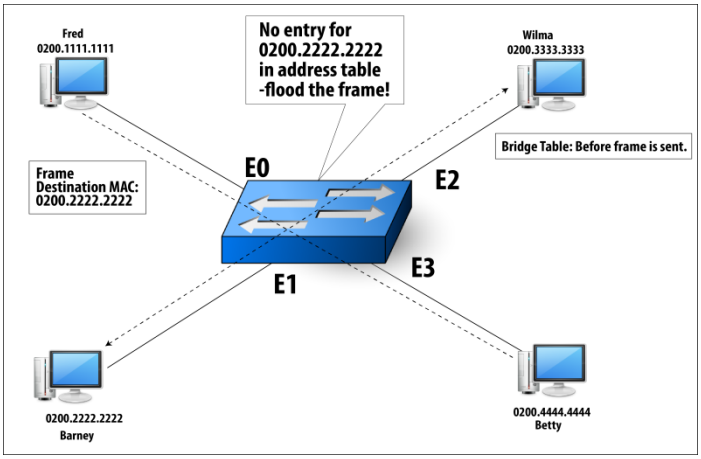


Figure 23.1: Switch Logic for Unknown Destinations

By flooding the frame, Barney, Wilma, and Betty all get a copy. Barney replies, and the switch enters Barney's MAC address in the table. Any future frames sent to Barney will be forwarded correctly.

An Ethernet or MAC address represents an individual NIC attached to a LAN –unicast MAC addresses. When a computer wants to forward a frame to all devices on the LAN, Ethernet defines a special MAC address, called the broadcast address. The value is FFFF.FFFF.FFFF.

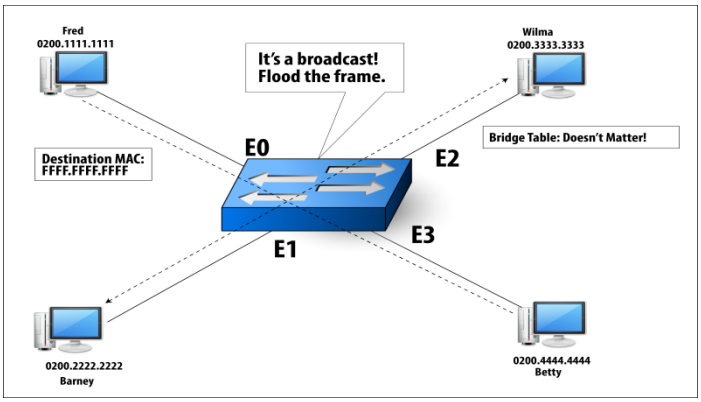


Figure 23.2: Switch Flood Broadcast Frames

Topic 24: Ethernet Network Speeds

This topic lists the different speeds that Ethernet supports.

When IEEE started working on Ethernet standards, Ethernet used a 10-Mbps transmission rate. The actual transmission of data— the bits cross the wires at 10 Mbps. Over the years, the IEEE has created many enhancements to the Ethernet standards. Increase in speed is one of the important enhancements. The first time Ethernet speed was enhanced, the IEEE created a working group named 802.3u. A specification called Fast Ethernet was created which runs at 100 Mbps. It is abbreviated as FE. The IEEE decided that the rest of Fast Ethernet should work the same as plain old Ethernet i.e. same headers and trailers, same CSMA/CD logic and same 6-byte MAC addresses. Only differences come in how the bits are encoded and the speed at which they are encoded. Vendors only needed to make small changes to existing Ethernet products to create Fast Ethernet products. This make them to be easy accepted in the marketplace. Today's enterprise networks widely use Fast Ethernet. The older 10 Mbps Ethernet, when using twisted pair cabling, was called 10BaseT. FE was called 100BaseT. The IEEE working groups 802.3z and 802.3ab created 1000 Mbps or 1 gigabit per second (Gbps). This standard is called Gigabit Ethernet (GigE). The difference between Gigabit Ethernet and Fast Ethernet is speed. To support the speed, the standards call for better cabling, but everything else is the same. This makes it to be quickly accepted in the market. The 802.3z working group defined how to do GigE over optical cable, and the 802.3ab working group defined how to do GigE over copper cabling. Optical cabling uses glass fibers instead of copper wire. The devices that are attached to an optical cable send light across the cable, instead of electricity, to encode 0s and 1s. The physics behind optical signals over optical glass-fiber cabling allow for higher speeds, longer distances, fewer errors, and better security, but at a higher cost than copper wiring. **10 Gigabit Ethernet** is defined by the IEEE 802.3ae working group. 10 GigE is used for short.

Because all the more advanced forms of Ethernet use the same header, switch forwarding and learning logic do not change based on what speed Ethernet is used. The switch can behave the same way as always, with some ports using Ethernet, some Fast Ethernet, some Gigabit Ethernet, and so on. Imagine that you want to support a bunch of users on a building floor, some with NICs that only support 10 Mbps 802.3, and some that only support 100 Mbps 802.3u Fast Ethernet. You might buy a switch that has 24 ports; 12 10-Mbps ports and 12 100-Mbps ports. Next we show the basic setup, with Fred using a 10-Mbps NIC and Wilma using a 100-Mbps NIC.

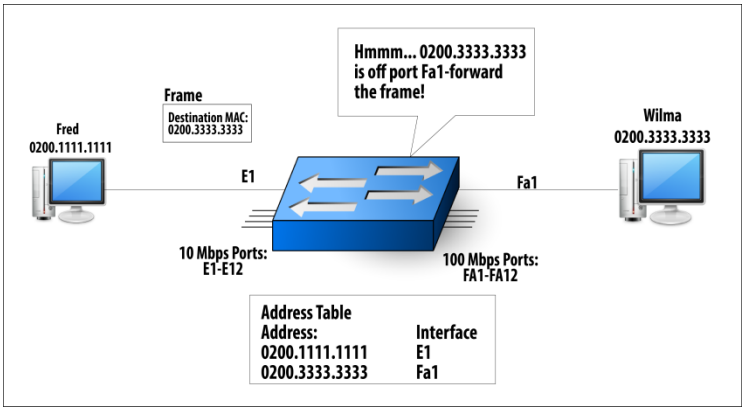


Figure 24.1: Supporting Multiple Speeds on a Single Switch

This type of switch does not provide an easy migration path from 10 Mbps to 100 Mbps. For the previous example, assume all FE ports are occupied. Can you add a new 100-Mbps NIC? Auto negotiation is an IEEE standard that allows the switch and NIC on either end of the cable to automatically negotiate to determine the speed. Full duplex or half duplex can also be negotiated. To perform auto negotiation, the switch and the NIC must support multiple speeds, as well as auto negotiation logic. "I want to use 100 Mbps," "Okay, me, too. Let's do it."

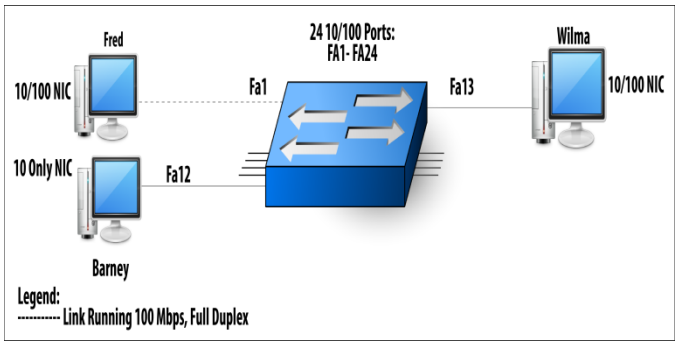


Figure 24.2: Auto negotiation with 10/100 Cards

Topic 25: Multiple Physical LANs

In this topic, we understand how physical LANs and multiple physical LANs handle broadcasts.

Hubs and switches behave differently. But process broadcast frames identically. A broadcast frame is an Ethernet frame that has a destination MAC address field set to FFFF.FFFF.FFFF. When a switch receives a broadcast frame, it forwards the frame out on all ports except to the incoming port. A hub works in the same fashion for all frames including broadcasts. A broadcast domain is a group of devices for which a broadcast frame sent by one device is received by all other devices in the same group. Next, we show three examples of broadcast domains. A single hub creates a single broadcast domain. A single switch also creates a single broadcast domain. A hub and a switch, connected together, also create a single broadcast domain.

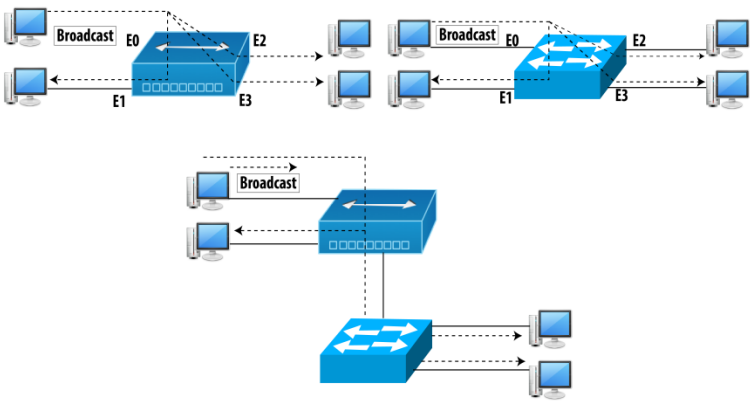


Figure 25.1: Three Broadcast Domains: A Hub, a Switch, and a Hub and Switch

A LAN consists of the devices inside a single broadcast domain. Let's imagine that you just took a job as a network engineer at a company with the small network shown next.

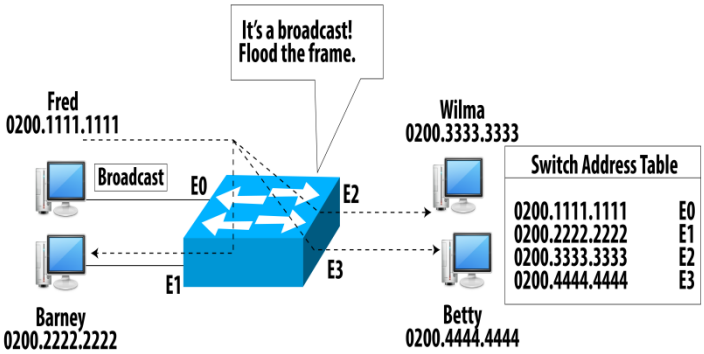


Figure 25.2: Small Physical LAN and You Are in Charge

Your boss told you that "We've got to get Fred and Barney on a different LAN than Betty and Wilma. They work with super-secret projects, and we can't meet our

security requirements if Betty and Wilma are on the same LAN". To put Betty and Wilma on a different LAN than the boys, you have to use two switches.

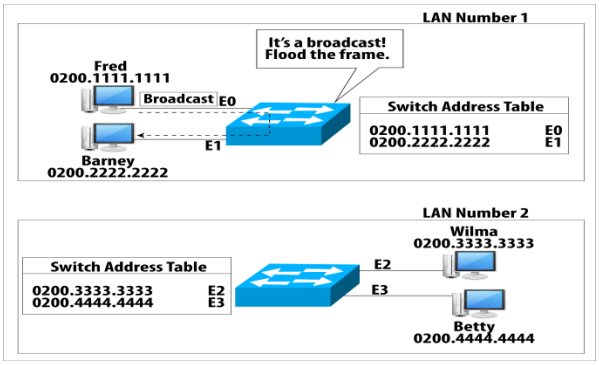


Figure 25.3: Two Physical LANs: Broadcasts Do Not Leave the Originating LAN

Both broadcast frames and unicast frames from the top LAN cannot be forwarded to the bottom LAN as there is no physical cable connecting the two switches in this case.

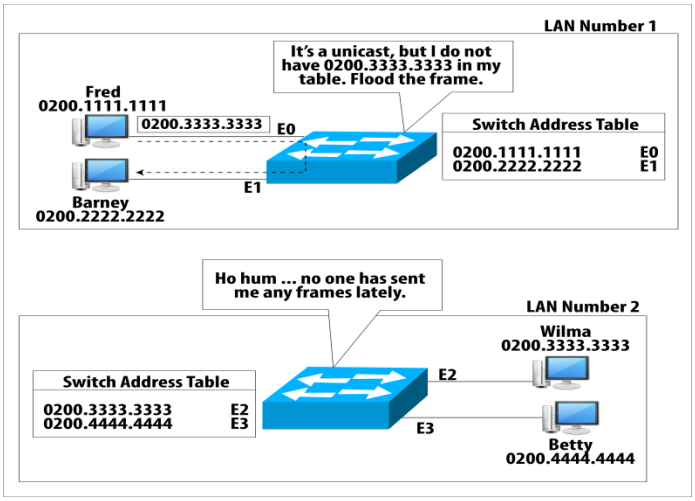


Figure 25.4: No Forwarding between the Two Physical LANs

Each LAN has an independent MAC address table as compared to the other LANs. Broadcasts originating in one LAN are flooded inside that LAN. Broadcasts originating in one LAN are not forwarded into the other LANs. Unicasts originating in one LAN are not forwarded into the other LANs.

Topic 26: Introduction to Virtual LANs

This topic explains how to create Virtual LANs.

A physical LAN or a broadcast domain is the group of devices for which a broadcast frame sent by one device is received by all devices in the group. To create multiple LANS, multiple LAN switches are required – expensive. VLANs allow you to create multiple LANs, but without requiring extra switch hardware.

A **Virtual LAN** is a broadcast domain, created by a switch, using a subset of the physical ports on the switch. LAN switch vendors include a feature in their products that allows you to create multiple broadcast domains in a single switch. A network engineer can configure some physical ports of a switch as if they are in one broadcast domain (one VLAN) and then configure other ports to be in a different broadcast domain (a different VLAN).

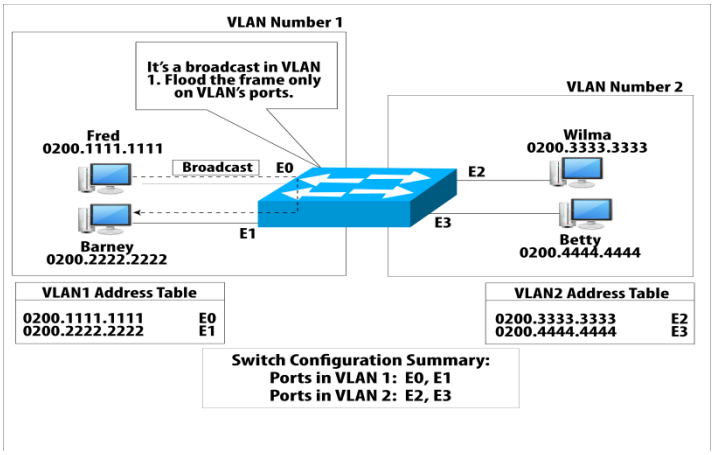


Figure 26.1: Two Virtual LANs: Broadcasts Do Not Leave the Originating VLAN

This network behaves just like it would with the two physical switches. However, you get the advantage of not having to buy another switch! In the previous example, the switch does learn all four MAC addresses, but the switch does not forward broadcasts or unicasts from one VLAN to the other. It keeps a separate address table for each VLAN.

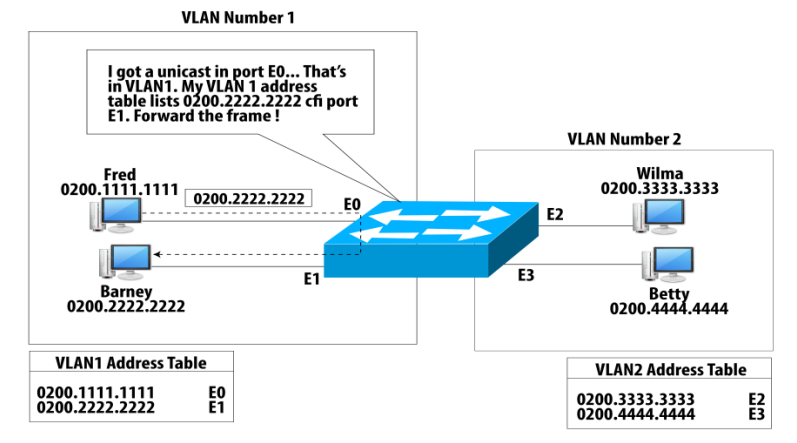


Figure 26.2: No Forwarding Between the Two VLANs

The switch knows that the frame came over port E0 and that E0 has been configured as part of VLAN1. The switch looks only at the VLAN1 address table and finds a match. So, the switch forwards the frame. Even if there had not been a match in the VLAN1 address table, the switch would have flooded the frame, but only out on ports in VLAN1. Therefore, neither Wilma nor Betty could get a copy of the frame. Broadcasts originating in one VLAN are not forwarded into the other VLANs. Unicasts originating in one VLAN are not forwarded into the other VLANs.

Advantages of VLAN

1. A PC must spend CPU cycles processing a received broadcast. As a LAN grows, every device has more broadcasts to process. Don't to put too many devices in a single VLAN.

2. Imagine payroll department of an organization moves to the same floor as the IT department. The payroll director is concerned that we will be on the same LAN as the IT group and sensitive payroll traffic can be disclosed.

3. Cost effective to just configure VLANs.

Topic 27: Packing VLAN's frames in a Trunk

In this topic, we discuss the need for VLAN trunking.

Let's assume 4 PCs owned by Fred, Betty, Barney and Wilma are connected via two switches with two PCs per switch. This allows devices on each switch to send frames to each other. The basic switch logic for each switch does not change when you use multiple switches. Both switches will populate their own address tables and each switch knows where to forward the frames.

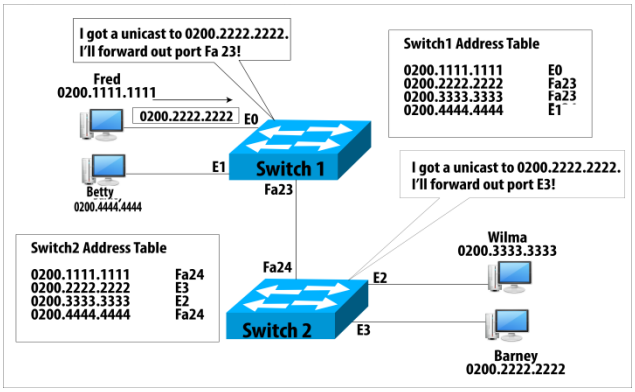


Figure 27.1: Forwarding Frames Between Two Switches

In the context of connecting multiple switches, the Ethernet cable segment between switch1 and switch2 is known as a trunk.

VLAN Trunking

Let's now add VLANs to the previous network such that Fred and Barney are connected to VLAN1 and Wilma and Betty are on VLAN2. Traffic must cross over the trunk between two switches. When a switch receives a frame over that trunk, it could be confused about which VLAN's MAC address table to use when deciding how to forward the frame. Should a switch look in both address tables?

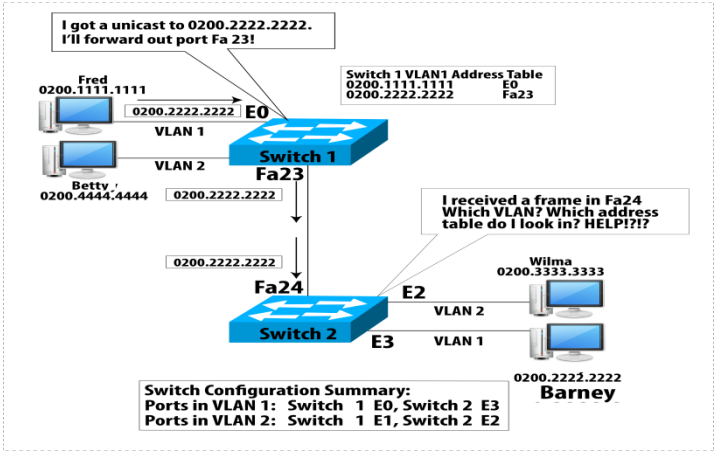


Figure 27.2: Switch2's Dilemma: Which VLAN?

To solve the problem, the switches use a mechanism called VLAN trunking. Before sending the frame over the Ethernet cable to the other switch, switch1 adds another header to the frame. An extra header identifies the frame as part of VLAN1. That tells switch2 which address table to use. Switch2 expects frames coming in over port Fa24 to have that extra header, so it can now process the frame.

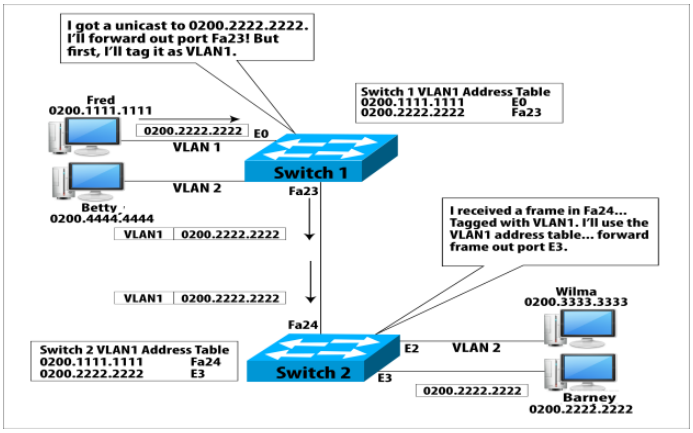


Figure 27.3: Trunking Header Tells Switch2 What to Do?

When switch2 needs to send frames out on port Fa24 to switch1, switch2 also adds a VLAN trunking header, knowing that switch1 expects to be able to find the header to identify the right VLAN. Initially, Cisco created its own standard and named it Inter-Switch Link (ISL). ISL defines the type of header that should be added to the frame, including the field in which the VLAN can be numbered. Later, the IEEE 802.1Q committee defined a standard for VLAN trunking called 802.1Q trunking, or simply "dot 1 Q." 802.1Q trunking differs from ISL. As a result, you need to pick between the two options. The switches on each end of the trunk must agree to which protocol to use, or trunking will not work.

Topic 28: Email: A Network Application

This topic describes how email works.

You can write a letter on paper and put it in an envelope. Write a correct name and address on the front of the envelope and put it in a mailbox. The postal service will try its best to deliver the mail to the right place. Put a return address on the envelope so that the recipient can reply by putting your address on the front of the envelope. To further elaborate the working of postal service, let's assume that you live in a house, and a postal worker typically comes by your place every working day. He leaves your mail in your mailbox. He also picks up any outgoing mail that you left either in your mailbox or in a centralized post office box (PO box) that was set up just for outgoing mail. This is shown next.

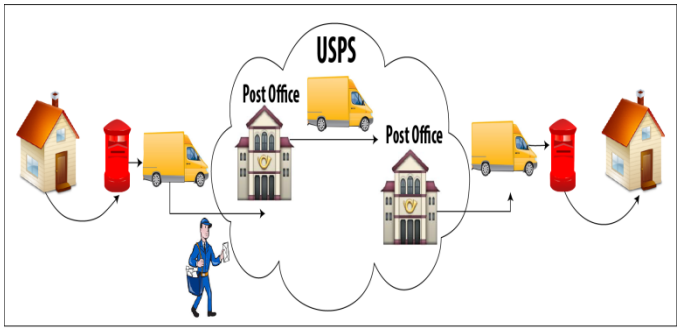


Figure 28.1: Postal Worker Picking Up and Dropping Off the Mail

Email allows you to do the same thing, but without the paper. You type some text, put that person's e-mail address at the top of the e-mail, and send the e-mail. By sending the e-mail, you do the equivalent of giving the e-mail to the postal service. The service delivers the e-mail, and the next time your friend checks his e-mail, he receives the message that you sent. Each e-mail includes the text you typed, the recipient's e-mail address, and your e-mail address. As the recipient now knows your e-mail address, he can easily respond to your e-mail. E-mail also enables you to send a message to multiple recipients at once. When you create and send an e-mail to your friend, your PC does not actually send the e-mail to your friend's PC. Instead, you would send the message to your e-mail server, which is the equivalent of dropping off a letter at the local post office. Your e-mail server would send the e-mail to your friend's e-mail server, which is the equivalent of the postal service delivering a paper letter to the post office near your friend. Then, at some point in the future, your friend would check his e-mail and retrieve the e-mail from his local e-mail server, which is the equivalent of retrieving his paper mail from his PO box.

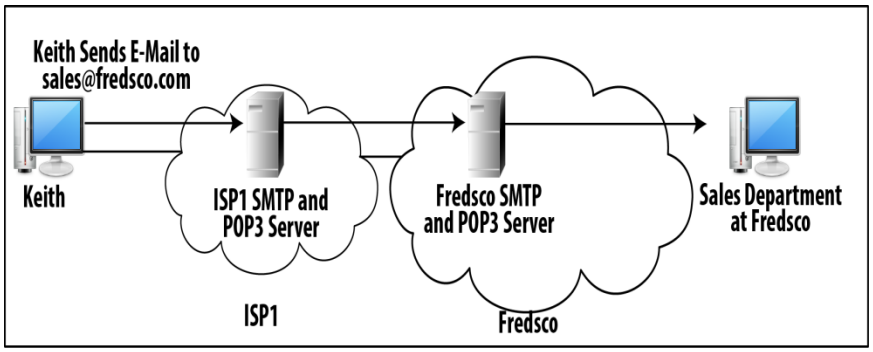


Figure 28.2: Sending E-Mail Using E-Mail Servers

Internet service providers (ISPs) have one (or more) e-mail servers. If you connect to an ISP from home, you would use that ISP's e-mail servers to drop off and pick up e-mail. If you use e-mail from your corporation's enterprise network, you typically use your company's e-mail servers to drop off and pick up e-mail. E-mail addresses have two parts: the name of the e-mail user and the name of the e-mail

server: barney@fredsco.com. Let's assume that Keith and Conner send e-mails to different people inside Fredsco. Next, we show why a two-part e-mail address is useful.

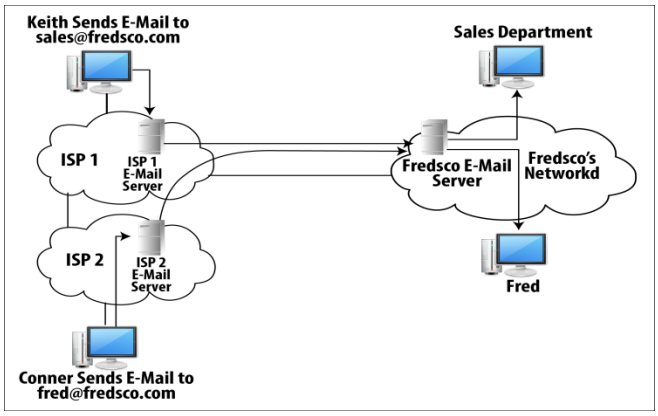


Figure 28.3: How a Two-Part E-Mail Address Is Used

The e-mail software on PCs does not think about the address at all. The PCs always send their e-mails to their respective local e-mail server. The servers look at the name after the @ sign – identifies the receiving side mail server. Local post office looks at the city and state on a letter, or the zip code, to figure out to which post office to send the letter.

Topic 29: TCP/IP Email Standards: SMTP, POP3

In this topic, we explain the use of Email standards such as SMTP and POP3.

Internet Message Format, Simple Mail Transport Protocol and Post Office Protocol Version 3 are the part of TCP/IP E-mail standard. Internet Message Format (IMF) is described in RFC 2822 and describes headers used to encapsulate the e-mail text, sender and receiver e-mail addresses. Simple Mail Transport Protocol (SMTP) is defined in 2821. It provides details about protocols for transmitting and receiving e-mails. Post Office Protocol Version 3 (POP3) and is defined in RFC 1939. It provides information about protocols for a client to retrieve e-mail from a server. A user uses e-mail client software to generate, send, receive, and read e-mails.

An **Email Client** software is a user interface, accepts text typed from the keyboard, understands what a user clicks on the screen, stores e-mails on the computer hard disk, and so on. E-mail TCP/IP protocols are implemented in the e-mail client software so that it can use the network. The e-mail client application is not the same thing as the application layer protocol.

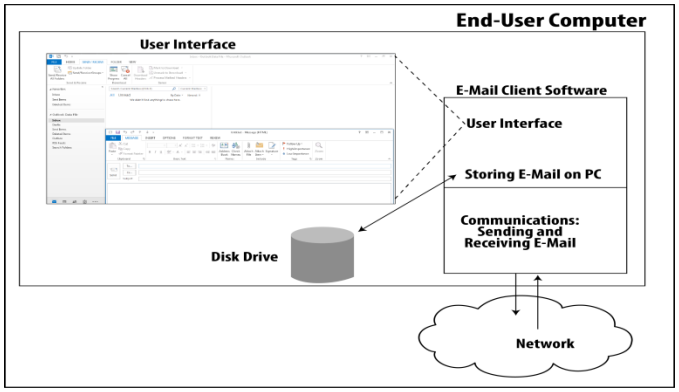


Figure 29.1: E-Mail Client Application and Its Use of Application Layer Protocols

An e-mail client sends not only the text of the e-mail message, but also a header. The header contains several fields, such as the recipient's and sender's e-mail addresses.

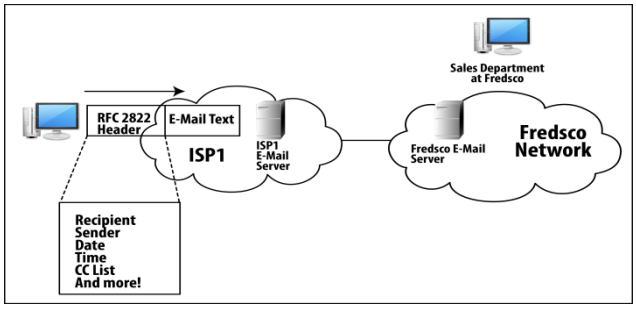


Figure 29.2: Sampling of the E-Mail Header Defined by RFC 2822

All the clients and servers know where to find all the information needed to forward the e-mail correctly. E-mail clients and servers use SMTP protocols to manage the process of sending and receiving e-mail. SMTP defines messages so that the e-mail clients and servers can manage the e-mail forwarding process. The Extended Hello (EHLO) command identifies the client. The Mail command tells the server that the client wants to either send or receive e-mail. The RCPT identifies recipient of e-mail. After the server replies with an acknowledgement (ACK) message to each of these first three commands, the e-mail can be transmitted.

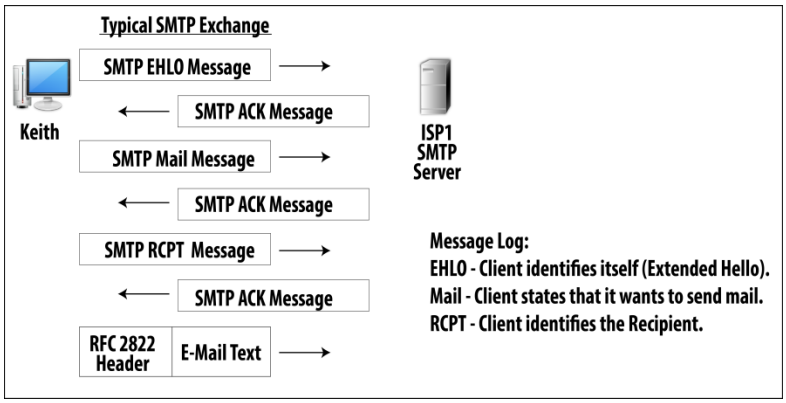


Figure 29.3: Simple SMTP Messages: Identifying the Client and the Recipient

The current version, POP3, was designed specifically for use between an e-mail client and its e-mail server. It cannot transfer e-mail between servers. POP3 allows for authentication, which refers to the process of one device identifying itself to another device via a name and password. The other device then decides whether the first device is allowed access.

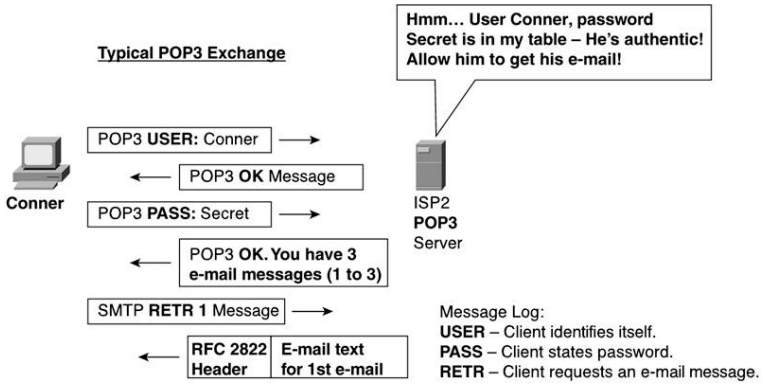


Figure 29.4: Basic Authentication with POP3

SMTP pushes emails between two devices. POP3 can be used to only pull the e-mail from the server. E-mail server (a single computer) needs to run both the server softwares. The SMTP server and the POP3 server on the same computer store and retrieve e-mails from the same message storage location.

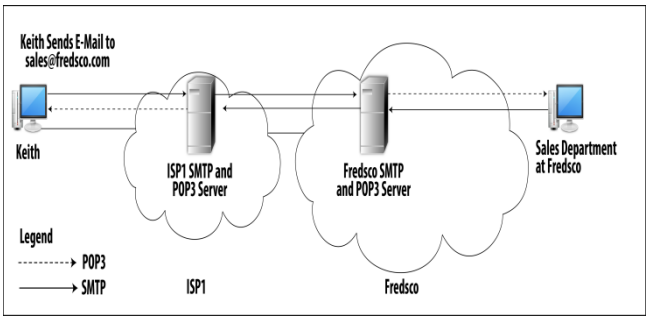


Figure 29.5 Typical Usages of SMTP and POP3

Topic 30: File Transfer Protocol (FTP)

This topic explains the working of file transfer protocol.

The working of FTP can be explained using a warehouse that a company might use to store goods. Imagine that a company has a bunch of stuff, and many people inside the company might need some of the stuff from time to time. Some of the stuff is big, and some of the stuff is small. The company leases a warehouse space and puts

its stuff in the warehouse. Then the company gives everyone a key, and anyone who needs some stuff can go get it when needed.

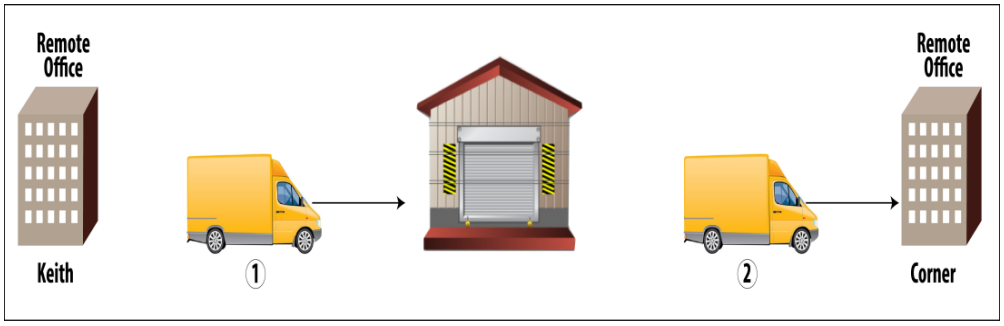


Figure 30.1: Warehousing Process for Transferring Stuff

Keith should put the widgets in the right place. Conner should know where to find Keith's widgets. Warehouse becomes useless if no mechanism to find widgets and keep track of inventory. A file transfer application called File Transfer Protocol (FTP) works by putting things on an FTP server and get them off the FTP server. Documentation is also needed as to where things are.

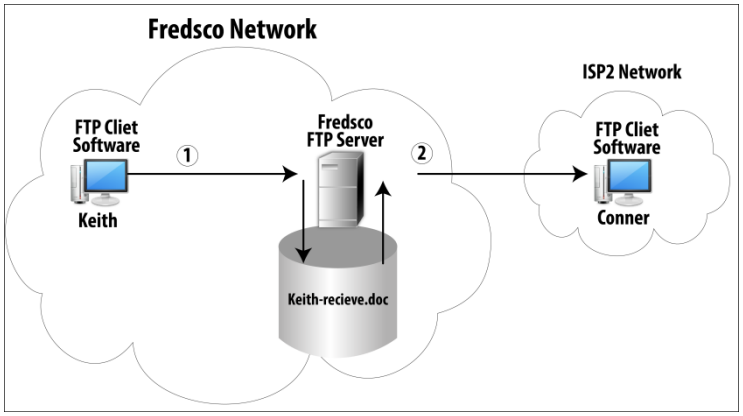


Figure 30.2: FTP Process for Transferring Files

FTP uses client software on the end user computer. It also implements application layer protocols. The FTP TCP/IP standard defines messages and headers to do something useful. FTP clients need to connect to a server to do anything useful. The client must identify itself to the server. FTP server software runs on a physical server.

An Example:

The sequence Keith needs to follow to stores files on an FTP server is described next.

Authentication:

1- FTP client uses the FTP USER command to provide the username to the FTP server.

2- The FTP PASS command supplies the password to the server.

Data Transfer:

3- If authenticated, then FTP client uses the PUT command to inform the server that the file's name is file1 and will be available in the upcoming messages.

4- Send the actual contents of the file.

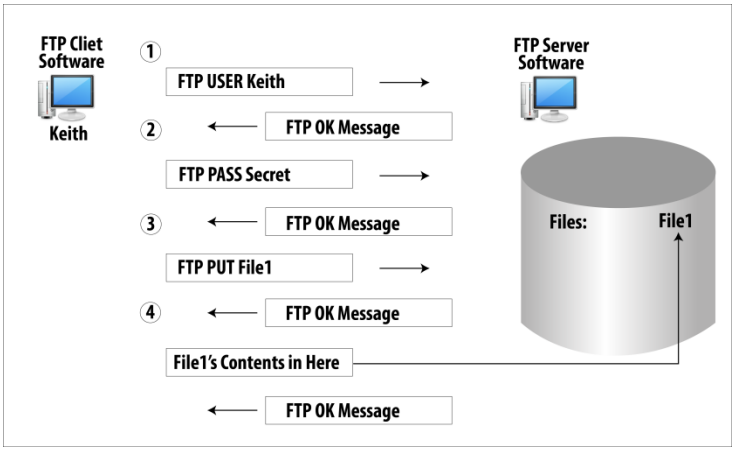


Figure 30.3: Stocking the FTP Warehouse

Assume Conner wants to get file1. He needs to follow the same sequence to connect to the FTP server and get file1 as followed by Keith except: Instead of issuing a PUT command, Conner issues a GET command, which refers to copying a file from the server to the client.

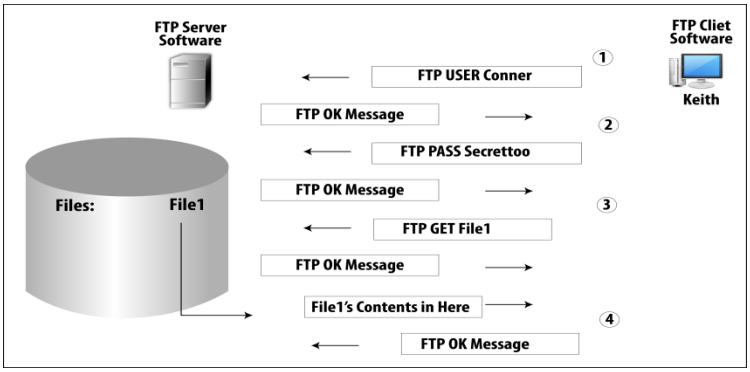


Figure 30.4: Copying Inventory (Files) from the FTP Warehouse

FTP is defined in RFC 959. FTP uses a different underlying TCP connection for the control messages, versus the actual file transfer.

Topic 31: World Wide Web and HTTP Protocol

This topic describes the working of the World Wide Web and the HTTP protocol.

The end user PC uses software called a web browser also known as a web client. Someone must create some content and put it on a web server before the end user can do anything useful. Content consists of individual web pages, the collection of which is called a website. As an example, let's imagine a company FredsCo wants to build a website so that clients can access it. Web server software must be installed on the computer that will be used as the web server. A number of files (content) created by someone should be put onto the web server and be displayed by the http://www.fredsco.com website. Now the web server is ready to respond to clients. A customer, Conner, opens his web browser and tries to connect to http://www.fredsco.com. The web server gets Conner's request and sends the web page back to Conner.

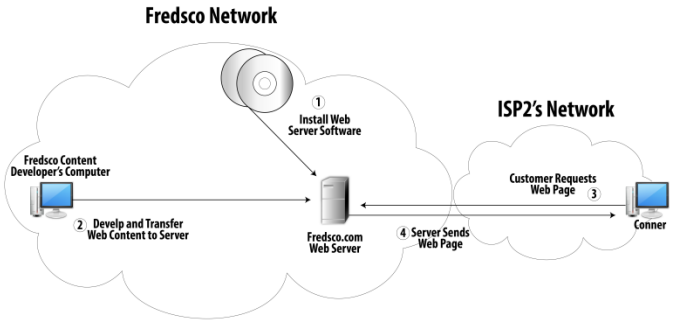


Figure 31.1: Building and Stocking the New Retail Store, AKA New Website

Rules for WWW:

When Conner types http://www.fredsco.com in his browser, the web page gets loaded. The above string is called a uniform resource locator (URL). A URL identifies the protocol in use and name of the server. HTTP stands for Hypertext Transfer Protocol and is the TCP/IP protocol you use to send the web page contents from the web server to the web browser. HTTP command GET requests the web server to send the server's default web page to the browser. When a web site is developed, one web page is defined as the default. The server then looks in its configuration and finds the name of the file that holds its home page. Using HTTP, the server sends the contents of a file called home.html back to the browser.

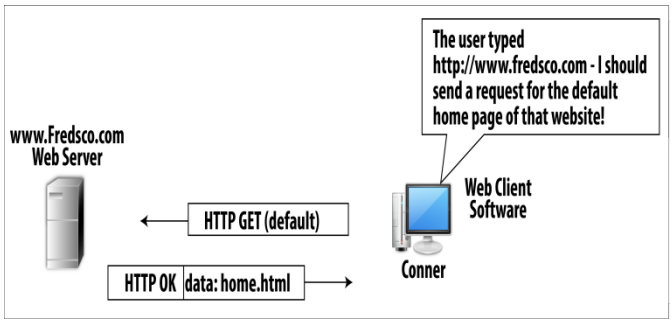


Figure 31.2: Connecting to the Fredsco Home Page

An .HTML file contains text that conforms to a specification called Hypertext Markup Language (HTML). HTML was the first language used to describe the contents of a web page. HTML tells the browser what to put in the browser window, what color to make it, what size, and so on, but it does not define anything about how to send and receive data. When a web page gets loaded, some parts show up right away while the rest of the page fills in slowly. A lot of files get transferred between a web client and server. The first individual file (known as object) downloaded by HTTP is an HTML file. HTML files include text that goes on the web page, formatting instructions, plus instructions to download other objects. When a web page gets loaded, some parts show up right away while the rest of the page fills in slowly. A lot of files get transferred between a web client and server. The first individual file (known as object) downloaded by HTTP is an HTML file. HTML files include text that goes on the web page, formatting instructions, plus instructions to download other objects.

An Example

Assume Conner types Fredsco's URL in his browser.

1- Conner's browser gets the HTML file using HTTP.

2- Conner's browser reads the file, displaying things on the screen as a result.

3 - When Conner's browser reads the file, it might have instructions that require Conner to download other objects. If so, it uses HTTP to get those objects.

4 - Conner's browser reads the contents of the new objects, displaying them on the screen.

5- Steps 3 and 4 are repeated until all objects are downloaded.

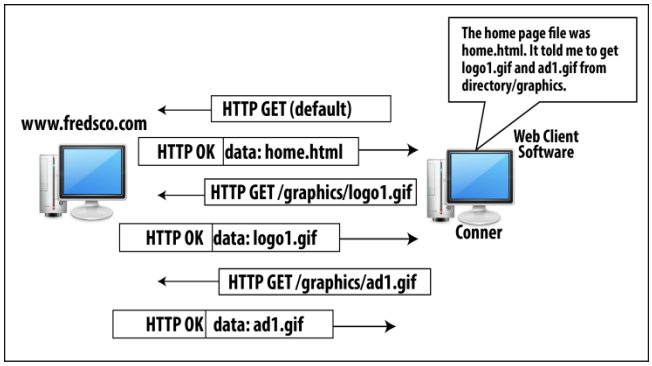


Figure 31.3: Transferring All the Files That Make Up a Web Page

Topic 32: Main Features of TCP

This topic discusses some of the main features of TCP.

The high points of TCP include ensuring delivery through error recovery, breaking large shipments into manageable sizes using segmentation, getting the data to the right individual program, not just the right computer by using port numbers, and simplifying the creation of applications by hiding the details of data delivery from the application. Assume Wilma's computer is sending three TCP segments to Fred. Sender numbers the segments so that if a receiver does not receive a segment or receives with some error, he can request sender to send again.

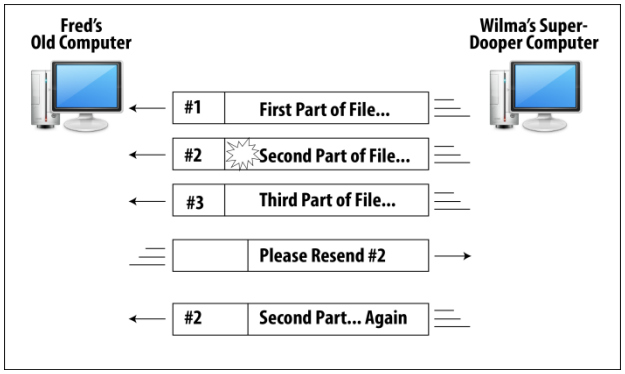


Figure 32.1: Assuring Data Delivery

TCP puts some interesting information into the TCP header. This is shown next.

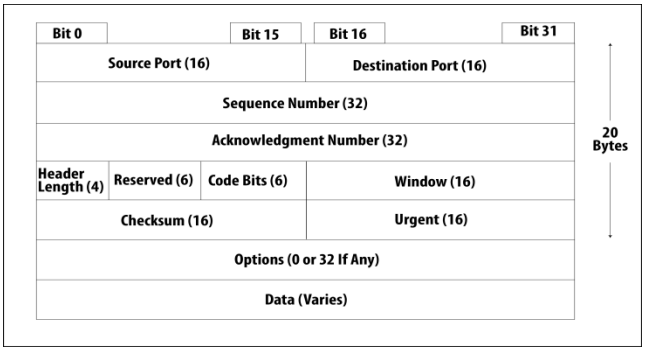


Figure 32.2: The Format of the Shipping Label: TCP Headers

For error recovery, it uses the sequence number and acknowledgment number fields. The sequence number identifies the segment, and the acknowledgement number is used when an error occurs. The ACK field means that this number is the number of the next segment receiver expects to receive. This procedure is called forward acknowledgment.

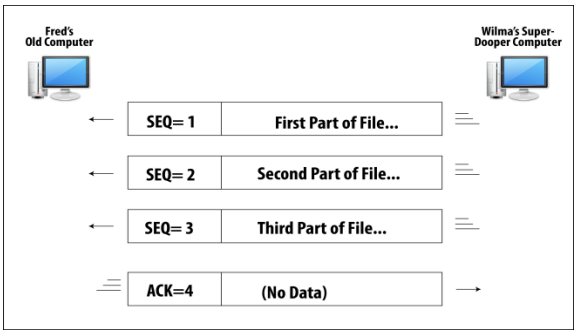


Figure 32.3: Delivery Confirmation, No Errors

TCP Error-Recovery Process

Assume while Wilma sent 3 segments, segment number 2 has some errors.

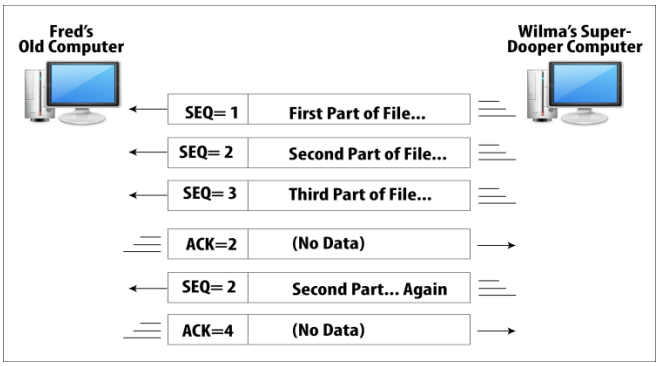


Figure 32.4: TCP Error-Recovery Process

Topic 33: Working of TCP

In this topic, we present the working of TCP protocol.

If you are using a TCP/IP application, the application layer protocol uses transport layer protocol to send their messages across the network. The application layer protocols are part of the application software. For example, HTTP is used for WWW and SMTP for email. The transport layer protocols are typically part of the operating system (OS) of the computer. The transport layer software hangs around, waiting on the application program specifically the part of the application program that implements the application layer protocols to ask it to do something.

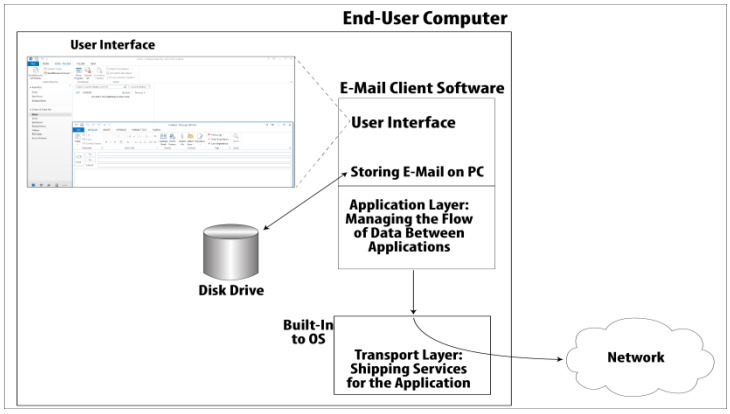


Figure 32.5: Segmenting Data Before Sending

An application layer protocol could avoid using a transport layer protocol. The transport layer protocols provide great services that many applications need. It takes a lot less time and effort for the application to use a transport layer protocol. It's better, faster, cheaper, and simpler for an application to use a transport layer protocol. A transport layer protocol provides a logical communication between application processes running on different hosts. Transport protocols run in end systems. On the sending side, transport layer breaks application messages into segments. On the receiving side, transport layer reassembles segments into messages, passes to application layer. For the **Internet** transport layer, there are two options. Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). TCP provides a reliable delivery while UDP is unreliable. The **minimal** transport-layer services are process-to-process data delivery and error checking – error detection.

TCP's Encapsulation

Assume Keith's browser requests a home page. The browser does not actually send the request over the network. It asks the TCP software on Keith's computer to send it.

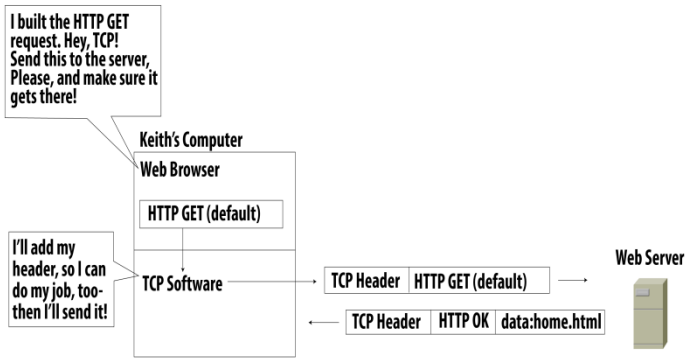


Figure 32.6: Acknowledging Each Byte

TCP provides several services, so it needs a place to record some information about those services. For this purpose, TCP defines a header. The TCP header and the data are called a TCP segment.

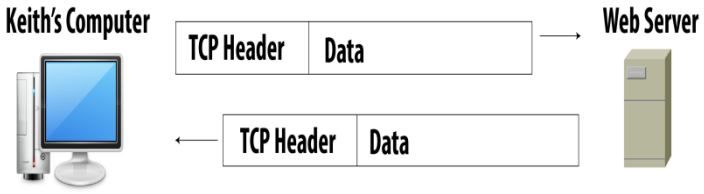


Figure 32.7: Keith's TCP Connections

TCP doesn't have to think about what HTTP is trying to do means that the TCP software does not need to know anything about how HTTP works. Software development becomes simpler.

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 34: TCP Flow and Congestion Control

This topic describes the TCP flow and congestion control mechanisms.

Hosts on each side of a TCP connection set aside a receive buffer for the connection. When the TCP connection receives bytes that are correct and in sequence, it places the data in the receive buffer. The associated application process will read the data from this buffer, but not necessarily at the instant the data arrives. If the application is relatively slow at reading the data, the sender can very easily overflow the connection's receive buffer by sending too much data too quickly.

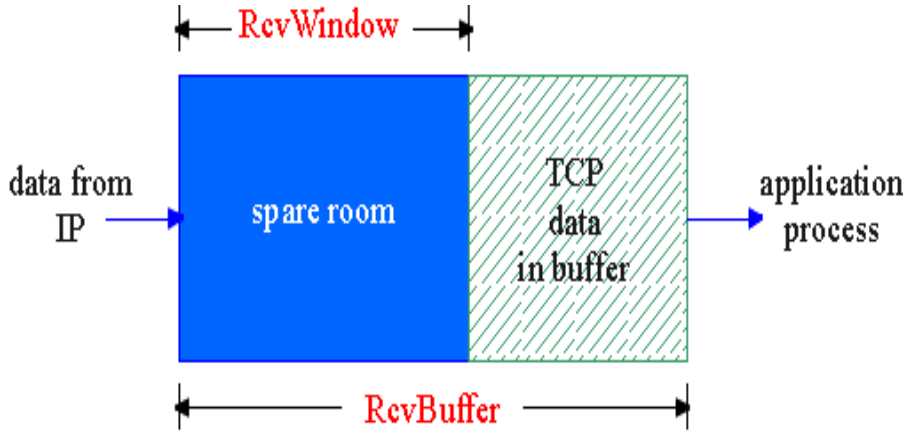


Figure 34.1 Receive Window

Flow Control does allow the sender to overflow receiver's buffer by transmitting too much, too fast. It is TCP's speed-matching service: matching the rate at which sender is sending against the rate at which receiving application is reading.

TCP Flow Control

Sending side of TCP maintains a variable, receive window. It gives the sender an idea about the free buffer space at receiver. TCP header contains a field named Receive Window. Receiver advertises spare room available in its receive buffer in the receive window field of every segment it sends to the sender.

Congestion means too many sources sending too much data too fast for network to handle. This can result into lost packets (buffer overflow at routers), long delays (queuing in router buffers).

TCP Congestion Control

Each sender limits the rate at which it sends traffic as a function of perceived congestion. In case the network is congestion-free, upon the arrival of ACKs, TCP sender indicates a congestion-free source-to-destination path. Occurrence of either timeout or receipt of three duplicate ACKs from receiver indicates congestion. If a sender perceives that there is little congestion on the path between itself and the destination, then it increases its send rate. In case there is congestion along the path, then it reduces its send rate.

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 35: User Datagram Protocol (UDP)

This topic describes the User Datagram Protocol (UDP).

The **Internet** Transport Layer can either use Transmission Control Protocol (TCP) or User Datagram Protocol (UDP). TCP is a reliable service while UDP provides unreliable delivery.

Household Analogy:

Consider two houses, one in Lahore and other in Islamabad. Each house is a home to a dozen kids. The kids are cousins and each kid writes letter to each cousin every week (144 letters in total). Each letter is delivered by traditional postal service in a separate envelope. In each house, one kid is responsible for mail collection and mail distribution. Hassan does this job in Lahore while Umer does it in Islamabad. Each week Hassan collects the mail and gives it to the postal service mail carrier. He also distributes the received mail. Umer performs a similar job in Islamabad. The postal service provides logical communication between the two houses and not from person to person.

Hassan and Umer provide logical communication among the cousins. Application messages are like letters in envelopes. Processes resemble cousins. Hosts (also called end systems) are same as houses. Job of the transport-layer protocol is the same as that of Hassan and Umer. The network-layer protocol is like the postal service.

Assume Hassan and Umer go on vacation, and another cousin pair -- say Fahad and Ahmed replace them. Being younger, they pick up and drop off the mail less frequently and occasionally lose letters. They do not provide the same set of services as Hassan and Umer. Transmission Control Protocol (TCP), and User Datagram Protocol (UDP) offer different service models to applications.

In contrast to TCP:

UDP provides “best effort” service. Segments may be lost, delivered out of order to application. There is no connection between UDP sender, receiver. Each UDP segment is handled independently of others. UDP does not support error recovery, congestion control, and flow control.

Why is there a UDP?

No connection establishment (which can add delay) is required by UDP. No connection state at sender, and receiver, thus making it simpler. As no congestion control is supported, UDP can blast away as fast as desired. UDP is more suitable for real-time apps (online streaming video).

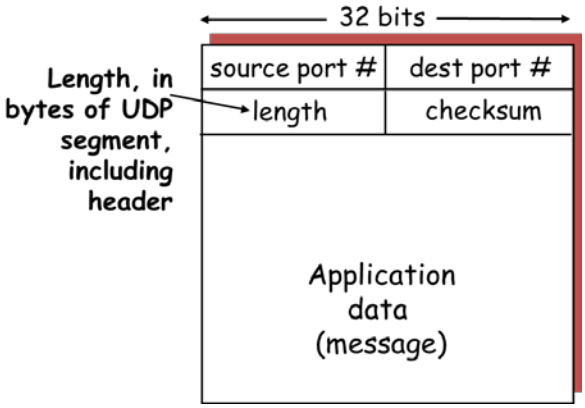


Figure 35.1: UDP segment structure

Usage of UDP

UDP is more suitable for streaming multimedia and Internet telephony (e.g. Skype).

Topic 36: TCP Ports Numbers

In this topic, we describe the importance of TCP port numbers.

Imagine that Keith has two browsers open: one to look at http://www.fredsco.com , and one to look at http://www.espn.com. Keith also has his e-mail client software up all the time. He also has an FTP client working, downloading some files. What happens when a new TCP segment arrives at Keith's computer? The segment gets to the right computer, but it might have data for one of the two browsers, the e-mail client, or the FTP client. Which one? This issue is depicted next.

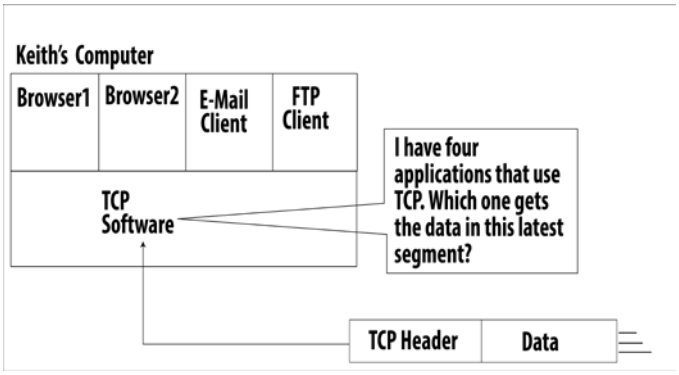


Figure 36.1: TCP ports Number

There's a field in the TCP header called the TCP destination port that tells the receiving computer which application program needs to be given the data. Let's look at the TCP header.

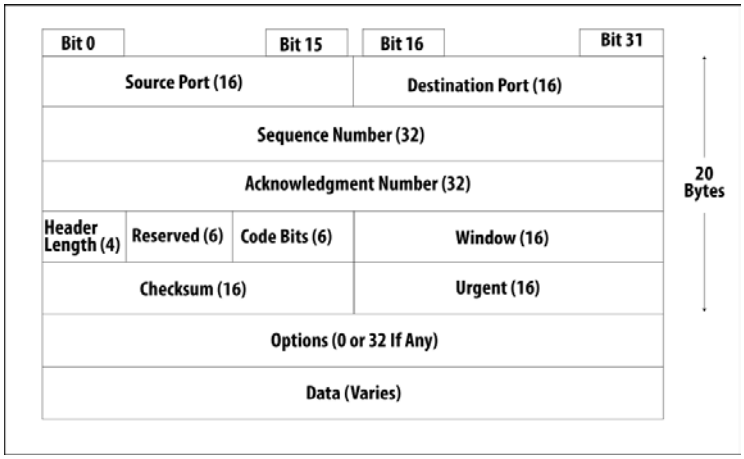


Figure 36.2: TCP Header

For each application program that is currently being run on a computer, a unique TCP port number is assigned to it.

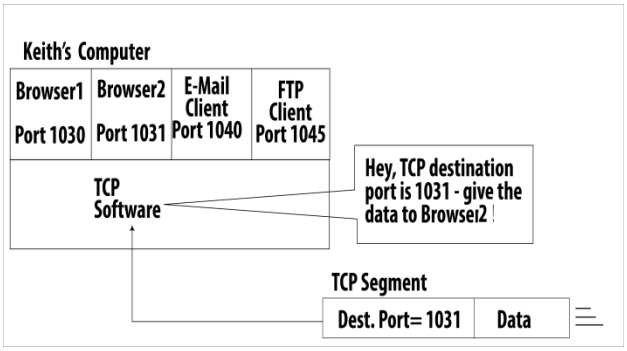


Figure 36.3: A unique TCP port number is assigned

Port Numbers range from 0-65,535 as port number field is of 16-bits. Well-known Port numbers are from 0 to 1023. These are used by well-known applications. For example, a web server uses port number 80. You can find the list of all well-known port numbers on website of www.iaina.org.

Dynamically assigned port numbers:

Typically, a client side of the application lets the transport layer automatically assign a port number.

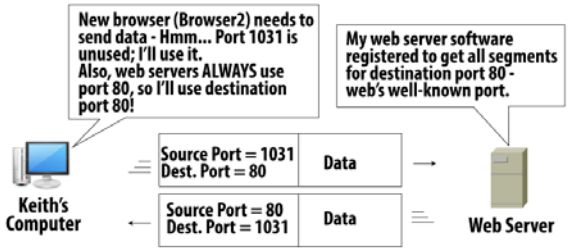


Figure 36.4: The transport layer automatically assigns a port number

Before useful data can be exchanged between a client and a server, a TCP connection is established with a three way handshaking phenomenon. A 3-way Handshaking takes place. Both endpoints agree to communicate with each other. Also, port numbers the client and server use, what values to start with in the sequence number field, and other details are also exchanged with each other.

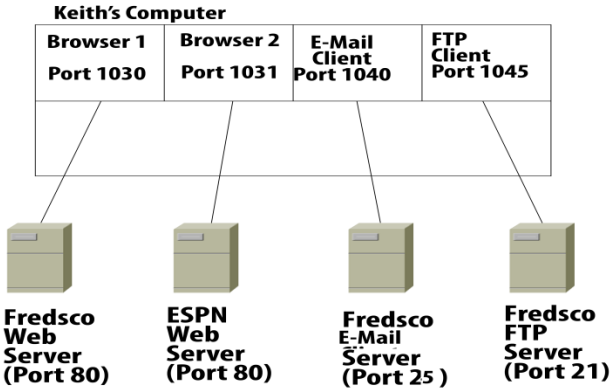


Figure 36.5: TCP ports

Topic 37: TCP Segmentation

This topic describes process and benefits of segmentation performed by TCP.

When a TCP/IP application such as email or web client has data to send, it gives it to transport layer protocol. The application layer protocol does not have a limit to the size of bytes it chooses to send. However, TCP segments data received from the applications to ensure that a TCP segment will fit into a single link-layer frame. The maximum amount of application-layer data that TCP can grab and place in a segment is called Maximum Segment Size (MSS). 1480 is a typical value for MSS. The process of breaking the application data into parts is called segmentation. The bytes that include the data and the TCP header are called TCP segments.

Example:

Let's assume a client contacts a web server. The home page has 3000 bytes of data. HTTP gives all 3000 bytes to TCP. MSS of TCP is 1480. Put 1460 bytes into data part of a segment.

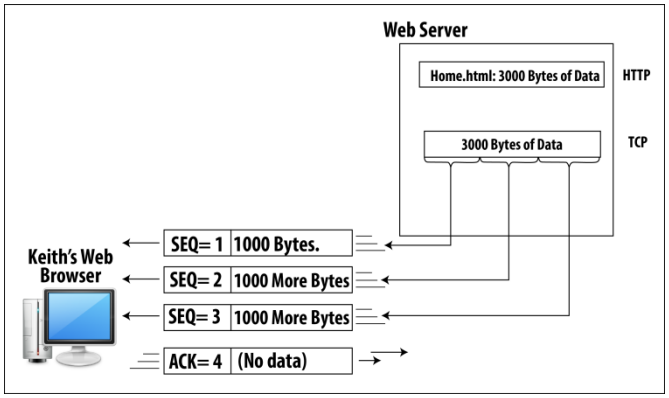


Figure 37.1: TCP Segmentation

Segmentation brings benefits too?

Imagine you download a web page, which contains a graphics file called logo.gif. Its size is 146 KB. If TCP sends all the data in one TCP segment a single bit can get an error during transmission. This will result in TCP will have to resend the entire packet. Now let TCP sends logo.gif as 100 segments with 1460 bytes in each segment. If a single bit error occurred, only one segment would have to be re-sent. Thus, improving the network performance.

When TCP segments the application data, it uses the first byte of each segment for sequence number. TCP actually numbers the bytes, not the segments. This is shown next.

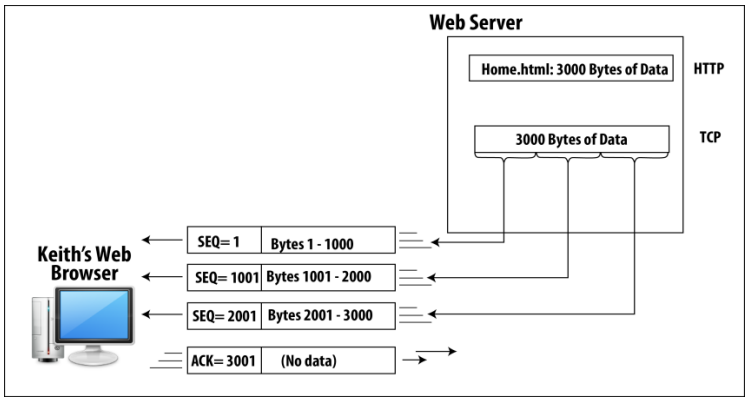


Figure 37.2: TCP segment the application Data

Topic 38: Basics of Internet Protocol (IP)

In this topic, we provide the basics of Internet Protocol (IP).

In a typical large network, many routers and LAN switches sit between a client PC and a server. **Routers** are networking devices that connect to multiple physical networks, such as multiple Ethernets. They make decisions about where to forward the data so that it reaches the correct destination.

Example

Assume Hannah on a LAN in Mason wants to get a web page from a web server http://www.cisco.com on a LAN in Cincinnati. This is shown next.

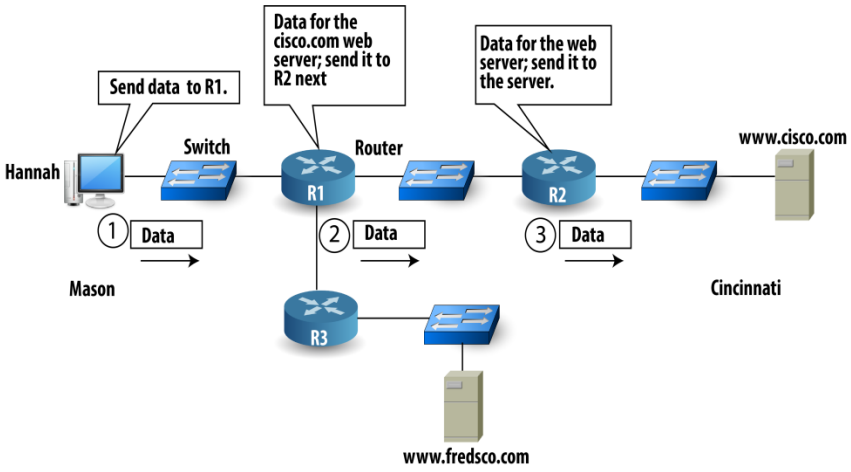


Figure 38.1: Topic 38: Basics of Internet Protocol (IP)

Routing is the complete process by which a computer sends the data, passing through all the routers and eventually arriving at the destination. Previous example shows only LANs, the routers could also be connected to a wide-area network (WAN).

Two Key functions

Forwarding is moving a packet from router's input to appropriate router output. Routing is the determination of the route taken by packets from source to destination. These ideas are shown next.

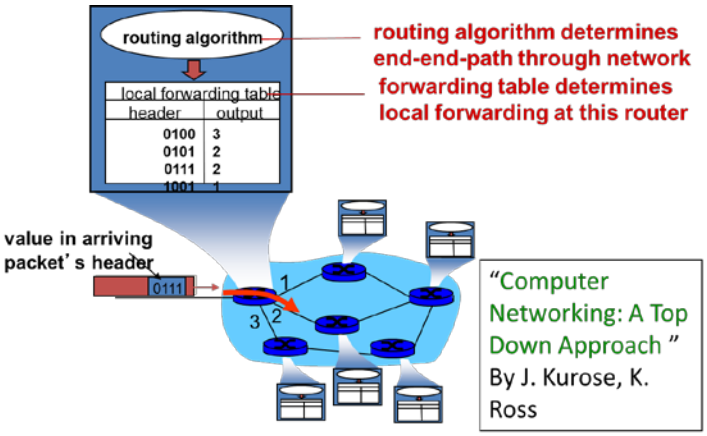


Figure 38.2: Routing with connected to wide area network (WAN)

IP provides logical communication between hosts. IP makes its best effort to deliver segments between communicating hosts, but it makes no guarantees. IP is said to be an unreliable service.

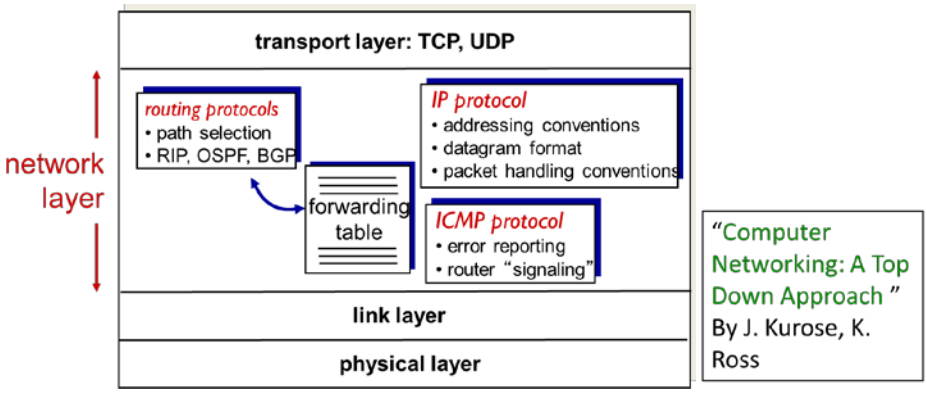


Figure 38.3: Transport Layer TCP, UDP

Topic 39: Working of IP and IP addresses

This topic explains the working of IP and usage of IP addresses.

Internet Protocol (IP) is the network layer protocol of TCP/IP model. IP defines addressing, forwarding and routing. The addressing details recommended by IP facilitate easy and efficient forwarding of IP packets. IP addresses are 32-bit binary numbers.

223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

Each of the decimal numbers in an IP address is called an octect. Range falls in [0 255]. 2^{32} is equal to 4 billion possible IP addresses. Everyone should have a unique IP address to avoid confusion when trying to deliver data to that address. Each network interface on a computer needs an IP address. A network interface is simply a card that has a physical connector for some type of network. Ethernet NIC is one such example. The NIC takes care of TCP/IP network interface layer details, which are the equivalent of OSI Layers 1 and 2. Most end user computers also known as TCP/IP hosts have a single network interface. Devices that have more than one network interface have more than one IP address. Routers are such devices. IP defines a 20-byte long header, which includes a 4-byte source IP address and a 4-byte destination IP address. An IP packet includes the IP header, along with any data that follows the IP header. To send data from one computer to the other, a sender puts the destination computer's IP address into the destination IP address field and puts its own IP address in the source IP address. This is shown next.

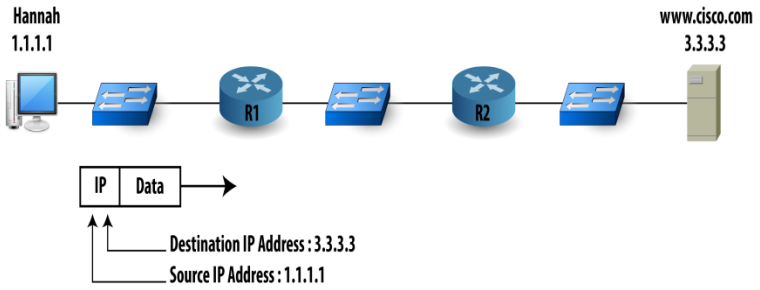


Figure 39.1: IP address field

Next, we show the process of getting a home page. Application layer generates an HTTP GET request. TCP adds its header. The TCP segment gets encapsulated in an IP packet.

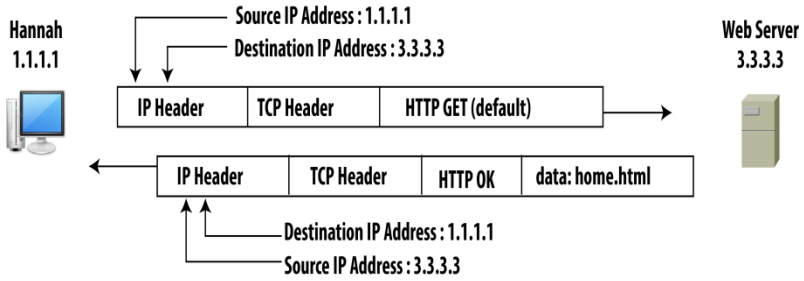


Figure 39.2: TCP segment gets encapsulated in an IP packet

HTTP is concerned about getting a web page to the user. TCP is concerned about segmentation, error recovery, and other things, on behalf of HTTP. IP provides an end-to-end delivery of packets service to TCP. Hannah types web server's name http://www.fredsco.com and corresponding IP address is 3.3.3.3. Names are more human friendly while addresses are more computer friendly.

Topic 40: How to run an IP Network?

This topic explains how an IP network runs.

The postal service provides a wonderful service. You put a letter into the mailbox, and it magically appears at the right address. By sending an IP packet into the network, the networking devices should collectively be able to forward the packet to the right destination. An example of an IP address is 1.1.1.1. There are 4 decimal numbers, between 0 and 255 inclusive, separated by periods. The structure and meaning of IP addresses tell us how IP addresses are used in an internetwork. To understand the concepts, let's take postal service as a reference. In addition to the number, street, town, and state, the postal service uses postal codes to make it easy

to sort the mail. Everyone in the same general geographical area such as a town has the same postal code. The only time the whole postal address is needed is when the letter gets to the final post office; the one that handles mail for that postal code.

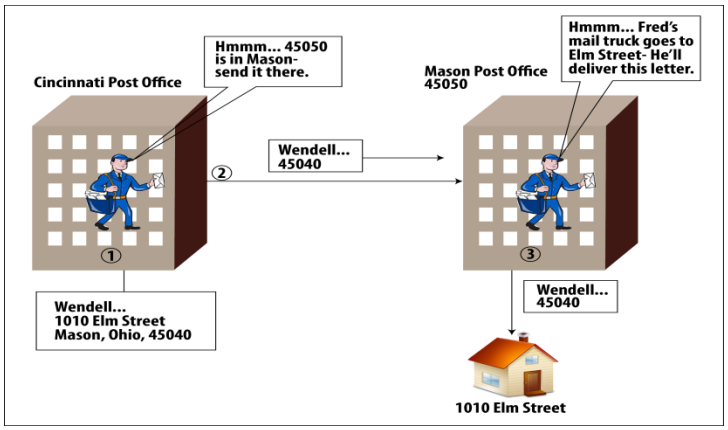


Figure 40.1: IP network

All IP addresses on the same physical network such as one Ethernet LAN have a portion of their IP addresses in common. This common portion works like a postal code. Like postal codes, all the IP addresses on the same Ethernet are in the same general area, so routing can take advantage of that fact.

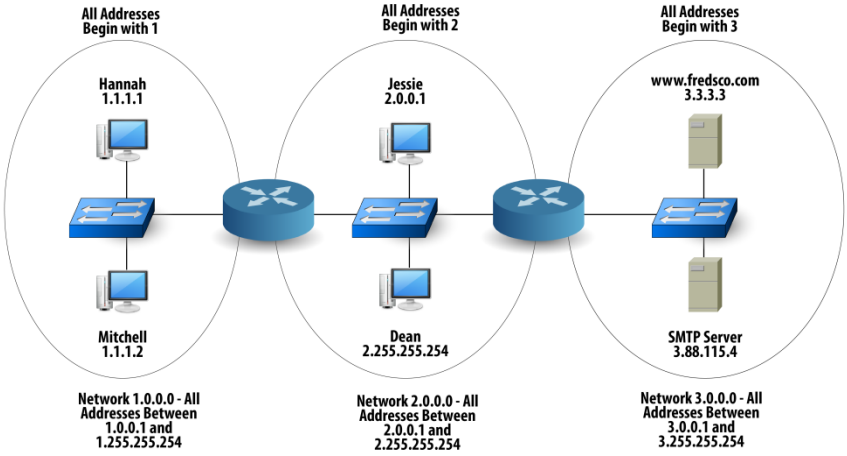


Figure 40.2: Same Ethernet are in the same general area

IP address grouping makes routing easy. Let's imagine the logic needed by R1: Packets whose destination begins with 1 should be forwarded to the left. Packets whose destination begins with 2 should be forwarded to the Ethernet on the right. Packets whose destination begins with 3 should be forwarded to R2 so that R2 can forward the packet. The routers do not have to know about every IP address in the

network. IP calls the group of IP addresses that share a common beginning to part of their addresses an IP network. The common portion is called network number and is used to represent a network. For an IP network number, the bits other than the common portion have all 0s. In previous example, the network numbers are 1.0.0.0, 2.0.0.0 and 3.0.0.0. A host cannot use a network number as an IP address in the network.

Topic 41: Classes of IP Networks

This topic describes the classes of IP networks.

Let's assume a simple internetwork with two routers and three IP networks.

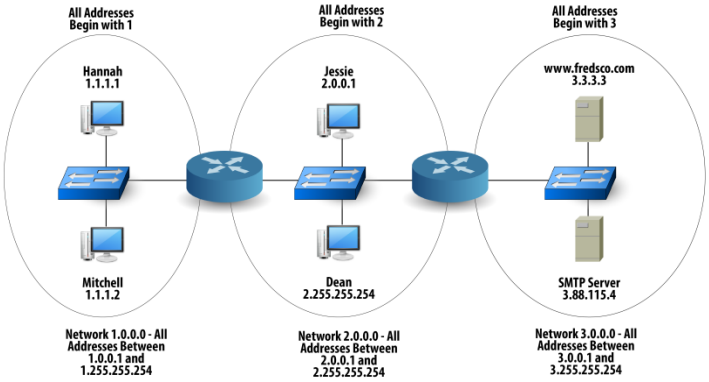


Figure 41.1: Classes of IP Networks

How many IP addresses can you have in network 1.0.0.0? You can't use 1.0.0.0 and 1.255.255.255 – are reserved. Valid addresses: more than 16 million addresses. IP defines three sizes of networks as different classes. The three different network classes are called Class A, B, and C. All addresses in the same Class A, B, or C network have the same numeric value for the network portion of the addresses. The rest of the address is called the host portion of the address.

Any Network of This Class	Number of Network Bytes (Bits)	Number of Host Bytes (Bits)	Number of Addresses per Network
A	1 (8)	3 (24)	2^{24} - 2, or 16,777,214
B	2 (16)	2 (16)	2^{16} - 2, or 65,534
C	3 (24)	1 (8)	2^{8} - 2, or 254

Let’s assume the same previous internetwork. By using one IP network number for each physical network, allows easy routing.

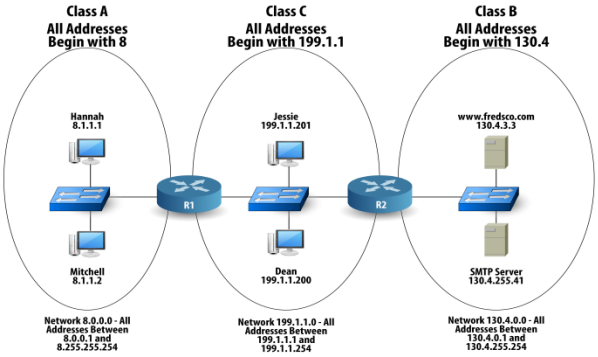


Figure 41.2: Classes of IP Networks

Class A networks allow for a ton of IP addresses in a single IP network. Class B networks allow for a pretty large number, and Class C networks allow for a smaller number of host IP addresses. The people who made up IP addressing chose three sizes of networks because one size doesn't fit all companies and organizations. Larger companies can use Class A, medium-sized companies can use Class B, and small companies can use Class C.

Class	First Octet Range	Valid Network Numbers	Total Number of Networks of This Class
A	1 to 126	1.0.0.0 to 126.0.0.0	2^7-2, or 126
B	128 to 191	128.1.0.0 to 191.254.0.0	2^{14} -2, or 16,382
C	192 to 223	192.0.1.0 to 223.255.254.0	2^{21} -2, or 2,097,150

Topic 42: IP Subnetting

In this topic, we explain the use of IP subnetting.

These days, single LANs with more than 1000 devices are extremely rare. Many IP addresses will go unused if you use a Class A or Class B network for the devices on a LAN. Subnetting provides a solution. Let’s assume that a design requires three networks, and uses three different Class B networks. Each Class B network can host 65,534 addresses.

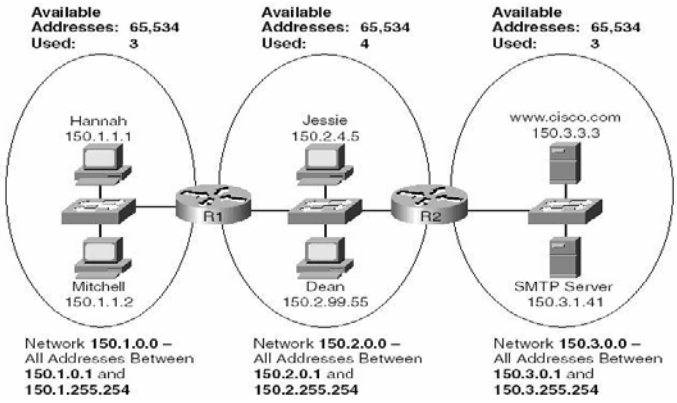


Figure 42.1: IP Subnetting

A subnet is just a subdivision of a larger Class A, B, or C network. Subnetting refers to the process whereby the engineer decides to create subnets. **Without Subnetting**, devices in the same Class A, B, or C network cannot be separated from each other by a router. Also, devices in different Class A, B, or C networks must be separated from each other by a router. **With Subnetting,** devices in the same subnet cannot be separated from each other by a router. Also, devices in different subnets must be separated from each other by a router. Subnetting allows a network engineer to configure network devices of a class B network for example, 150.1.0.0, such that they can think that the first 3 octets of the addresses identify the network. Following subnets can be created: all addresses that begin with 150.1.1, all addresses that begin with 150.1.2, all addresses that begin with 150.1.3 and so on.

An IP subnet number is used to represent a subnet. The subnet number has the same value in the first part of the number as all the host addresses, and 0s in the last part.

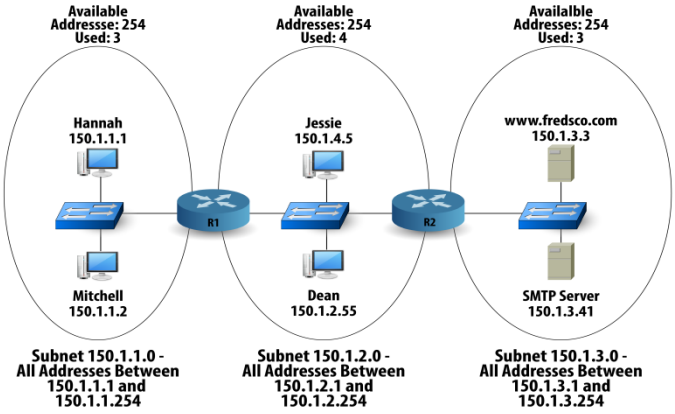


Figure 42.2: IP Subnetting

This internetwork of three Ethernet LANs only uses a part of Class B network 150.1.0.0. The same internetwork without subnetting fully uses three B classes (150.1.0.0, 150.2.0.0, and 150.3.0.0).

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 43: Network Address Translation (NAT)

This topic describes explain the concept of NAT.

Small office, home office (SOHO) subnets connect devices such as cameras, computers, smartphones, game consoles. Every IP-capable device needs an IP address. A SOHO needs a range of addresses that can be allocated by the ISP. With 32-bits, possible IP addresses are equal to 2^{32} or 4 billion. If the subnet grew bigger, a larger block of addresses would have to be allocated. But what if the ISP had already allocated the contiguous portions of the SOHO network's current address range? Network address translation (NAT) is a simpler approach to address allocation. It is defined in RFC 2663. It has found increasingly widespread use.

An Example

Assume a home network with 3 computers. A NAT-enabled router, residing in the home has an interface that is part of the home network. All four interfaces in the home network have the same subnet address of 10.0.0/24.

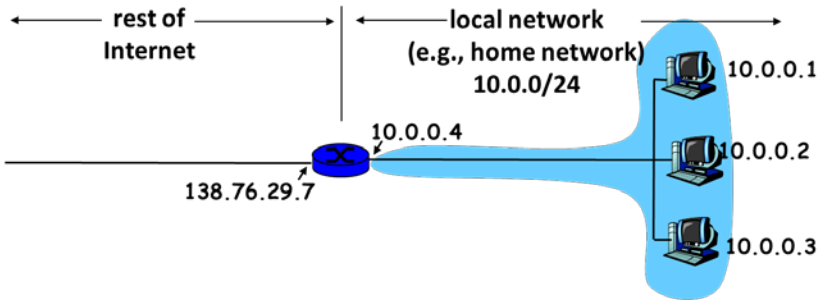


Figure 43.1: Network Address Translation (NAT)

There can be hundreds of home networks, many using the same address space, 10.0.0.0/24. Devices within a given home network can send packets using 10.0.0.0/24 addressing. How is addressing handled when packets are sent to or

received from the Internet? The NAT-enabled router does not look like a router to the outside world. Instead, it behaves to the outside world as a single device with a single IP address. All traffic leaving the home router for the Internet has a source IP address of 138.76.29.7, and all traffic entering the home router must have a destination address of 138.76.29.7 NAT-enabled router hides the details of the home network from the outside world. If all datagrams arriving at the NAT router from the Internet have the same destination IP address, then how does the router know the internal host to which it should forward a given datagram?

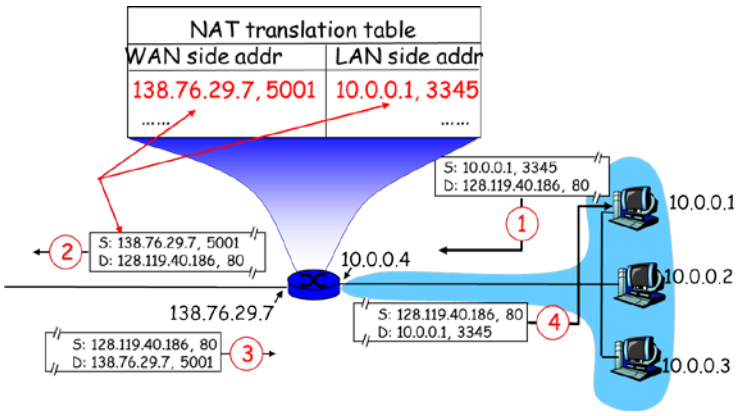


Figure 43.2: NAT-enabled router

Motivations:

Local network uses just one IP address as far as outside world is concerned: 1) range of addresses not needed from ISP. 2) Addresses of devices in local network can change without notifying outside world. 3) ISP can change without changing addresses of devices in local network.

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 44: Dynamic Host Configuration Protocol (DHCP)

In this topic, we describe the Dynamic Host Configuration Protocol.

An organization obtains a block of IP addresses from an ISP. Then, it can assign individual IP addresses to the host and router interfaces in its organization. A system

administrator will typically manually configure the IP addresses into the router. Host addresses can be configured manually or Dynamic Host Configuration Protocol.

1- Manual configuration: manually done

- Windows: control-panel->network-> configuration-> tcp/ip-> properties
- UNIX: /etc/rc.config

2- DHCP: allows a host to dynamically obtain its IP address from network server when it joins network. Because a host gets connected automatically into a network, it is “plug-and-play” protocol.

Motivating Example1

Consider a student who carries a laptop from a dormitory room to a library to a classroom. In each location, he connects to a new subnet and hence will need a new IP address.

Motivating Example2

Consider a residential ISP that has 2,000 customers, but no more than 400 customers are ever online at the same time. The ISP does not need 2,048 IP addresses. Only get a block of 512 IP addresses. As the hosts join and leave, the DHCP server allocates an arbitrary address from its current pool of available addresses. Each time a host leaves, its address is returned to the pool.

DHCP is ideally suited to these situations, as there are many users coming and going, and addresses are needed for only a limited amount of time. DHCP is a client-server protocol. A client is typically a newly arriving host wanting to obtain network configuration information, including an IP address for itself.

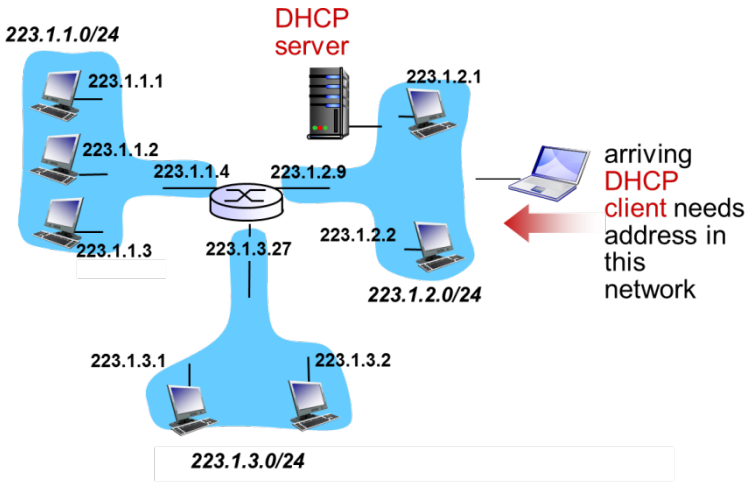


Figure 44.1: Dynamic Host Configuration Protocol (DHCP)

Working of DHCP:

For a newly arriving host, DHCP protocol is a four-step process.

1- DHCP server discovery: Host generates a UDP packet with destination port 67. Broadcast to all nodes attached to subnet.

2- DHCP server offer: Server generates a message with proposed IP address for the client, the network mask, and an IP address lease time.

3- DHCP Request: Client echoes back the configuration parameters.

4- DHCP ACK: Server confirms the requested parameters.

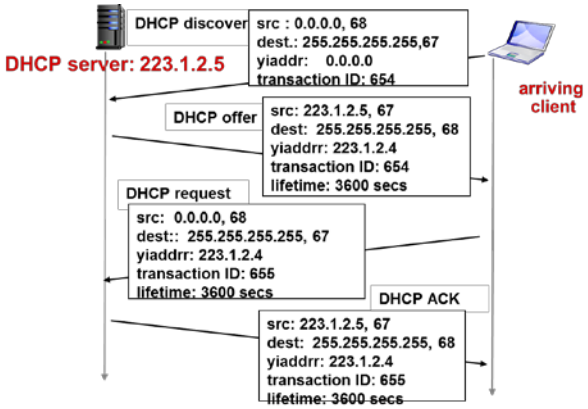


Figure 44.2: Working of DHCP

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 45: Internet Control Message Protocol (ICMP)

In this topic, we explain the usage of ICMP.

There are three Major Components of Network Layer namely, IP protocol, routing component, and a facility to report errors in IP datagrams called ICMP.

ICMP is used by hosts and routers to communicate network-layer info to each other. Error messages: unreachable host, network, port, etc. Informational messages: echo request/reply. ICMP is often considered part of IP, but architecturally lies above IP. ICMP messages are carried in IP datagrams as IP payload. An **ICMP message** consists

of type, code and first 8 bytes of IP datagram that caused the ICMP message to be generated in the first place (sender can determine the datagram that caused the error).

Type	Code	description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest. host unreachable
3	2	dest. protocol unreachable
3	3	dest. port unreachable
3	6	dest. network unknown
3	7	dest. host unknown
4	0	source quench (congestion control)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header

Many tools obtain information about the Internet by sending probes and waiting for ICMP responses. For example, ping , traceroute etc.

Ping and ICMP

The ping program sends a datagram to a specified destination to test if it can be reached. It then reports the results of the probe by declaring whether the destination responds. The ping uses ICMP echo messages. When a user invokes it by giving the IP address or hostname, ping sends datagram that contains an ICMP type 8 code 0 message (echo request) to the specified host. The destination host, seeing an echo request, sends back a type 0 code 0 ICMP echo reply message.

Traceroute & ICMP

It allows us to trace a route from a host to any host in the world. It employs TTL expired and a destination port unreachable ICMP messages. The source sends a series of IP datagrams to the destination. Each carries a UDP segment with an unlikely UDP port number.

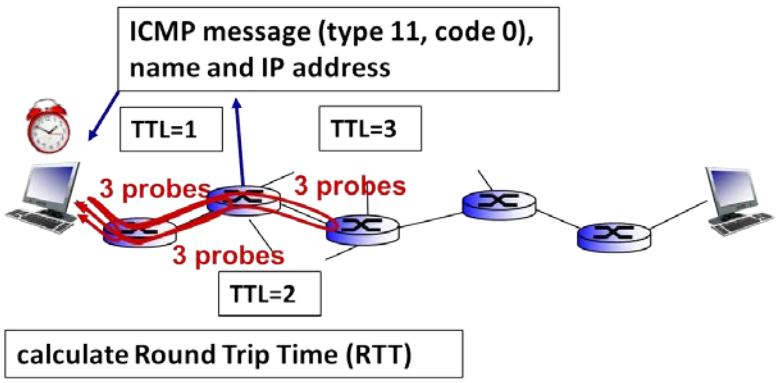


Figure45.1 Traceroute & ICMP

The **Stopping Criterion** creates an UDP segment eventually arrives at destination host. Destination returns ICMP "destination port unreachable" ICMP (type 3, code 3) message. When source gets this ICMP, it stops.

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 46: End-to-End: Processing IP Packet

In this topic, we describe fragmentation i.e. processing of IP packet along the end-to-end route.

At the link-layer, an IP datagram is encapsulated within a link-layer frame. All link layer protocols cannot carry network-layer packets of same size e.g. Ethernet frames can carry up to 1500 bytes of data. The maximum amount of data a link-layer frame can carry is called Maximum Transmission Unit (MTU). The MTU of the link-layer protocol places a hard limit on the length of an IP datagram.

Problem

Each of the links along route between sender and destination use different link-layer protocols with different MTUs. When a router is about to forward an IP packet, it may find that its length is greater than MTU.

Solution

Fragment data in IP datagram into two or more smaller IP datagrams, and encapsulate each of these smaller IP datagrams in a separate link-layer frame.

IP Reassembly & Fragmentation

Each of these smaller datagrams is referred to as a fragment. Fragments need to be reassembled before they reach the transport layer at the destination. Both TCP and UDP are expecting to receive complete, un-fragmented segments from the network layer. Datagram reassembly is done in the end systems. Keep the network core simple.

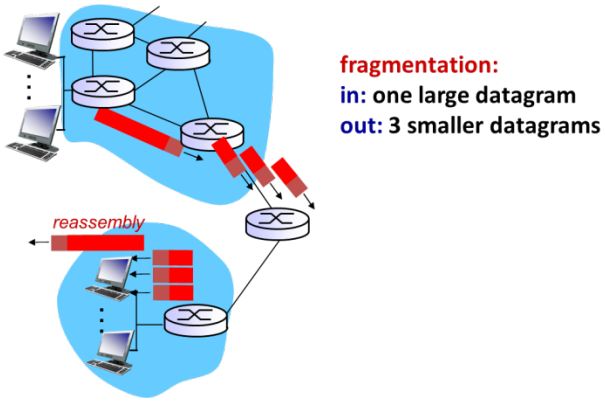
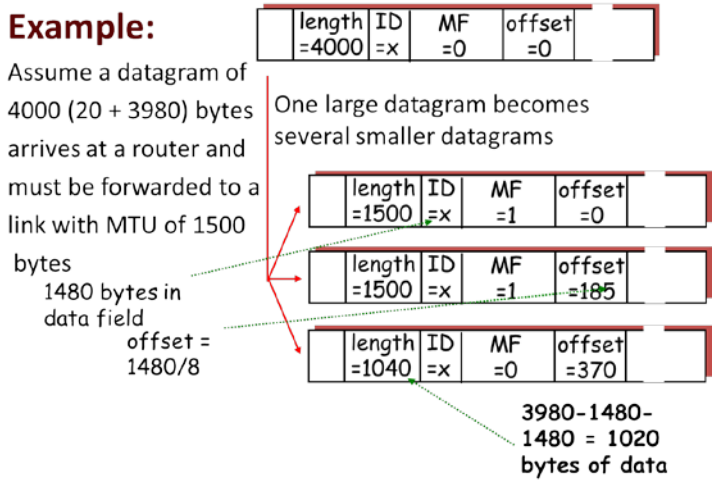


Figure 46.1: IP Reassembly & Fragmentation

There are three fields in IP header. **Identification:** allows a destination host to determine which datagram a newly arrived fragment belongs to. A sender increments identification number for each datagram. **MF:** stands for more fragments and is set for all fragments except the last one. **Fragmentation offset:** tells where in the current datagram this fragment belongs.



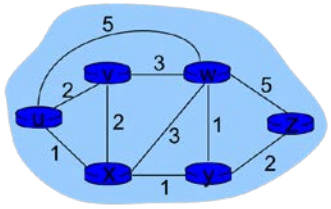
Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 47: A Link State Routing Algorithm

In this topic, we explain the working of a link state routing algorithm.

When an IP packet arrives to a router, the router indexes a forwarding table and determines the link interface to which the packet is to be directed. Routing algorithms, operating in network routers, exchange and compute the information

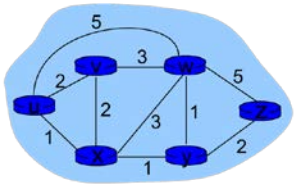
that is used to configure these forwarding tables. The job of routing is to determine good paths from senders to receivers, through the network of routers. A “good” path is one that has the least cost, e.g. physical length of the link, link speed, or monetary cost associated with it.



graph: G = (N,E)

N = set of routers = { u, v, w, x, y, z }

E = set of links ={ (u,v), (u,x), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z) }



Cost of path $(x_1, x_2, x_3, \ldots, x_p) = c(x_1,x_2) + c(x_2,x_3) + \ldots + c(x_{p-1},x_p)$

- many paths between u and z exist – how many? – 17
- Question: What’s the least-cost path between u and z ?
- Routing algorithm: finds a path between the source and
- destination that has least cost.

Figure 47.1: A Link State Routing Algorithm

Link State routing algorithm uses global information such as network topology and all link costs are known. Each node broadcasts identities and costs of its attached links to all other nodes.

Pseudo-code:

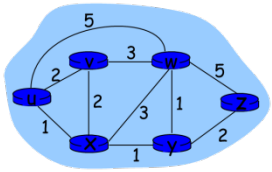
```
1  Initialization:
2   N' = {u}
3   for all nodes v
4    if v adjacent to u
5       then D(v) = c(u,v)
6    else D(v) = ∞
7  Loop
8   find w not in N' such that D(w) is a minimum
9   add w to N'
10   update D(v) for all v adjacent to w and not in N' :
11     D(v) = min( D(v), D(w) + c(w,v) )
12  until all nodes in N' or N' = N
```

Notation

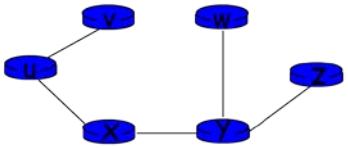
c(x,y): link cost from node x to y; = ∞ if not direct neighbors. D(v): current value of cost of path from source to destination v. p(v): predecessor node along path from source to v. N': subset of nodes

An Example:

Step	N'	D(v),p(v)	D(w),p(w)	D(x),p(x)	D(y),p(y)	D(z),p(z)
0	u	2,u	5,u	1,u	∞	∞
1	ux	2,u	4,x		2,x	∞
2	uxy	2,u	3,y			4,y
3	uxyv		3,y			4,y
4	uxyvw					4,y
5	uxyvwz					



Resulting shortest-path tree from u:



Resulting forwarding table in u:

destination	link
v	(u,v)
x	(u,x)
y	(u,x)
w	(u,x)
z	(u,x)

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

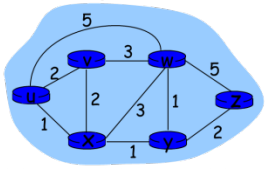
Topic 48: Distance Vector Routing Algorithm

This topic explains the working of a distance vector routing algorithm.

Bellman-Ford Equation

If dx(y) := cost of least-cost path from x to y, then dx(y) = min {c(x,v) + dv(y) }, where min is taken over all neighbors v of x.

Bellman-Ford Example



Clearly, $d_v(z) = 5$, $d_x(z) = 3$, $d_w(z) = 3$

B-F equation says:

$$d_u(z) = \min \{ c(u,v) + d_v(z), c(u,x) + d_x(z), c(u,w) + d_w(z) \}$$
$$= \min \{2 + 5, 1 + 3, 5 + 3\} = 4$$

Node that achieves minimum is next hop in shortest path. Thus, the solution to the Bellman-Ford eq. provides the entries in a node's forwarding table. Each node x maintains the following routing information:

1-For each neighbor v, the cost c(x,v)

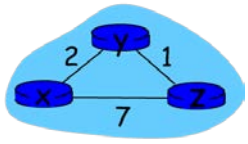
2-Node x's distance vector Dx = [Dx(y): y ϵ N], where Dx(y) = an estimate of cost of least-cost path from itself to y.

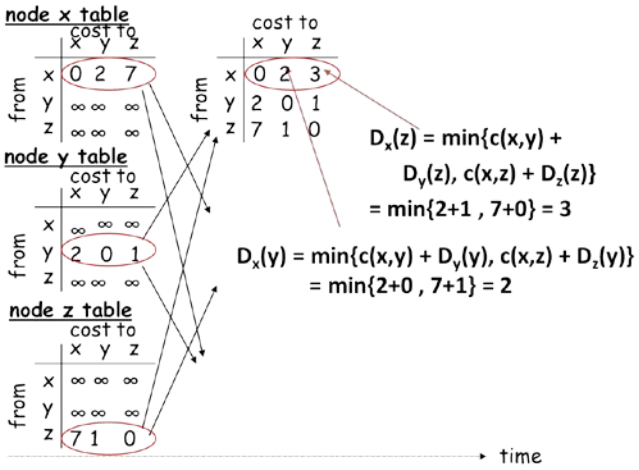
3- The distance vectors of each of its neighbors. i.e., Dv = [Dv(y): y ϵ N] for each neighbor v of x

Basic idea:

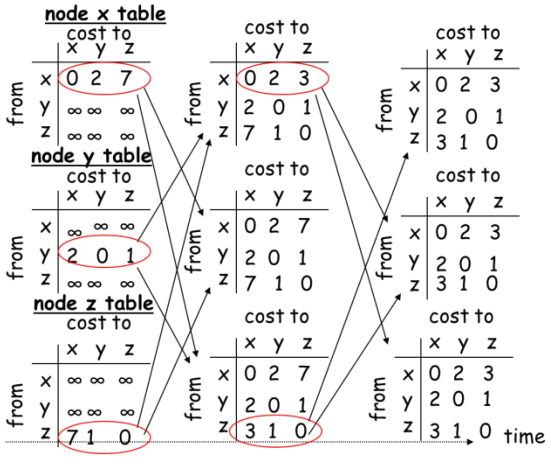
From time-to-time, each node sends a copy of its distance vector to each of its neighbors. When a node x receives a new distance vector from any of its neighbors v, it saves v's distance vector, and then uses the Bellman-Ford equation to update its own distance vector as follows. If x's distance vector has changed as a result of this update step, x will then send its updated distance vector to each of its neighbors, which can in turn update their own distance vectors. The estimate Dx(y) converges to the actual least cost dx(y).

An Example:





The DV algorithm continues until no update messages are sent.



Topic 49: Working of Default Gateway Router

In this topic, we explain the working of a default gateway router.

Let's assume that Hannah wants to access the webpage www.example.com residing on a webserver. The internetwork consists of three different IP networks, each with one IP network number.

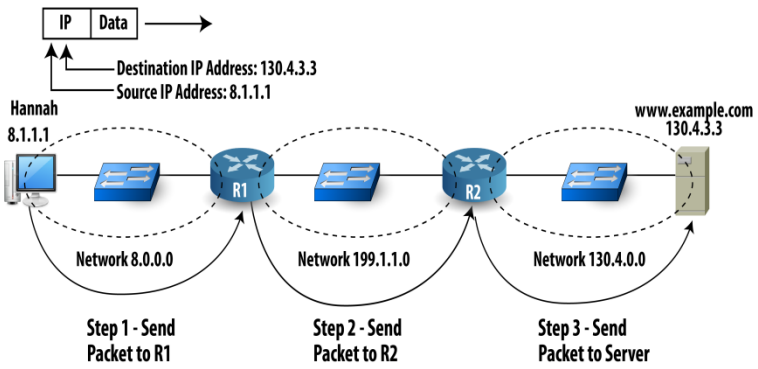


Figure 49.1: Working of Default Gateway Router

After IP software of Hannah's PC has built the IP packet that needs to be sent to the server, it needs to know where to send the packet first. To send the packet to R1, Hannah needs to know R1's IP address of the router interface that's connected to the same Ethernet as Hannah. R1 is termed as Hannah's default router/gateway. A PC's default router is simply the router to which that PC sends packets when the destination is in another network or subnet.

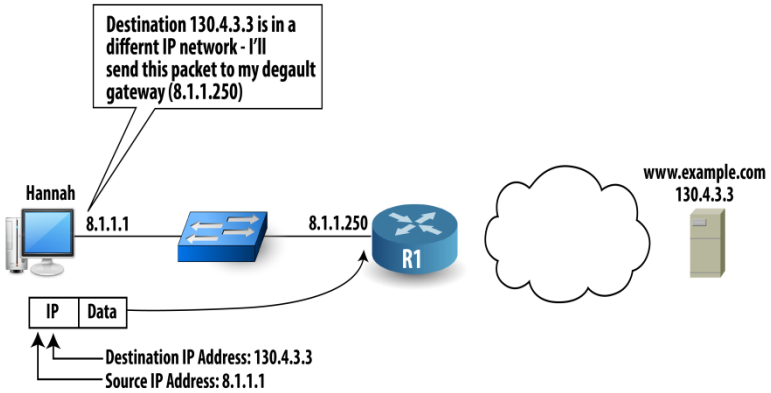


Figure 49.2: Software of Hannah's PC has built the IP

Routers typically have one IP address per physical interface. Routers have lots of interfaces of many different types, which are labeled with a name and a number, such as Ethernet1.

Topic 50: Address Resolution Protocol

In this topic, we explain how IP packets get encapsulated in Ethernet frames and how ARP works. Let's assume that Hannah's PC is connected to an internetwork that uses three different IP networks, each with one IP network number. She accesses www.example.com from a webserver.

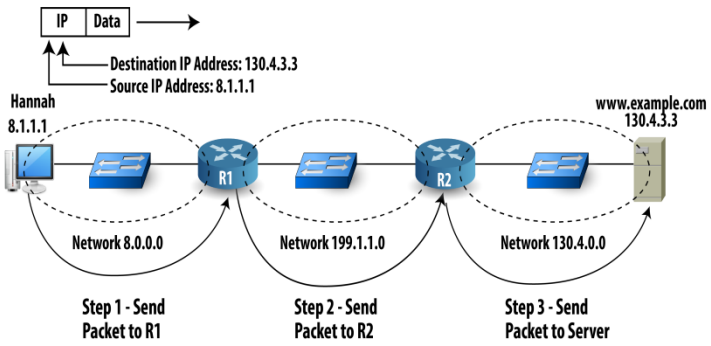


Figure 50.1: Address Resolution Protocol

Two issues need attention. 1 - Hannah can't send an IP packet over an Ethernet, but she can send an Ethernet frame over an Ethernet. 2- The destination address field of IP header holds IP address of the destination web server. There is no place for "default gateway IP address" in the header. Hannah must have some other means to ensure that R1 receives the packet. **Solution of issue 1:** Encapsulation. Hannah encapsulates the IP packet in an Ethernet frame for transmission over the LAN. Ethernet places IP packet between a header and trailer. The Ethernet header contains source and destination Ethernet address fields. The trailer contains a frame check sequence field (FCS) to determine whether errors occurred during transmission.

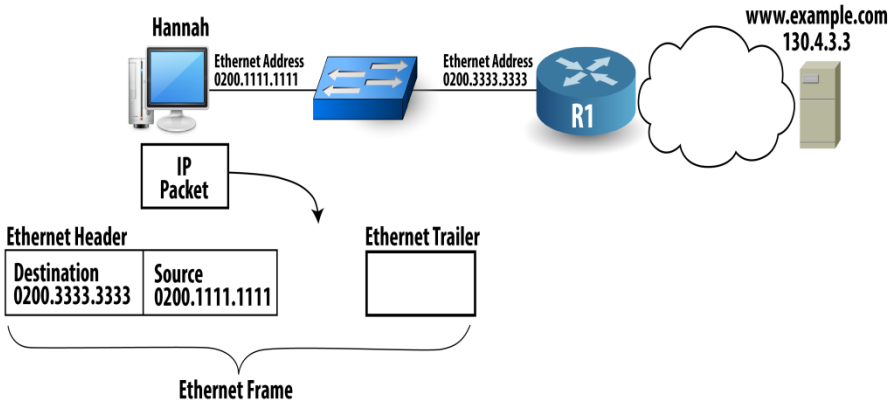


Figure 50.2: Solution of issue 1

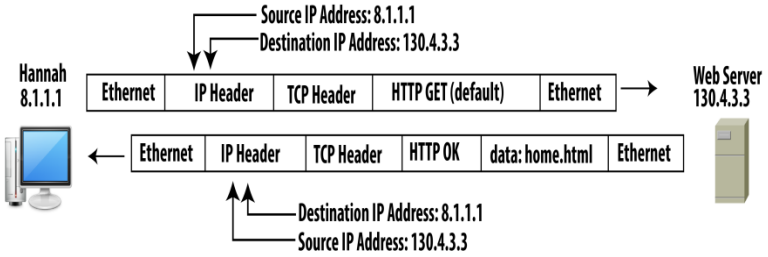


Figure 50.3: Solution of issue 1

Solution of issue 2: To deliver the packet to R1, Hannah includes R1's Ethernet address as the destination in the frame.

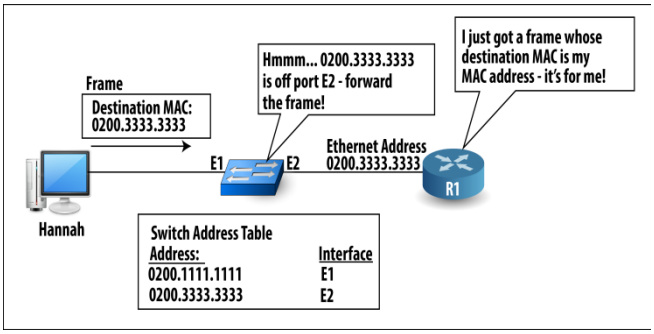


Figure 50.4: Solution of issue 2

Hannah learns the IP address of default router manually or via Dynamic Host Configuration Protocol (DHCP). To learn MAC address of R1, Hannah uses address resolution protocol (ARP).

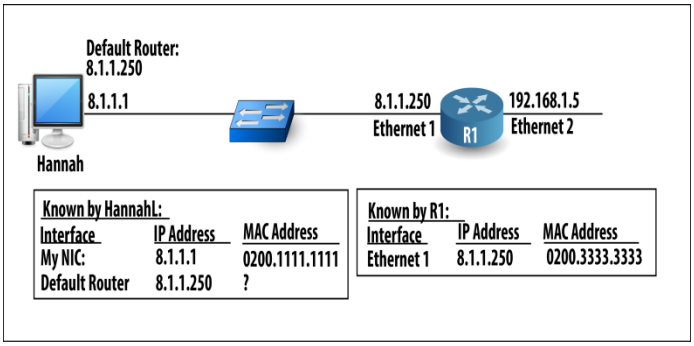


Figure 50.5 Dynamic Host Configuration Protocol (DHCP)

Hannah generates an ARP broadcast "Hey, if this is your IP address, tell me your Ethernet MAC address." Everyone on the LAN gets ARP broadcast as switch forwards LAN broadcasts to all devices in network.

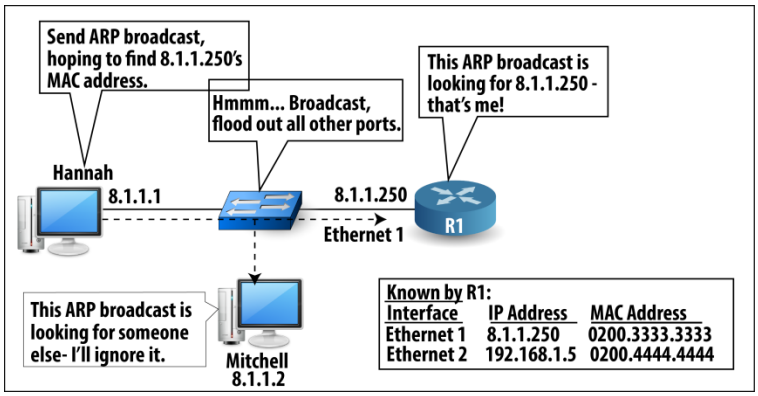


Figure 50.6: Ethernet MAC Address

Topic 51: Router's Routing Logic and Table

This topic describes the router's routing logic and contents of IP routing table.

Let's assume that Hannah's PC is connected to an internetwork that uses three different IP networks, each with one IP network number. She accesses www.example.com from a webserver.

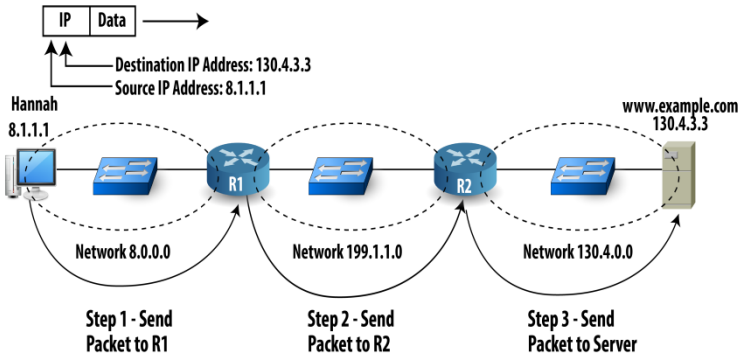
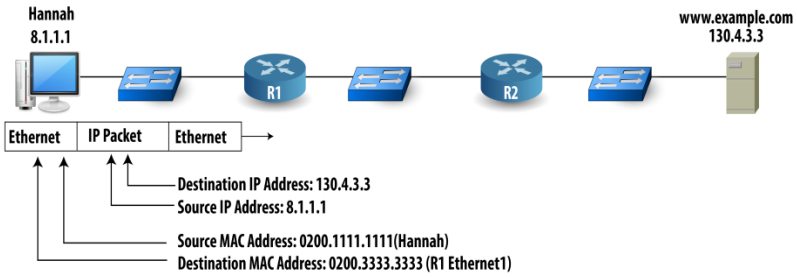


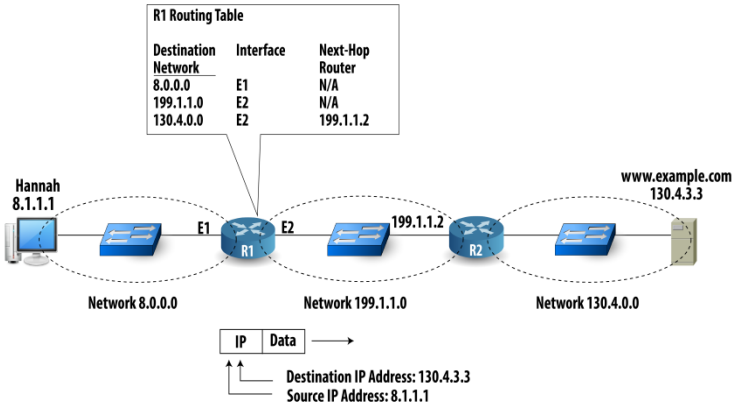
Figure 51.1: Router's Routing Logic and Table

As R1 receives the packet, it needs to forward it to R2 next. This process can be broken down into 3 steps: 1. De-capsulation. 2. Decide where to forward the packet next. 3. Encapsulation.



1. De-capsulation: Check the incoming frame's FCS. If there are errors, discard it. Otherwise, remove header and trailer, leaving the original IP packet whose source and destination addresses are 8.1.1.1 and 130.4.3.3

2. Decide where to forward the packet next: A router makes a decision about where to forward the packet next by looking at the destination IP address of the IP packet. For routing to work well, the router needs to know how to reach the various IP networks and subnets in the internetwork. This info is contained in a routing table. RIP and OSPF are examples of routing protocols.



3. Encapsulation: At this point, R1 has an IP packet sitting in memory. To send the IP packet out on E2, R1 needs to encapsulate it in a frame. In the newly created Ethernet frame: source address is MAC address of my E2 interface. Destination address is the MAC address of R2. If not known, use ARP to find R2's MAC address – put it in a cache for future use.

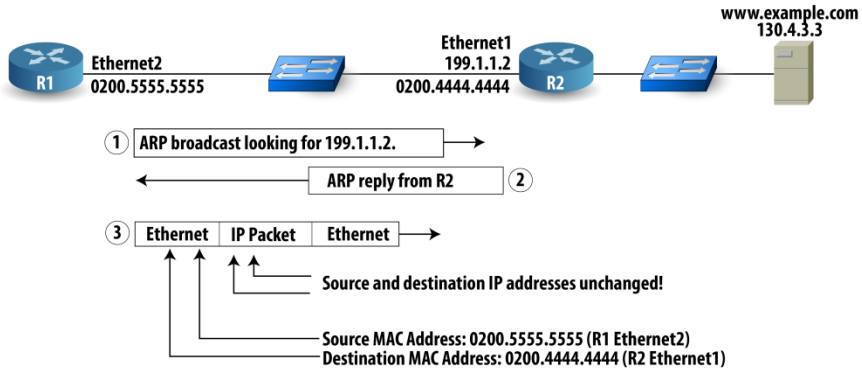
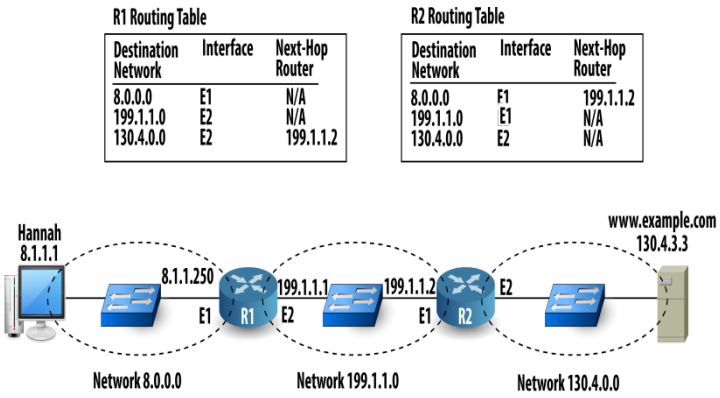


Figure 51.2: Encapsulation

Logic of Final Router: R2 has the same logic as that of R1 except R2's routing table differs from R1's: R2 does not need to send the packet to another router, but it should instead send the packet directly to the web server.



From R2 to web server: Create a new Ethernet frame. Own Ethernet address on the outgoing interface as source MAC. Use ARP to learn web server's MAC and use it as

destination. Finally, the web server has the frame and extracts the packet. The routing of the packet is complete!

Topic 52: Routing with Subnets

This topic explains how a router's routing logic works with subnets.

Let's assume an internetwork of a single Class B IP network 150.1.0.0. This IP network is subdivided into three subnets namely, 150.1.1.0, 150.1.2.0, and 150.1.3.0. All hosts in a given IP subnet have the same value in the first 3 octets of their IP addresses. Next, we look at the routing tables.

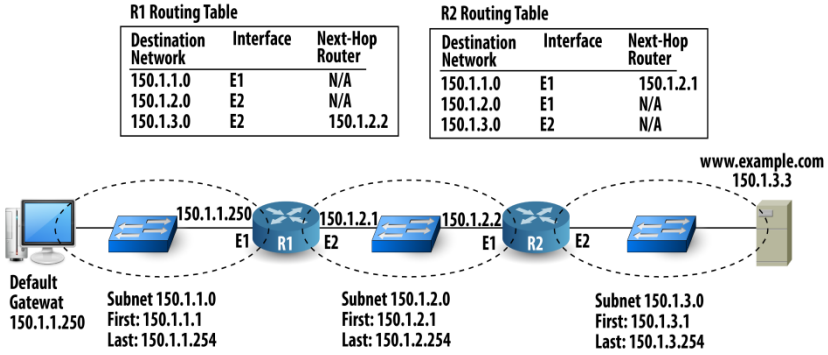
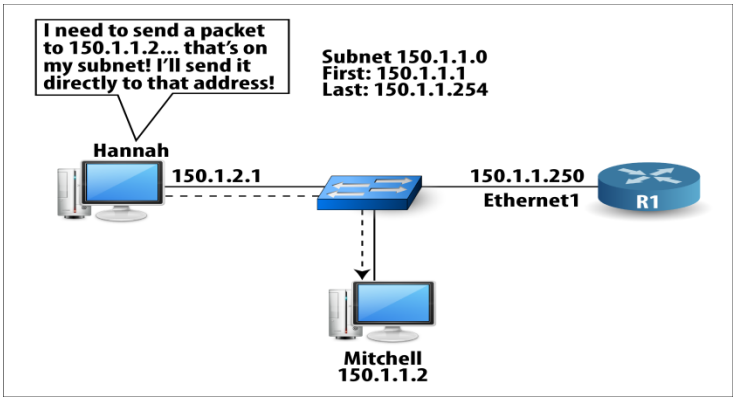


Figure 52.1: Routing with Subnets

When Hannah sends a packet to the web server, destination address is 150.1.3.3. Hannah's logic works like it did without subnettting. Hannah's default gateway is R1. Hannah sends an ARP broadcast for IP address 150.1.1.250. R1 replies and Hannah sends a frame to R1 with the IP packet inside the Ethernet frame. R1 receives the frame, and if it is error free, it extracts the IP packet. R1 uses destination address and finds an entry for it in its IP routing table. R1 forwards packet out on its E2 interface to R2 next. Finally, when R2 receives the frame, it does the usual error check and extracts the IP packet. R2 finds an entry for destination IP address. R2 can forward the packet directly to the web server. Whether or not an internetwork uses subnetting, the basic routing logic remains the same. If Hannah sends a packet to someone who's on the same subnet, she can send it directly to the destination without involving default router.



Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 53: Router Hardware Architecture

In this topic, we explain the router hardware components.

There are two key router functions: run routing algorithms (RIP, OSPF) and, forwarding datagrams from incoming links to appropriate outgoing links. A Generic router architecture is shown next.

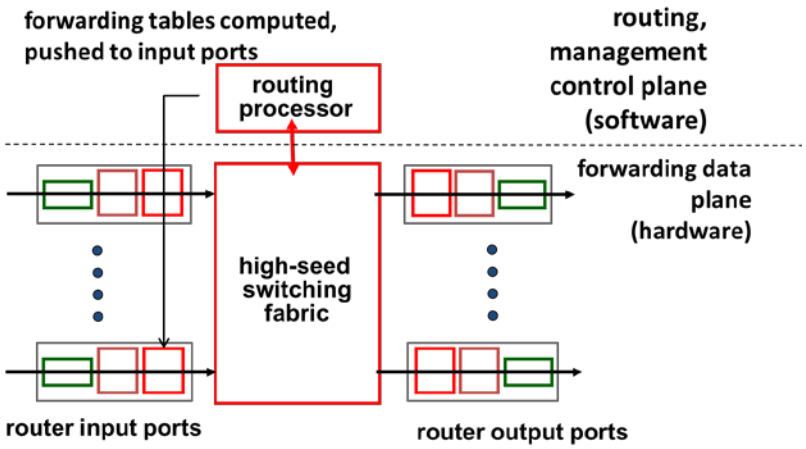


Figure 53.1: Router Hardware Architecture

Input Ports

Input ports perform physical & data link layer functions of an incoming physical link at a router. They determine output port to which an arriving packet will be forwarded via the switching fabric.

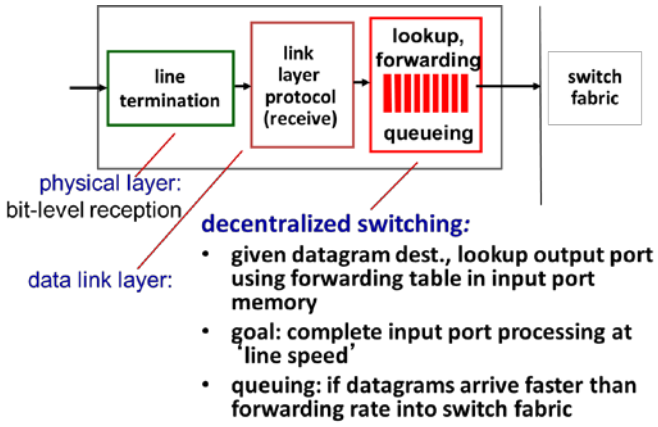


Figure 53.2: Input Ports

Switching fabrics

Switching fabrics transfer packet from input buffer to appropriate output buffer. Rate at which packets can be transferred from inputs to outputs is called switching rate. The three types are shown next.

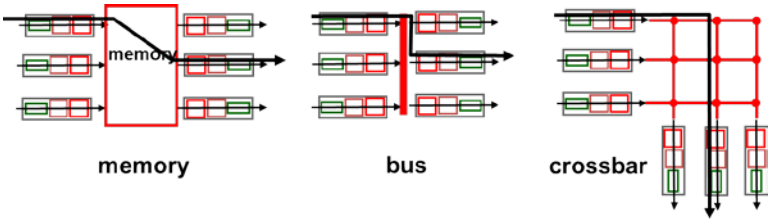


Figure 53.3: Switching fabrics

Output port

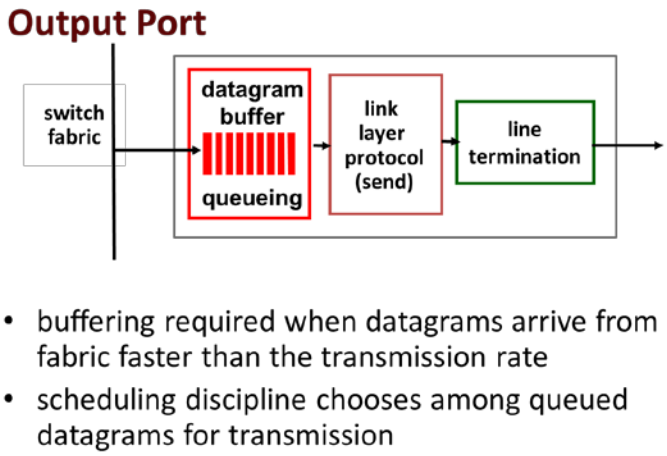


Figure 53.4: Output port

Where does queuing occur?

Packet queues can form at both input and output ports. The location and extent of queuing will depend on the traffic load, speed of switching fabric and line speed. As these queues grow large, router's buffer space will eventually be exhausted and packet loss will occur when no memory is available to store arriving packets. Suppose switch speed is N times faster than speed of line. Even then output buffering will still occur when multiple inputs send to same output. This scenario is shown next.

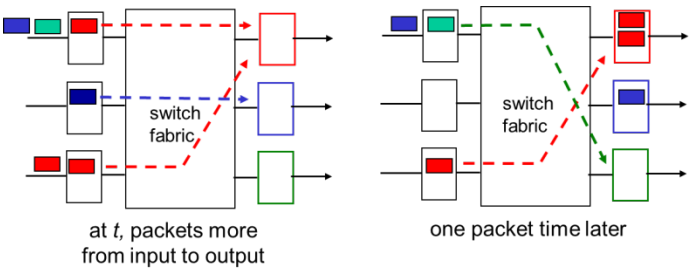


Figure 53.5: Packet queues

The Head-of-the-Line (HOL) blocking at Input Port is shown next.

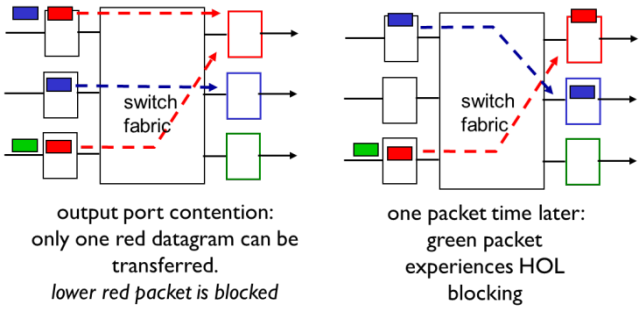


Figure 53.6: The Head-of-the-Line (HOL) blocking at Input Port

Topic 54: Routing to Nearby Places

In this topic, we explain how a router learns routing table for networks/subnets that are directly connected to it.

At a given time, a router knows which of its physical interfaces are up and working. It knows the IP addresses used on each interface. Also, it knows about IP networks or subnets that are connected to its interfaces. The router can add a route to the subnet in its routing table.

Configuring a Router When you buy a brand new router, a network engineer connects to the router and tells the router which IP addresses to use. For each interface, use an IP Address and Subnet mask to figure out the range of valid IP addresses in each subnet.

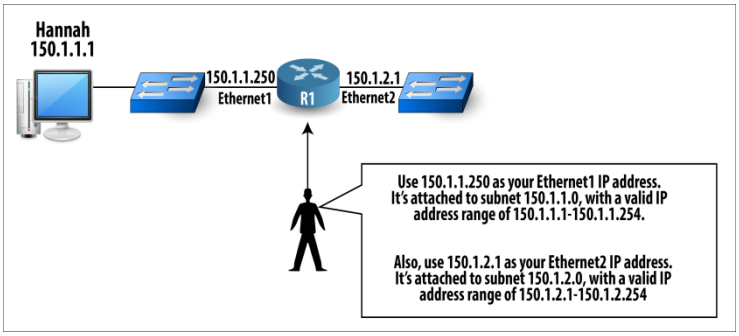


Figure 54.1 Configuring a Router

After R1's interfaces are up, it knows about subnets: the subnet numbers, the outgoing interface it should use to forward packets to them. There is no need to send packets to another router for them. In our previous example, R1's Ethernet1 interface is connected directly to the same subnet as Hannah. As a result, R1 simply adds a route for each directly connected subnet to its routing table.

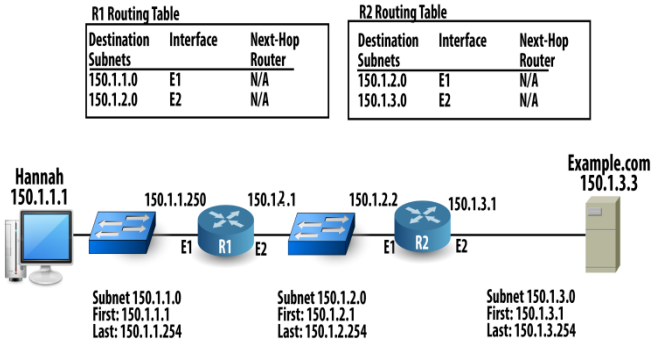


Figure 54.2: Configuring a Router

Routers always add routes for directly connected subnets and networks, as long as the interface is both configured and working. Also, they should include other routes in their routing tables. In previous example, R1 didn't have a route to subnet 150.1.3.0, so it could not forward a packet that was destined for IP address 150.1.3.3.

Static IP route: The network engineer can address this problem by configuring a static route on R1 for subnet 150.1.3.0, with outgoing interface Ethernet2, and next-hop router of 150.1.2.2.

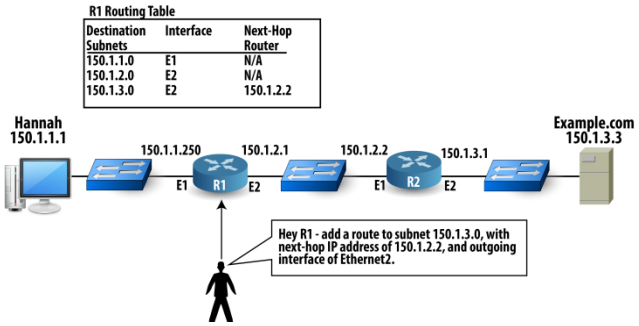


Figure 54.3: Static IP route

Network topologies tend to change a lot. Static routes make it difficult to use all the possible routes to the same part of the network when you have multiple possible physical paths.

Topic 55: Dynamically Learning Routing Tables

This topic explains explain how routing table entries are learnt dynamically.

The most typical way a router learns all the rest of the routes in an internetwork, beyond just its directly connected routes, is by using a routing protocol. **Routing Protocols** define messages by which routers can exchange route information with other routers. If all the routers participate, all routers should have routes for all

subnets or networks. Let's assume an internetwork that consists of two routers and three subnets. Several steps that occur over time are:

1- Each router knows only its directly connected routes.
2- A router generates a routing protocol message (routing update) that contains information about IP networks and subnets and send it to another router.
3- The receiving router: a) puts that interface into the route in which it received the routing update. b) Also puts the IP address of the router that sent the routing update as the next-hop router.

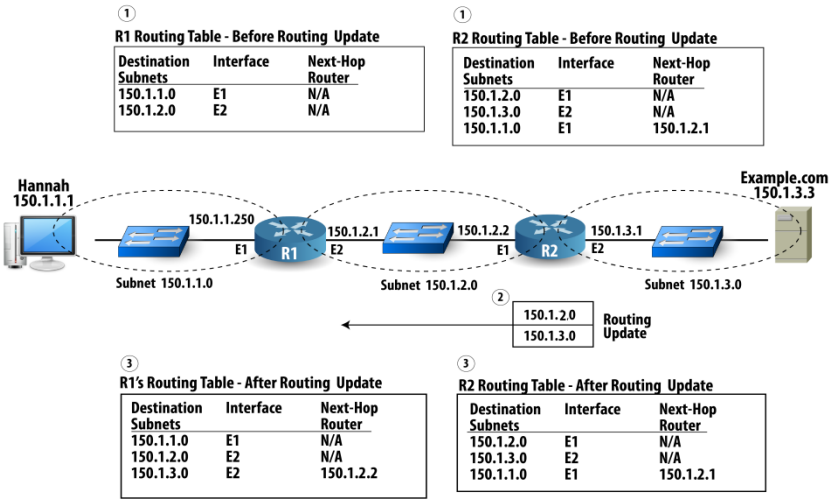


Figure 55.1: Dynamically Learning Routing Tables

Next, we show R2 advertising its routes, with R1 learning a route to subnet 150.1.3.0.

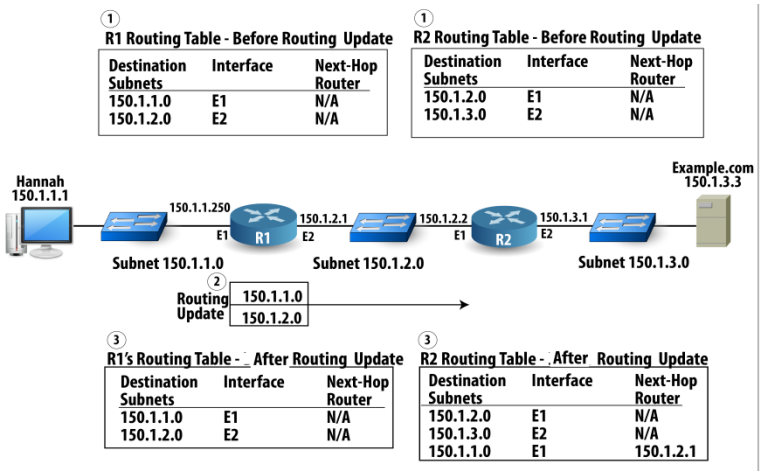


Figure 55.2: Dynamically Learning Routing Tables

Topic 56: How to Pick the Best Route

In this topic, we describe how the best route gets selected.

Routing protocols not only help routers learn routes, but they also help routers learn the best routes to a destination when there is more than one way to get there. Let's assume an internetwork consisting of three routers. R1 can send packets to subnet 150.1.3.0 through R2 or through R3.

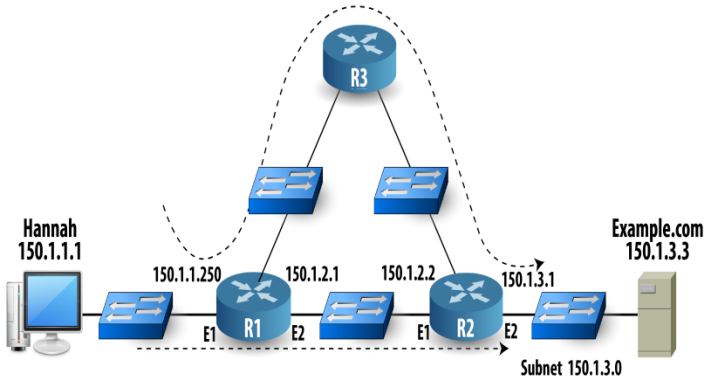


Figure 56.1: How the best route gets selected

Routing protocols define a number called a metric that's associated with each route in a routing update. That number represents how good or how bad that route is. When a router receives multiple routing updates, it might learn of multiple ways to reach a subnet. By looking at the metrics, the router can pick the best route.

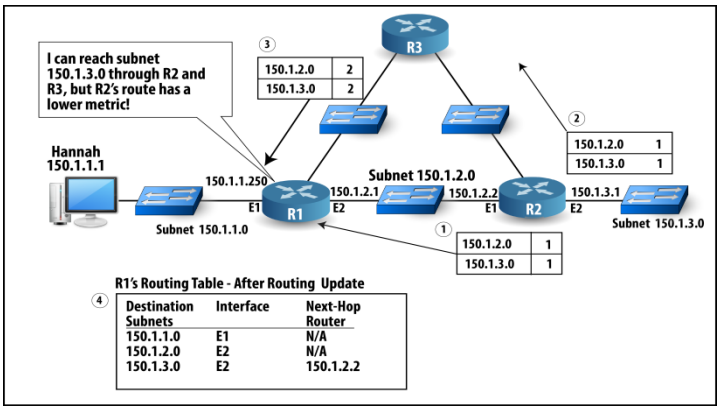


Figure 56.2: The router can pick the best route

Imagine that someone turns off the power on the Ethernet switch between R1 and R2. That route would then fail and be unavailable. The routing protocol on R1 would remove the route from the routing table. At the same time, R1's routing protocol

would notice that another route exists the one through R3 and add that route to the routing table.

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 57: Interior & Exterior Routing Protocols

In this topic, we explain the need for interior and exterior routing protocols.

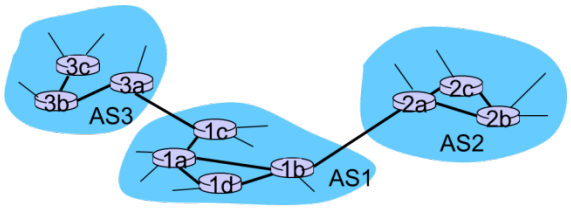
Hierarchical Routing

Considering network to be flat, taking all routers to be identical and running one single routing protocol is not realistic. At least two reasons:

1-Scale: with hundreds of millions destinations can't store all destinations in routing tables. Similarly, routing table exchange would swamp links.

2-Administrative Autonomy: internet is a network of networks. Each network admin may want to control routing in its own network

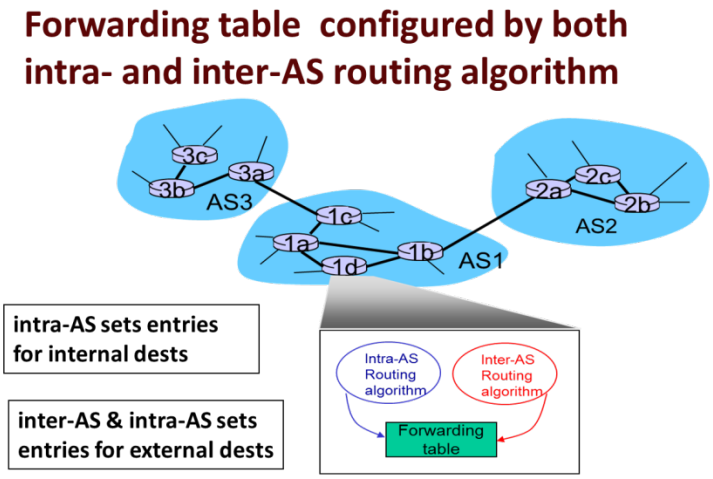
Autonomous System (AS): Organize routers into regions. An AS is under the same administrative control. For example, operated by the same ISP or belonging to same company network. All routers within the same AS run the same routing protocol (intra-AS or interior routing protocol) and have information about each other. Routers in different AS can run different intra-AS routing protocols. To connect ASes to each other, one or more of the routers in an AS will have to be responsible for forwarding packets to destinations outside the AS – Gateway routers.



routers 1b, 1c, 2a, and 3a are gateway routers

If a router in AS1 receives an IP packet destined outside of AS1, then it uses an inter-AS (exterior) routing algorithm 1- to learn which destinations are reachable through

AS2, which through AS3, and 2- propagate this information to all routers in AS1. This is shown next.



Well-known IP routing protocols are listed next.

IP Routing Protocols

Routing Protocol	Public or Proprietary?	Interior or Exterior?
Routing Information Protocol (RIP)	Public	Interior
Interior Gateway Routing Protocol (IGRP)	Proprietary	Interior
Open Shortest Path First (OSPF)	Public	Interior
Enhanced IGRP (EIGRP)	Proprietary	Interior
Border Gateway Protocol (BGP)	Public	Exterior

Topic 58: Introduction to Domain Name System

In this topic, we explain why a domain name system (DNS) is required.

People have many identifiers. For example, name, passport#, NTN#, NIC#. One identifier cannot be used everywhere. Can Hassan Hamid be used to recognize a tax payer? Similarly, Internet hosts have many identifiers. A “hostname”, e.g., www.yahoo.com is human friendly but difficult for routers to process variable length alphanumeric characters. IP address (32 bit) is router friendly. If you need to call someone and you know the person's name but not the phone number, you can just look up the information in the phone book. It's simple and easy provided the info is present in the book. TCP/IP hosts can have the equivalent of a phone book in a file. The local host file contains a list of TCP/IP host computer names and their corresponding IP addresses. Assume Hannah types http://www.example.com in a

browser. Hannah's PC can send an IP packet to the web server, if its IP address is known. Look local host file (www.example.com, 150.1.3.3).

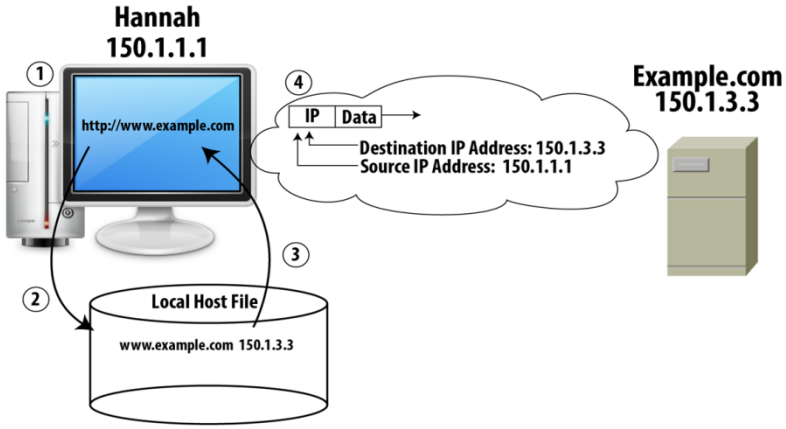


Figure 58.1: Domain name system (DNS)

A local host file cannot list the names and IP addresses of every server on the planet. If the pair changes, conveying this updated info to everyone is cumbersome. TCP/IP uses a domain name system (DNS) instead of local host file. DNS defines how to discover which names correspond to which IP address. DNS also defines the structure and format of TCP/IP host and names.

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 59: Domain Name System (DNS) Servers

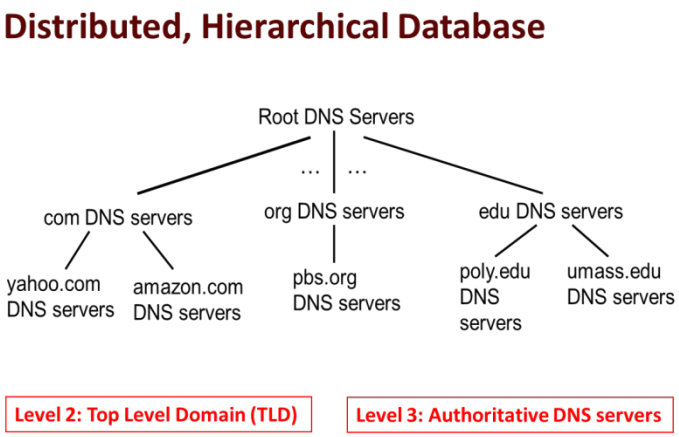
In this topic, we explain the need for different domain name system (DNS) servers.

DNS is an application-layer protocol that allows hosts to query the database and to resolve names (name, address). It is employed by other application-layer protocols such as HTTP, SMTP, and FTP.

Problems with centralized DNS

Single point of failure: If the DNS server crashes, so does the entire Internet. Traffic volume: a single server would have to handle all DNS queries. Distant centralized database: a single server cannot be "close to" all the querying clients –significant delays. Maintenance: a centralized database would have to be updated frequently for every new host. In order to deal with the issue of scale, the DNS uses a large

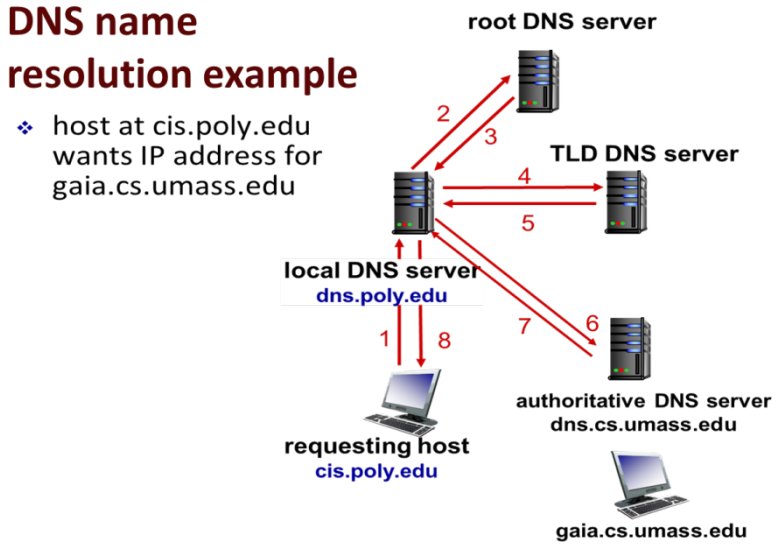
number of servers, organized in a hierarchical fashion and distributed around the world.



Interaction of Servers: an approximation

Let's assume a client wants IP address for www.amazon.com. 1- The client queries a root server to find com DNS server. 2- The client queries com DNS server (TLD) to get amazon.com DNS server. 3-client queries amazon.com DNS server (Authoritative) to get IP address for www.amazon.com.

Root Name Servers: in the Internet there are 13 root servers. **Top-level Domain (TLD) Servers** are responsible for com, org, net, edu, gov, and all top-level country domains, e.g.: uk, fr, ca, jp. **Authoritative Servers:** organizations with publicly accessible hosts (e.g. web servers) must provide publicly accessible DNS records that map the names of those hosts to IP addresses. **Local DNS Servers** do not strictly belong to hierarchy. Each ISP has one server which is also called "default name server". When host makes DNS query, query is sent to its local DNS server.



DNS Caching: once (any) name server learns mapping, it caches mapping.

Topic 60: Working of Domain Name System

In this topic, we explain working of domain name system (DNS) inside and outside company.

DNS defines how to figure out names and IP addresses for the entire Internet, as well as inside a single site at a single company.

Inside the Company: Let's assume that Hannah's PC is inside the example.com corporation's enterprise network. She wants to view http://www.example.com.

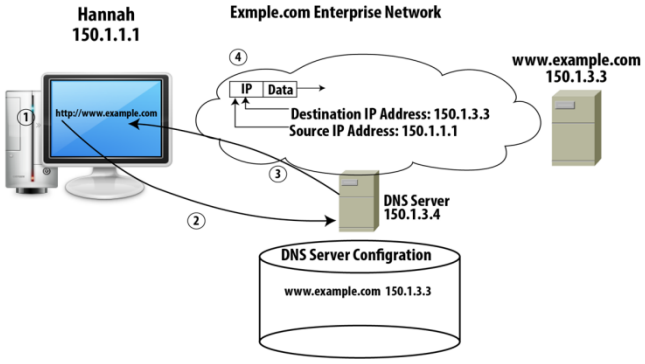


Figure 60.1: Working of Domain Name System

For DNS to work well inside a company, someone must be responsible for supporting it. That work includes updating and changing the list of names and IP addresses.

Outside the Company: Let's assume that Hannah wants to access the http://www.fredsco.com website, which is located in Fredsco enterprise network.

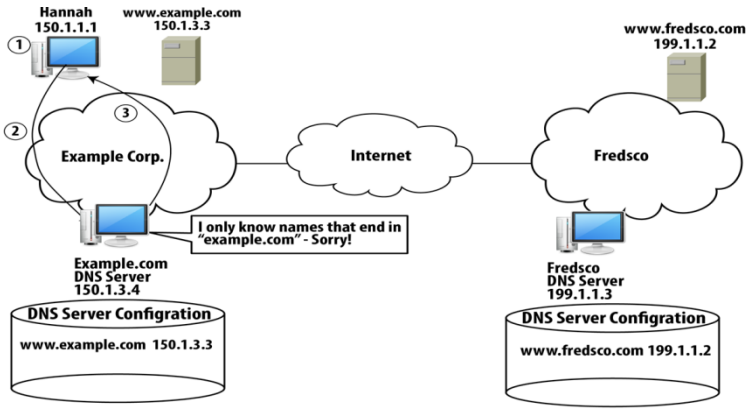


Figure 60.2: Fredsco enterprise network

The DNS servers must work together as shown next.

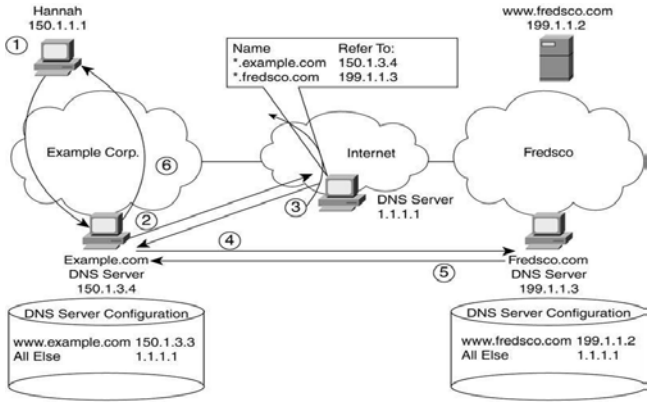


Figure 60.3: The DNS servers

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 61: DNS Resource Records

This topic describes the use of domain name system (DNS) Resource Records.

The domain name service (DNS) is a directory service, which translates hostnames into IP addresses. It is a distributed database implemented in a hierarchy of many DNS servers. The DNS distributed database is stored on servers in the form of resource records (RRs):

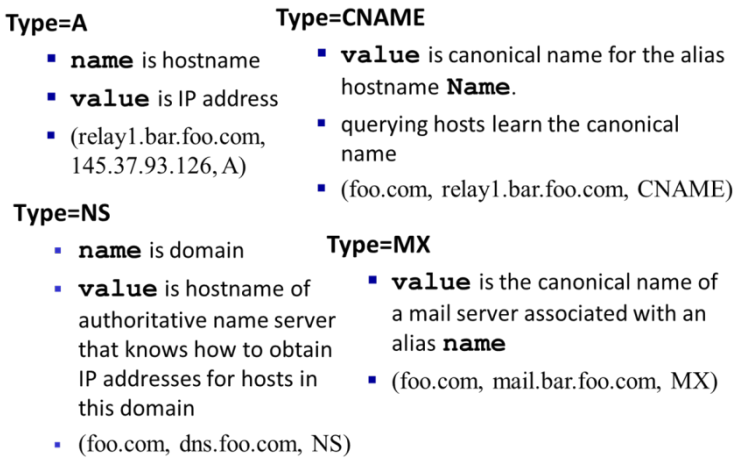
DNS Resource Record Format:

RR format: **(name, value, type, TTL)**

Time to live (TTL) – after this time a resource record becomes invalid

The meaning of **name** and **value** depend on **type**

The type field is defined as:



Inserting resource records into DNS

Let's assume that Alice just created a new startup company "Network Utopia". She wants to register domain name networkuptopia.com.

1- She needs to contact a registrar (A registrar accredited by Internet Corporation for Assigned Names and Numbers (ICANN) verifies the uniqueness of the domain name, enters it into the database and collects a small fee for its services.)

2- She needs to provide registrar with names and IP addresses of her primary and secondary authoritative name servers.

3-Registrar inserts two RRs (NS and A) into the TLD com server:

- (networkutopia.com, dns1.networkutopia.com, NS)
- (dns1.networkutopia.com, 212.212.212.1, A)

4 -She also has to make sure that Type A record for web server www.networkuptopia.com and Type MX record for her mail server mail.networkutopia.com are entered into her authoritative DNS servers.

Now suppose Bob views www.networkutopia.com. His host will first send a DNS query to his local DNS server, which will then contact a TLD com server. This TLD com server contains the NS and A RRs listed above and sends a reply back to Bob's local DNS server. This local DNS server then sends a query to 212.212.212.1, asking the type A record. This record provides the IP address, say 212.212.71.4, to Bob's host and now browser can initiate a TCP connection.

Topic 62: Introduction to Wide Area Network

In this topic, we describe what a wide area network (WAN) is.

A wide-area network (WAN) defines a type of a network, or part of a network, in which the devices are relatively far apart. A WAN is a network, or part of a network, for which the cabling must pass outside the property of one company. The distance might only be a few miles, or it might be thousands of miles! We next show a WAN.

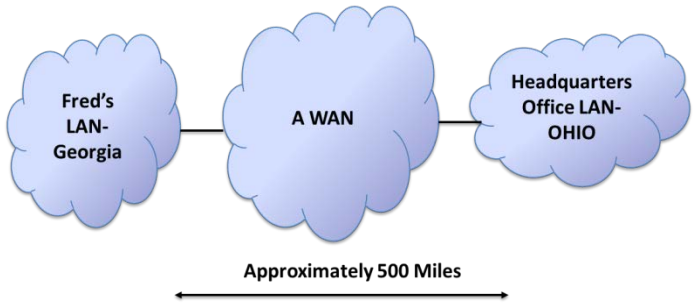
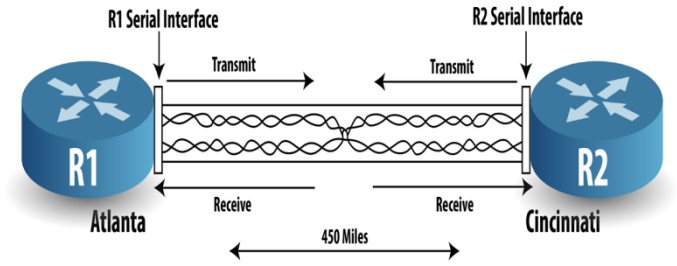


Figure 62.1: Wide Area Network

You can run an Ethernet cross-over cable between two devices and the two devices can communicate with Ethernet. That works well, but can we use it for longer distances? If two routers in two cities need to forward packets to each other, they need some sort of physical medium over which to send the packets.



When R1 sends out an electrical signal over the cable, R2 needs to receive that same signal on the wires that it expects to receive data. Likewise, R1 needs to receive what R2 transmits. Because the physical interfaces on the routers use the same pins to transmit, the cable connects the twisted pair used for transmitting by R1 over to R2's receive pins, and vice versa. In short, all that the two routers need is a cable between them, with transmit and receive pairs of wires, so that they can send and receive anytime they want.

In the previous example, there are two problems stop you from using Ethernet:

- 1-You are not legally allowed to run a cable between Atlanta and Cincinnati.

- 2-Those who can run the cable namely, the telephone companies (telcos) do not lease or sell 450-mile Ethernet cross-over cables.

Topic 63: Different Aspects of WAN Link

In this topic, we describe different aspects of a WAN Link.

To connect two routers located let's say at Atlanta and Cincinnati (450 miles), a telephone company (telco) should offer:

1- A service between two routers that acts like a cable with four wires (two pairs) in it.

2- When a router sends on one pair, that pair is crossed to the other pair before it gets to the other end cable. That way, when one router sends on one pair, the other router receives on the other pair.

3- Your routers use a serial interface because the service requires to physically encode data a little differently than on an Ethernet.

Result is that two routers can send and receive data to and from each other. Essentially, a telco can lease you a 4-wire cable, or 4-wire circuit, between two points. Telcos have already run cables between almost every town and city. Telcos have offices, called central offices (COs), almost everywhere. In addition, telcos have the right-of-way, which is the legal right to dig up roads and put cabling in the ground.

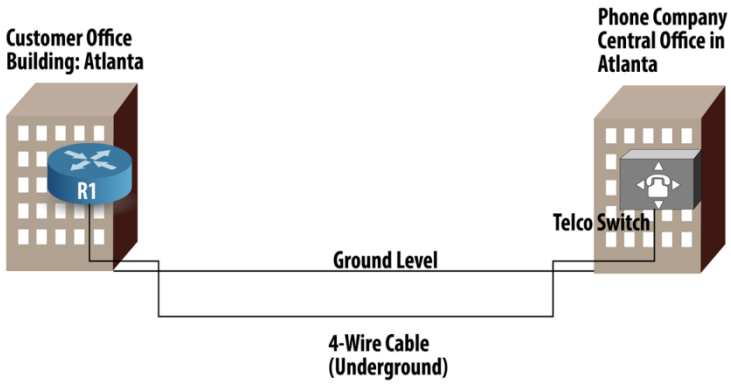
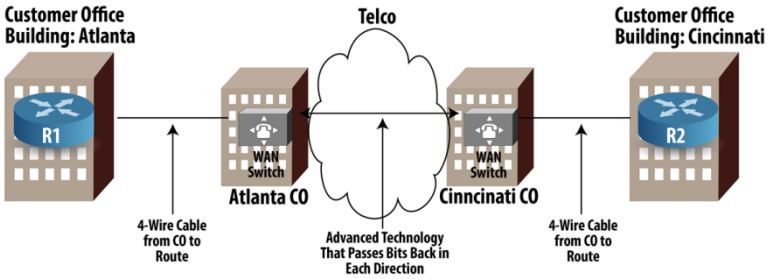


Figure 63.1: Aspects of WAN Link

Switches in the CO are called telco switches, phone switches, or WAN switches. Telco needs to ensure path between Atlanta and Cincinnati:

1- A cable from office building in Cincinnati where other router sits and telco CO in Cincinnati.

2- Electrical signals between Atlanta CO and Cincinnati CO.



Topic 64: A Cross-over Cable versus Leased Circuit

In this topic, we describe differences between a cross-over cable and a leased circuit.

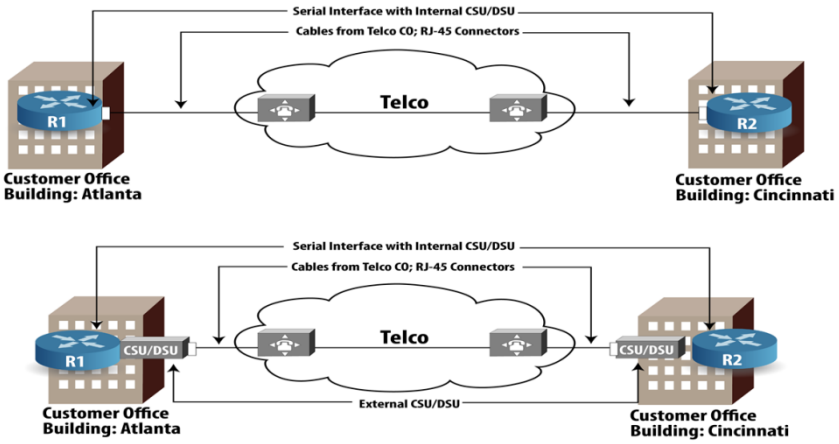
If you install an Ethernet cross-over cable between two routers by plugging the cable into Ethernet interface on the routers, the two routers can forward Ethernet frames to each other. Ethernet can support transmission speeds of 10 Mbps, 100 Mbps, 1000 Mbps (1 gigabit/second), and even 10 Gbps. If you install a WAN link between two routers, a telco creates something similar to a cross-over cable with some differences. With WAN links, many different transmission speeds are supported. Typically, WAN links use speeds that are multiples of 64 Kbps. For example, a telco offers a service called T1 line or T1 circuit whose speed is 1.5 Mbps, which is 24 times 64 Kbps. A telco can also offer links in multiples of 1.544 Mbps. You can also order even higher speeds that generally come in multiples of 51.84 Mbps.

Key points about speed of WAN links

Many different speeds are possible. You specify the speed when you order the leased line. You need to configure the routers to use the right speed.

How to control the WAN link speed

Serial links run at different speeds, and must be preconfigured. The channel service unit/data service unit (CSU/DSU) of a serial interface controls the speed. The CSU/DSU functions can be done with an external device or as a function of the serial interface card on the router. If you use a CSU/DSU that sits outside the router, you must configure the speed on that external device. If CSU/DSU is built into the router, you must configure the speed of the WAN link on the router.



A WAN Link Installation Plan

1. Contract with the phone company to provide a leased line at a certain speed.

2. Install a router at each site, near where the telco will run its cable.

3. Install an external CSU/DSU near the routers at each site, if you didn't buy routers with internal CSU/DSUs.

4. Configure the CSU/DSUs with the correct speed.

5. After the phone company runs the cables, install the cables into the CSU/DSU (external) or serial interface of the router (internal CSU/DSU) at each site.

Topic 65: Routers and WANS

This topic describes how WANs and Routers work together.

Routers use WAN links when they need to forward IP packets to a subnet at a remote site. End user devices at a company's office site use an Ethernet NIC and never directly connect to a WAN link. To send traffic to an IP host at another site, end user devices send the data to router. The router forwards the IP packet to another router at the other site, which then forwards the packet to the other IP host.

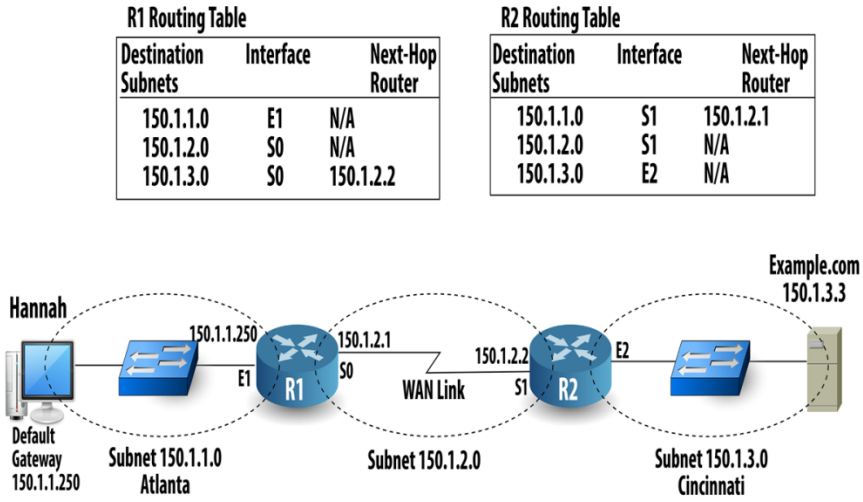


Figure 65.1: WANs and Routers work together

WAN data link framing

Let's assume that Hannah sends a packet to the www.example.com web server at IP address 150.1.3.3. The IP packet arrives to her default gateway namely R1. As R1 receives the Ethernet frame, it checks to see whether errors occurred. If no errors occurred, R1 extracts the IP destination address 150.1.3.3 and find a match in his routing table.

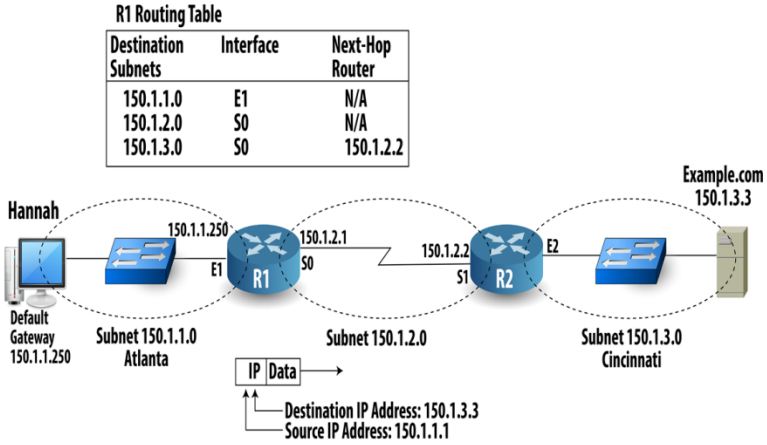


Figure 65.2: WAN data link framing

R1 needs to encapsulate the IP packet inside a data link layer frame. Two popular data link layer protocols for point-to-point WAN links are high-level data link control (HDLC) and Point-to-Point Protocol (PPP).

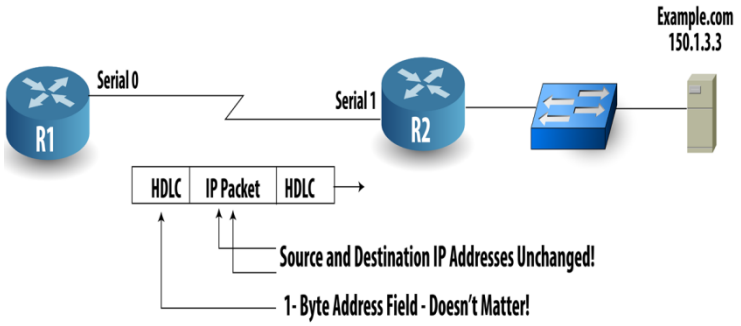


Figure 65.3: High-level data link control (HDLC) and Point-to-Point Protocol (PPP)

R1 needs to encapsulate the IP packet inside a data link layer frame. Two popular data link layer protocols for point-to-point WAN links are high-level data link control (HDLC) and Point-to-Point Protocol (PPP).

WAN data link addressing

Inside the HDLC and PPP header, there's only one address field, and it is 1 byte long. When R1 sends anything on this point-to-point WAN link, the only device that could possibly get the data is R2. So, although the address field exists, it doesn't really matter.

Differences bet. HDLC and PPP: HDLC was defined by the ITU in the 1970s. PPP was defined in RFC 1661 during the 1990s. PPP has more advanced features. Cisco uses a nonstandard version of HDLC. Cisco also conforms to the standard for PPP.

Topic 66: Frame Relay

In this topic, we explain the basics of Frame Relay.

Frame Relay is a wide area network (WAN) technology that uses one physical WAN link connected to each site, while allowing each site to send data to each other site. When you want to build a network to connect multiple remote sites, you can use a lot of serial links. Frame Relay requires less work, less new hardware and is more cost-effective solution compared to leased lines. A Frame Relay network acts like a big WAN switch, with routers connecting to it. To send data to another router, the sending router just needs to send a frame with the right address in it.

To make Frame Relay work, each router needs a physical cable between itself and a device called a Frame Relay switch. A Frame Relay switch is the equipment that understands Frame Relay and can forward traffic based on Frame Relay protocols. The telco uses Frame Relay switches in its local central offices (COs) that together switches the data to the correct sites. When a router physically connects to a Frame Relay switch, it is connecting to a Frame Relay service. The company that sells Frame Relay services is called a Frame Relay service provider. Often, a Frame Relay service

provider is also a telco. In most cases, that company works with other telcos to create the Frame Relay network.

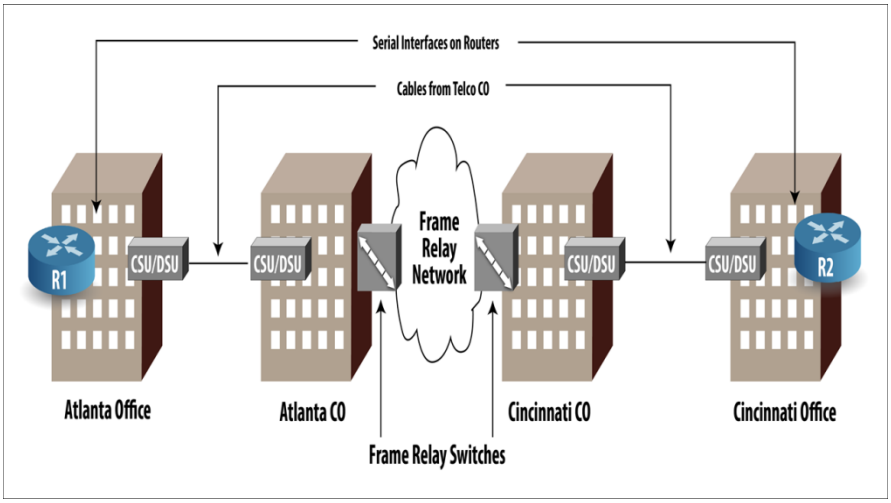


Figure 66.1: Physical Parts of Frame Relay

Although the cabling and channel service unit/data service units (CSU/DSU) are the same as with a leased line, the telco does something different in the CO: It connects the cable to a Frame Relay switch. The provider's collective set of Frame Relay switches, along with the other equipment between them, form that provider's Frame Relay network. Frame Relay is a set of protocol specifications, all matching the functions of OSI Layer 2; data-link layer.

Topic 67: Frame Relay Switching

This topic explains the working of Frame Relay switching to multiple remote sites.

When a telco sells you a Frame Relay service, it forwards Frame Relay frames sent by one router to another router. Before a router can send a packet, it must add the correct data link header and trailer to the packet. Each Frame Relay header contains a single address field called a data-link connection identifier (DLCI). It is a 10-bit number, usually written as a decimal number between 0 and 1023. Each Frame Relay switch forwards the frame, based on the DLCI, through the network, until it gets to the router on the other side. Frame Relay switches must be configured to know where to forward frames with particular DLCIs in their headers. They cannot learn addresses automatically.

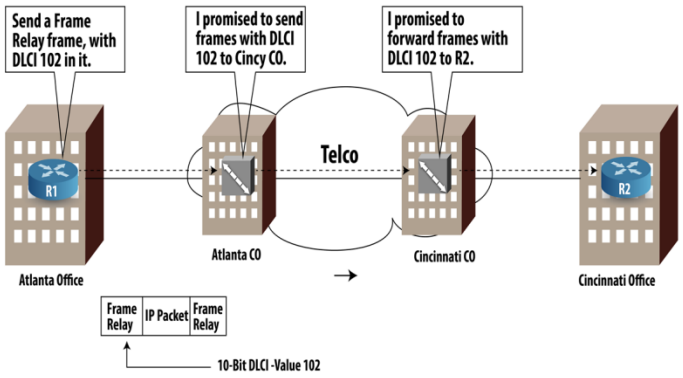


Figure 67.1: Cabling with Internal and External CSU/DSUs

To see the real advantage of Frame Relay over leased lines, let's look at an example with three Frame Relay sites. We further assume router R1 (Atlanta) wants to send data to both R2 (Cincinnati) and R3 (Boston). With Frame Relay, a router can use its single physical access link to forward traffic to multiple remote routers. This is shown next.

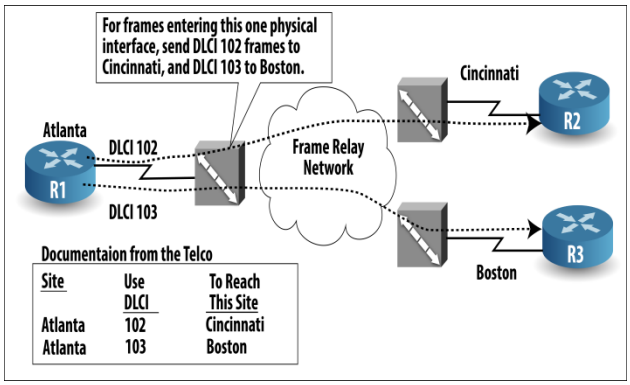


Figure 67.2: Three Leased Lines to Connect Three Routers

Topic 68: Virtual Circuits

In this topic, we explain the concept of virtual circuits.

Let's assume that there are three sites using Frame Relay network and frames are going from one site (R1) to the other two sites (R2 and R3).

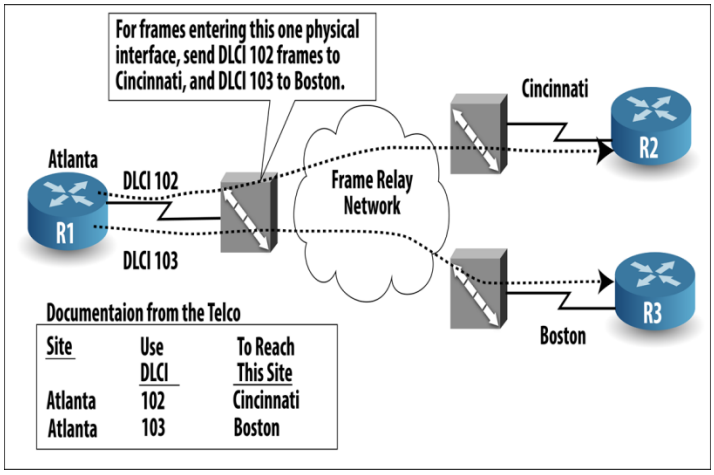


Figure 68.1: Frame Relay Switching to Multiple Remote Sites

In Frame Relay lingo, the ability for R1 to send data to R2 over the Frame Relay network is called a virtual circuit (VC). A VC is like a leased circuit, in that exactly two devices can send and receive data using it. It is called virtual to contrast it with a physical leased circuit. As a VC is typically predefined to always be there, VCs are often called permanent virtual circuits (PVCs). It is shown next.

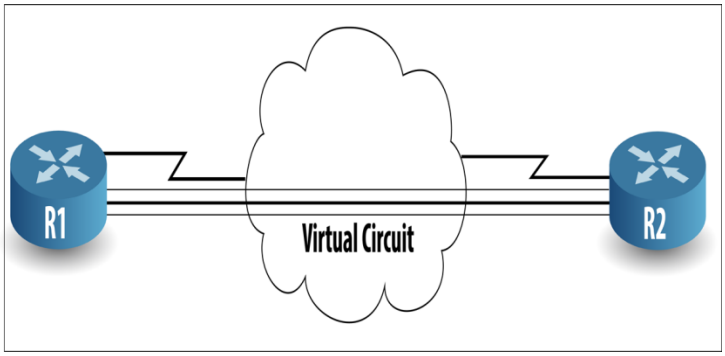


Figure 68.2: Frame Relay PVC Concepts

The service provider preconfigures all the required details of a PVC. Configuring the switches to forward frames with DLCI 102 to Cincinnati and frames with DLCI 103 to Boston. In the previous network, there is no PVC between R2 and R3. The choice of which sites need to have a PVC depends on where the network engineers think that traffic needs to flow in the network. When routers use Frame Relay, and there is a PVC between each pair of routers, the PVCs are in a full mesh. When not all routers have a PVC, it's called a partial mesh. A full mesh is shown next.

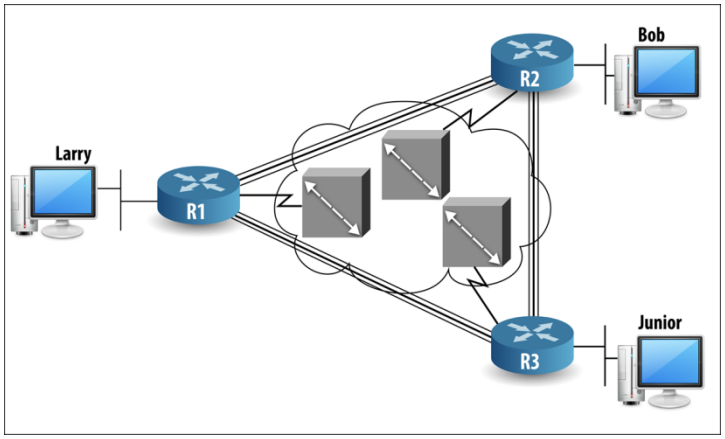


Figure 68.3: Frame Relay Full Mesh

Topic 69: Point-to-Point WANs & Frame Relay

In this topic, we compare point-to-point WANs and Frame Relay.

Frame Relay is considered to be faster, cheaper, and better than using leased lines for a WAN. Point-to-point WANs tend to require more hardware than does the equivalent network built with Frame Relay. Let's consider what the telco does to create three leased circuits. A router requires two serial interfaces and two separate channel service/data service units (CSU/DSU). The telco has to install two cables between the local CO and the office building in Atlanta where R1 resides.

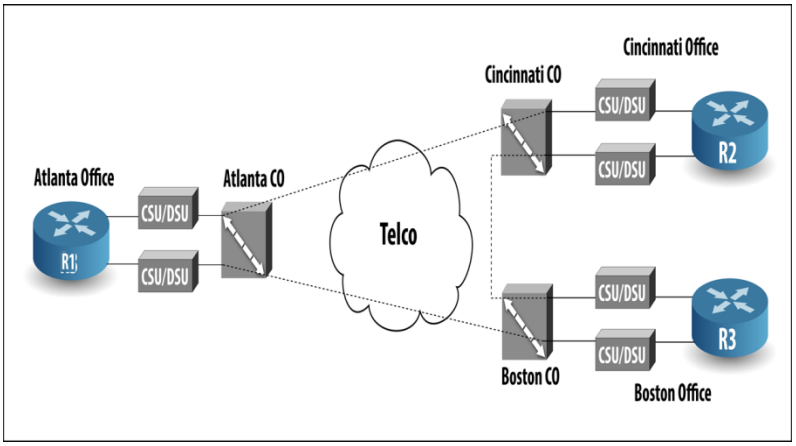


Figure 69.1: Three Leased Lines to Connect Three Routers

Next, we show the equivalent Frame Relay network for the three sites. One cable from each router is needed to the telco, one serial interface, and one CSU/DSU at each router.

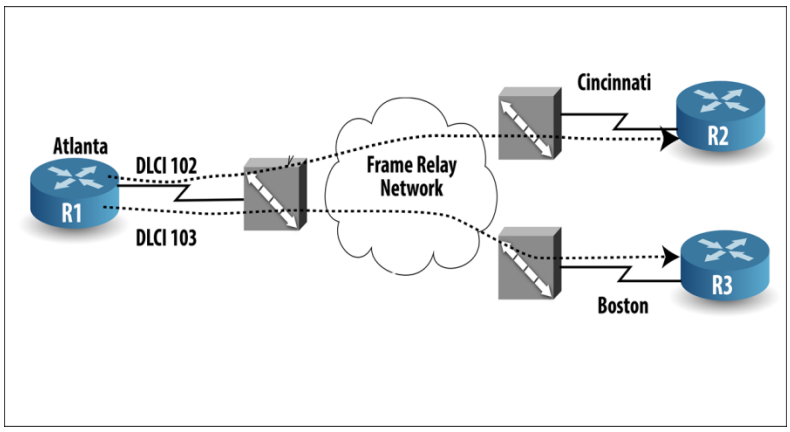


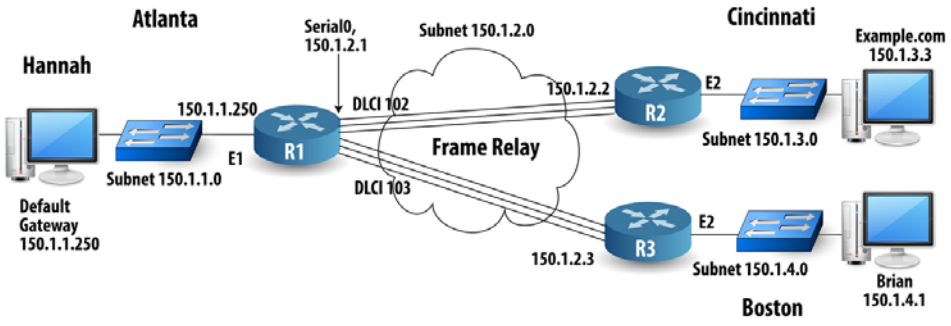
Figure 69.2: Typical Frame Relay Network with Three Sites

What happens when the company grows to 10 sites or 100 sites and employs point-to-point WANS? For each point-to-point line, R1 will need a separate physical serial interface and a separate CSU/DSU. This requires a lot of extra money for router and CSU/DSU hardware. The telco has to run many more cables and more cost.

Topic 70: Routing over PVCs

This topic explains routing over permanent virtual circuits (PVCs).

Assume an internetwork that uses three routers at three sites. Each has an access link to a local CO, and there is no PVC between R2 and R3, making the network a partial mesh of PVCs. The Frame Relay provider (the telco) tells the customer to configure R1 so that it uses data-link connection identifier (DLCI) 102 to send frames to R2, and DLCI 103 to send frames to R3.



R1 Routing Table

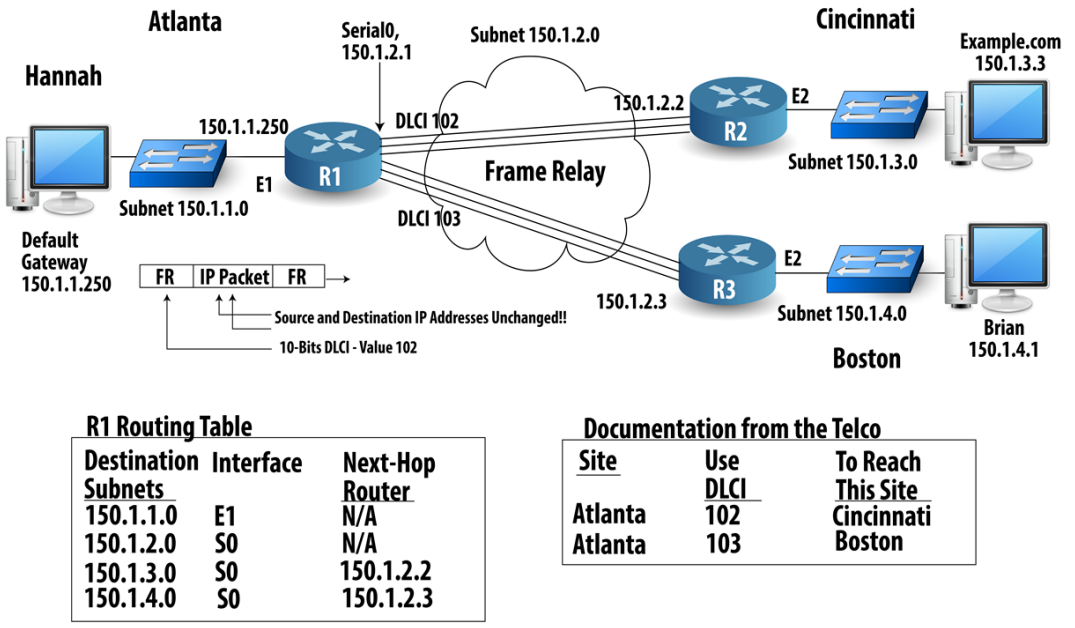
Destination Subnets	Interface	Next-Hop Router
150.1.1.0	E1	N/A
150.1.2.0	S0	N/A
150.1.3.0	S0	150.1.2.2
150.1.4.0	S0	150.1.2.3

Documentation from the Telco

Site	Use DLCI	To Reach This Site
Atlanta	102	Cincinnati
Atlanta	103	Boston

Figure 70.1: Routing over PVCs

Now assume Hannah opens a browser to connect to the www.example.com. After using DNS to discover that www.example.com's IP address is 150.1.3.3, Hannah sends a packet to 150.1.3.3. Because 150.1.3.3 is in a different subnet, Hannah's PC sends the packet to her default gateway namely, R1. When R1 receives the Ethernet frame, it checks to see if errors occurred. If no error, then R1 performs Frame Relay encapsulation. Frame Relay header holds the 10-bit-long DLCI field that identifies the PVC. The trailer has a frame check sequence (FCS).



R1 Routing Table

Destination Subnets	Interface	Next-Hop Router
150.1.1.0	E1	N/A
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150.1.3.0	S0	150.1.2.2
150.1.4.0	S0	150.1.2.3

Documentation from the Telco

Site	Use DLCI	To Reach This Site
Atlanta	102	Cincinnati
Atlanta	103	Boston

Figure 70.2: Forwarding an IP Packet over a Frame Relay PVC

When R1 looks at his routing table for subnet 150.1.3.0, it lists next-hop router of 150.1.2.2, which is R2's IP address, and outgoing interface S0. It does not list which DLCI to use to get to 150.1.2.2. As soon as the PVC starts working, R2 announces its IP address to R1, using the VC between the two routers. R1 also announces its IP address to R2, using that same VC. In this way, both routers learn the other router's IP address that is used on that VC. The message used to announce the IP address and DLCI is called an Inverse ARP message.

Topic 71: The Internet: A Large IP Network

This topic explains why connecting to the Internet provides a path for IP packets to be sent almost anywhere.

A company cannot run a cable between two far-away buildings for legal and practical reasons. A telco already has the ability to let you connect to its network physically,

and then deliver the data over its network. With WAN links, the telco allows two sites to communicate. With Frame Relay, many sites can communicate, but they all must use the same Frame Relay service from the same telco. The company can connect to the Internet with a WAN link or Frame Relay. With that one physical connection, that company gains access to a huge number of people who also have access to the Internet. Next, we show an example depicting reaching the world through one connection to the Internet.

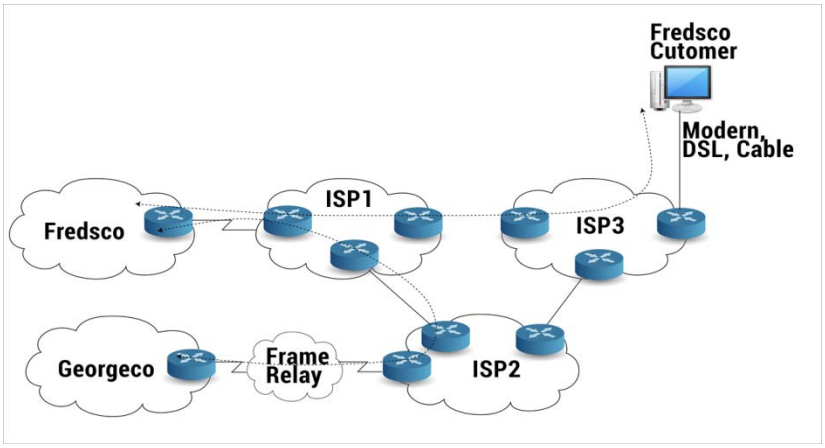


Figure 71.1: Reaching the World through One Connection to the Internet

An Internet service provider (ISP) creates an IP network over which IP packets can be forwarded, similar to the way a telco creates a network over which bits (for WAN links) and Frame Relay frames (for Frame Relay) can be forwarded. Some ISPs are also telcos. The Internet consists of three major components:

- The IP networks that ISPs create.
- The enterprise IP networks that attach to one or more ISPs.
- The individuals who connect their computers to ISPs.

WAN Type	Generic Name of Provider	Physical Connectivity	Description of Service
WAN link (leased line)	Telco	4-wire cable from customer to telco CO at each site	Telco forwards bits between two sites
Frame Relay	Frame Relay service provider	4-wire cable from customer to telco CO at each site	Provider forwards frames, based on DLCI
Internet	Internet service provider	Either WAN link or Frame Relay bet. customer and ISP	ISP routes IP packets to any IP host on the Internet

Table 71.1: Comparisons of WAN Links, Frame Relay and the Internet

Topic 72: Using a Phone Line for Data

In this topic, we describe how a modem can be used to transmit data from home.

A telephone includes a microphone, which converts sound waves into an analog electrical signal. It is carried by a local loop (phone line between a house and a telco CO). The telco can send the electrical signal between one phone and another. On the receiving side, the phone converts the electrical signal back to sound waves using a speaker. The characteristics of the analog signal are:

- Frequency: the number of times a signal repeats itself, from peak to peak, in one second.
- Amplitude: how strong the signal is.

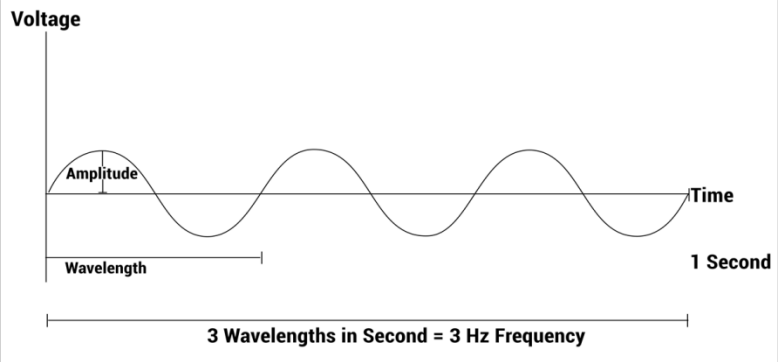


Figure 72.1: Analog Electrical Signal: Frequency and Amplitude

The sounds that your voice makes happen to be a continuously changing sound wave, so analog electrical signals that continuously change work well for voice. Modems allow two computers to send and receive a serial stream of bits over an analog phone circuit, with no physical changes required on the local loop between a residence and the telco CO. As the telephone switch in the CO expects to send and receive analog voice signals over the local loop, modems simply send an analog signal to the PSTN and expect to receive an analog signal from the PSTN. Instead of voice, a modem converts a string of binary digits on a computer into a representative analog electrical signal.

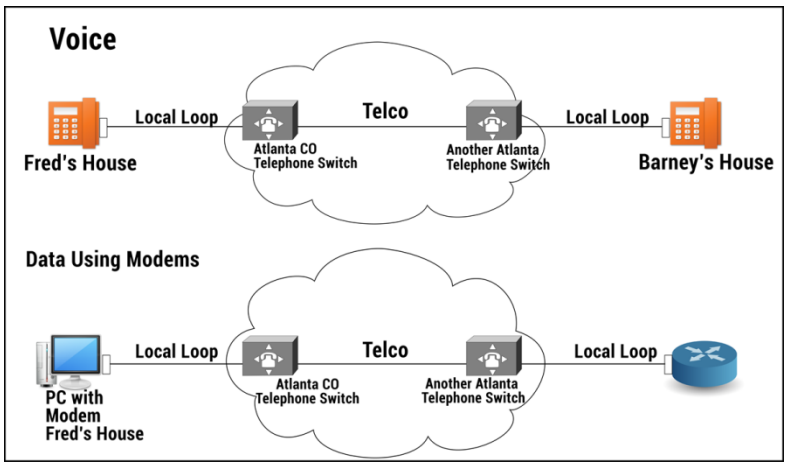


Figure 72.2: Comparing a Phone to a Modem

Modems encode a binary 0 or 1 onto the analog signal by varying frequency or amplitude. Changing these characteristics of the analog signal is referred to as modulation. Basic Operation of Modems over PSTN are shown next.

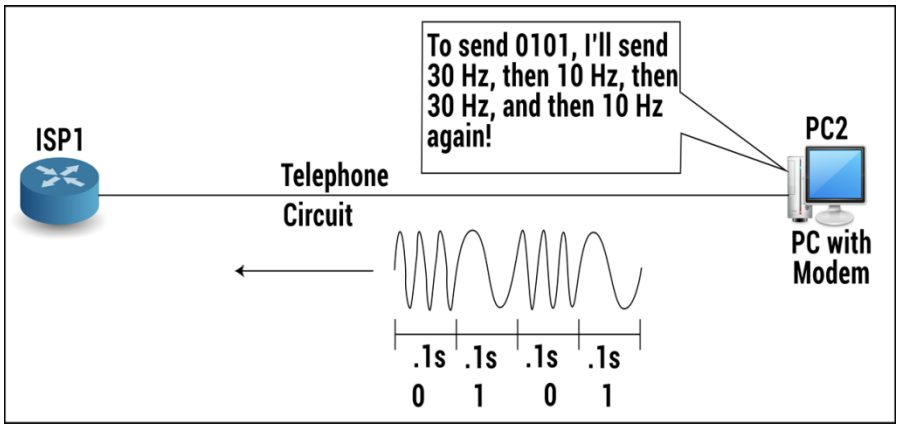


Figure 72.3: Basic Operation of Modems over PSTN

In previous example, frequency changes every .1 seconds, PC can send 10 bits/sec. If a modems sends at 9600 bps, the receiving modem needs to sample the incoming analog signal every 1/9600 of a second. The details of modem relate to OSI Layer 1, the physical layer.

Topic 73: Digital Subscriber Line (DSL)

In this topic, we describe the usage of DSL for Internet.

Modems use the phone line to make what the telco thinks is a voice call, so you cannot make another call while you are surfing the Internet. Another big negative is the speed. Digital subscriber line (DSL) is an alternative technology for sending and receiving data to and from an ISP, using the same old phone line, but running at much faster speeds. Also, you can make phones calls and surf (send IP packets) at

the same time. But it is a little more expensive. DSL allows the same old analog voice signal to be sent over the line by a phone. At the same time, DSL allows a separate digital signal to go over the same phone line. The telephone generates analog signals ranging from 0 to 4000 Hz. Most speech ranges from 300 to 3300 Hz. The digital DSL signal uses frequencies higher than 4000 Hz – do not interfere with speech/hearing. DSL uses the same local loop wiring that is already installed between the CO and your house, but now the CO connects the local loop wiring to a device called a DSL access multiplexer (DSLAM). The DSLAM splits out the digital signal and analog signal from the local loop. The DSLAM gives the analog voice signal to a telephone switch while forwards the data traffic to a router.

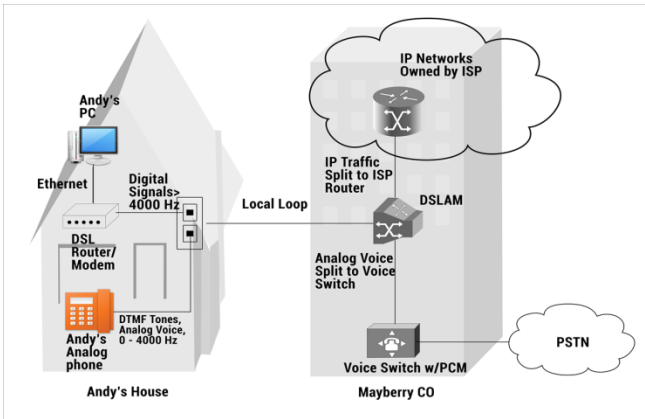


Figure 73.1: DSL Connection from the Home

Some DSL variants allow the local loop to be much longer than some other DSL variants, whereas others only allow for a shorter local loop. For a shorter local loop, transmission rates are much higher – design tradeoff. The speed at which data goes from the Internet to the home is faster than the other direction a feature called asymmetric transmission rates. More bandwidth is needed for downloading.

Figures and Material used for this topic have been adapted from Kurose and Ross's book with the title "*Computer Networking: A Top-down Approach*", 6th Edition, 2013.

Topic 74: Sending Data without a Phone Line

In this topic, we describe how TV cable networks can be used for the Internet.

Cable Internet access makes use of the cable television company's existing cable television infrastructure. A residence obtains cable Internet access from the same

company that provides its cable television. A cable head end broad casts television channels.

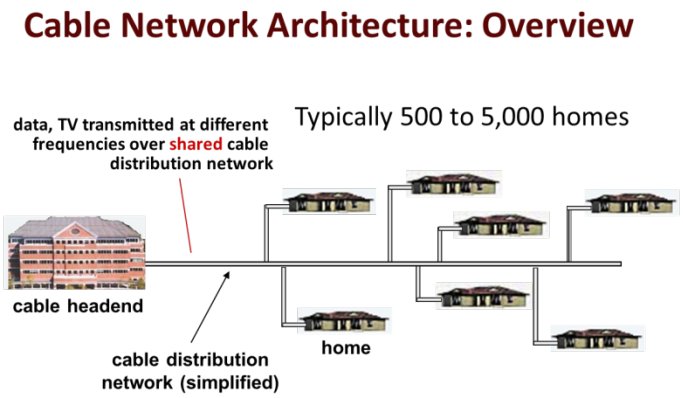


Figure 74.1: A hybrid fiber-coaxial access network

Fiber optics connects the cable head end to neighborhood-level junctions, from which traditional coaxial cable is then used to reach individual houses. This is called Hybrid fiber coax (HFC) and is shown next in detail.

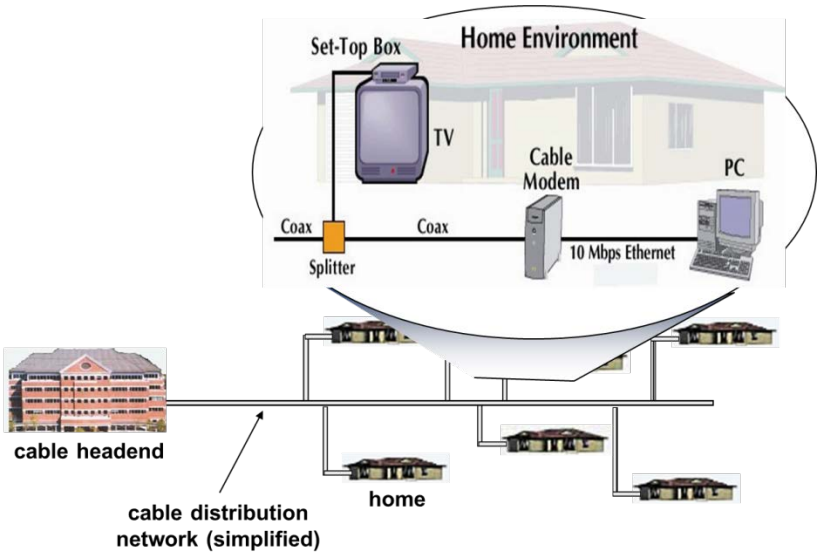


Figure 74.2: A hybrid fiber-coaxial access network

Frequency division multiplexing: different channels transmitted in different frequency bands.

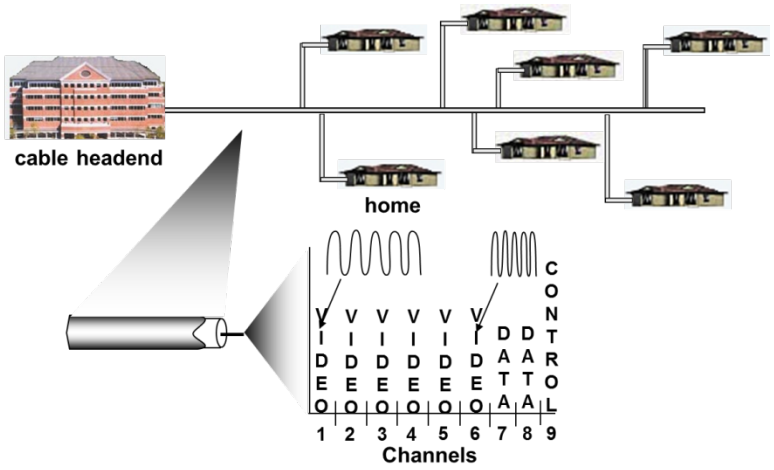


Figure 74.3: A typical home network

Topic 75: Introduction to AAA Security Model

In this topic, we list and describe the three components of the AAA security model.

AAA stands for authentication, authorization, and accounting. The AAA model refers to three areas of security. All three relate to issues regarding an individual device or user. Before you can use most servers, you need to have the right to use that server. A username and a password are required. **Authentication** is a five-step process.

- 1. Fred requests a web page.
- 2. The web server replies, asking for a username, password.
- 3. Fred types in and sends his username, password to server.
- 4. The web server checks its list of usernames and verifies that the password is correct.
- 5. If the username and password are correct, the web page returns the contents of the web page.

The working of basic authentication process is shown next:

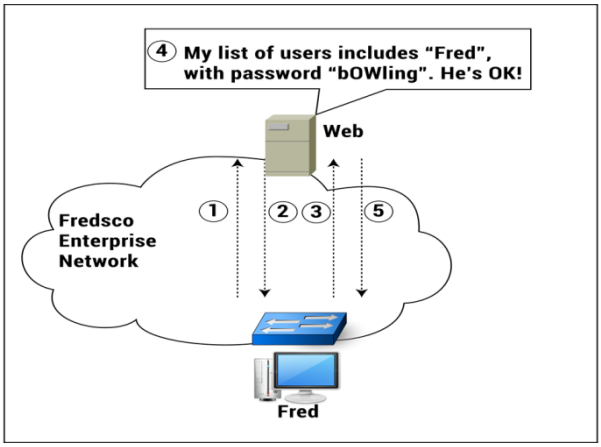


Figure 75.1: Basic Authentication Using a Username and Password

Username, password can be listed on a server called authentication server. Application servers query authentication server. Kerberos protocol runs between application and authentication servers. This is shown next.

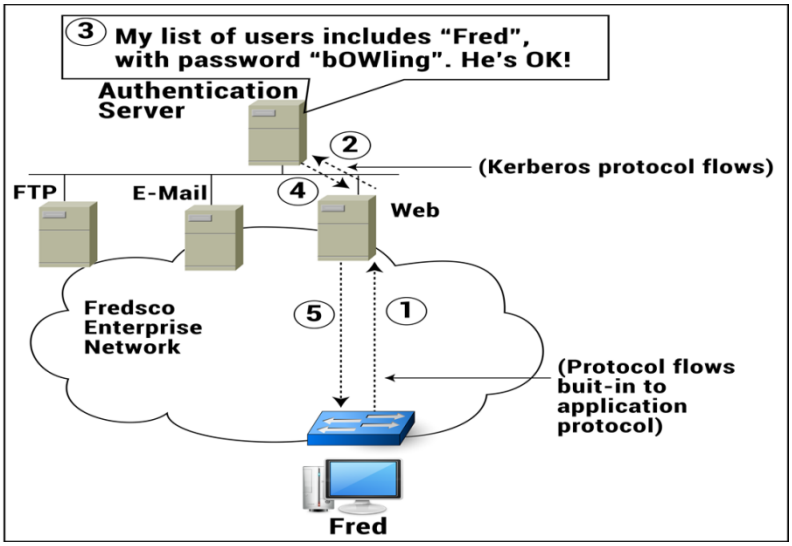


Figure 75.2: Basic Authentication Using a Username and Password

The second "A" in AAA is for **Authorization**. It refers to the process of figuring out what a particular user is allowed to do.

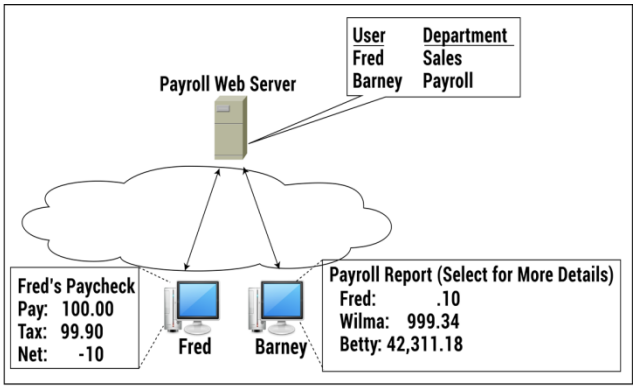


Figure 75.3: Fred Can't See Others' Payroll Information

The last "A" in AAA is **accounting**. The same servers that perform authentication and authorization services can keep a record of each request to authenticate or authorize a user. Accounting allows to record and report when users type the wrong password. Several consecutive attempts to connect to a server with an invalid password each time signals someone is trying to guess Fred's password. Accounting features can record individual attempts, generate reports, and notify personnel if too many invalid attempts happen in a short timeframe.

Topic 76: Password Authentication Protocol

In this topic, we describe the working of password authentication protocol (PAP).

Unlike those people who are attached to a LAN in a physically secure office building, people who use modems or DSL to connect to the Internet from home have to go through an additional authentication step. ISPs authenticate users before they can even use the network. This helps ISPs to determine whether a customer has paid his bill or not. Password Authentication Protocol (PAP) and Challenge Handshake Authentication Protocol (CHAP) are used by ISPs. Both are part of Point-to-Point Protocol (PPP) — a data link protocol. Let’s assume that Fred dials an ISP with a modem, PAP is used between himself and the ISP router. The following sequence is used:

1-Fred uses PAP to send a username, password.

2-The router sends a request to an authentication server using RADIUS protocol messages.

3-The authentication server checks the username, password.

4-The authentication server confirms that Fred is authentic using RADIUS.

5-The router uses PAP to confirm that Fred is allowed to use the Internet.

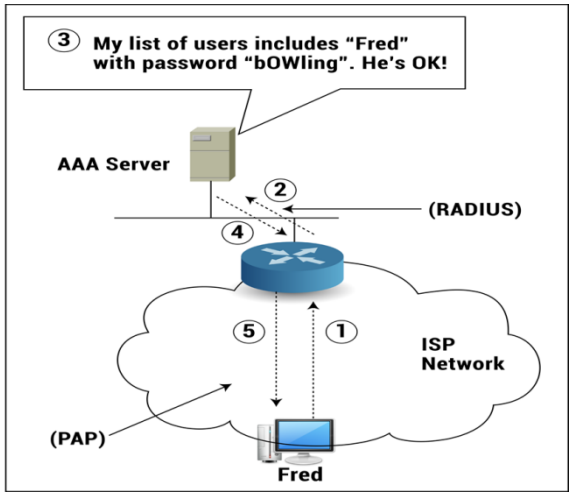


Figure 76.1: Basics of PAP

TACACS+ is a popular proprietary protocol that Cisco developed before RADIUS existed and can be used in place of RADIUS. Also, CHAP can be used instead of PAP. PAP sends the username and password in clear-text. Anyone with the right tools can actually read your username and password. To protect against password theft, CHAP does not send the password as clear-text. Process of CHAP starts as soon as a modem calls a phone number at the ISP or DSL modem is powered on. CHAP uses six steps to authenticate user.

1- Router generates a random number and sends it in a CHAP message to the PC.

2-PC runs a math function with the random number and the password typed by the user as input.

3-The PC sends the results of the function called a message digest back to the router.

4-The router sends the username, the random number, and the message digest to the AAA server.

5a-The AAA server uses the same math that the client used in Step 2, with the same random number, plus the password associated with that username in the AAA user database.

5b- The result is another message digest.

5c-If the message digest calculated by the AAA server matches the one calculated by the PC, the password that the user typed must be the right one.

6. The AAA server tells the router that the user is authentic; the router tells the PC, and life goes on.

The password was never passed through a network connection during this procedure. This is shown next.

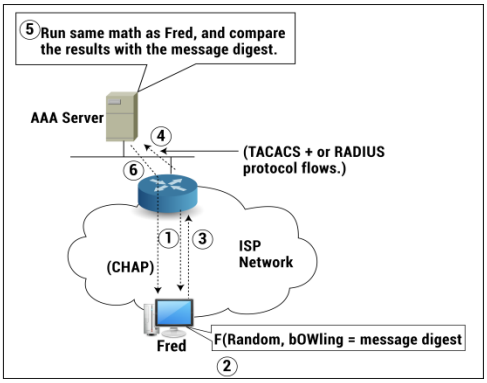


Figure 76.2: Hashing Passwords to Create a Message Digest

Topic 77: Virtual Private Network (VPN)

This topic explains benefits of using a virtual private network (VPN).

Encryption allows a computer to apply a mathematical formula to data, sending the results of the mathematical function over the network. The data just looks like a bunch of random bits. The computer receiving the data can then re-create the original data by decrypting the data. To decrypt the data, you need a secret password called an encryption key. These days, it is common for users to encrypt data before sending it over the Internet. Instead calling it encryption; it is called a virtual private network (VPN). The packets go across the Internet, it is still a physical public network. VPNs create a private network, but they do so logically, or virtually.

Let's assume Barney works for a company. The enterprise network at Barney's company is a private network, with all the components inside privately controlled office space. The Internet is public. For Barney to use the VPN, he must encrypt the packet as he creates it. To do this, Barney needs to have VPN software installed on his computer. He also needs to know the encryption key to use. A VPN device inside the corporate network is called a VPN concentrator, which decrypts packets received from Barney and others. This is shown next.

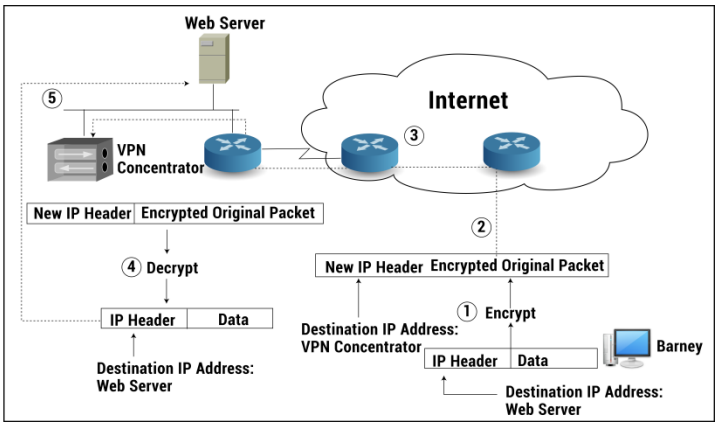


Figure 77.1: Encrypting IP Packets for a VPN

Topic 78: Enterprise Network and the Internet

In this topic, we list the traffic that should and shouldn't be allowed between an enterprise network and the Internet. When you connect an enterprise network to the Internet, one of the first things you must decide about is what you want to allow to pass to and from the Internet, and what you don't. Assume an enterprise network 'Internal IP Network'. There is an internal web server that has stuff only appropriate for employees who work for Fredsco. The external web server is meant for external users, but internal clients will also want to browse that web server.

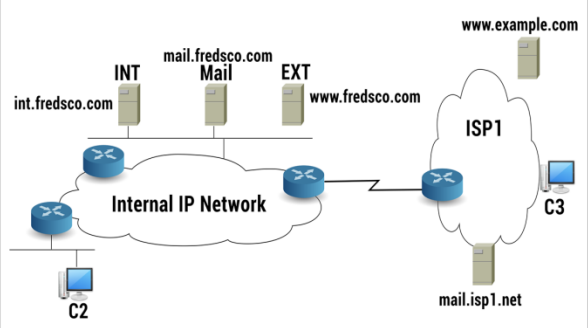


Figure 78.1: An Enterprise Network Connecting to the Internet

To secure Fredsco's network, two things have to be kept in mind: Between which two hosts do packets need to flow? Which host begins that communication? To secure Fredsco's network, two things have to be kept in mind: Between which two hosts do packets need to flow? Which host begins that communication? Typical types of traffic allowed are shown next.

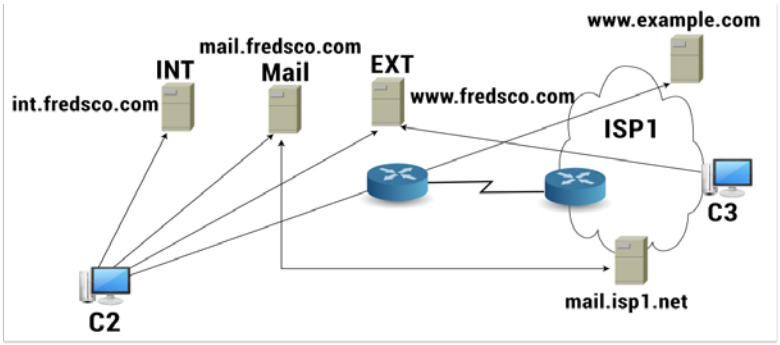


Figure 78.2: Typical Types of Traffic Between an Enterprise and the Internet

The bad guys on the Internet who are trying to get into Fredsco's network should be prevented. Traffic that is typically not allowed is shown next.

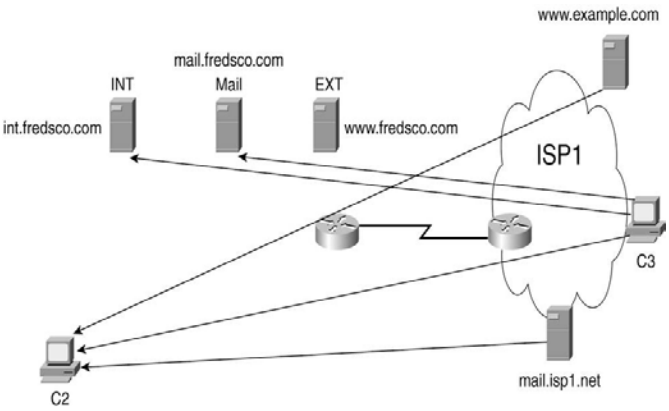


Figure 78.3: Traffic That's Typically Not Allowed

Topic 79: Firewalls, Demilitarized Zone, IDS

In this topic, we describe the use of firewalls, demilitarized zone (DMZ) and intrusion detection systems (IDS).

A network engineer configures the firewall with a set of rules that tells it what's legal and what isn't. Then the firewall allows some packets to pass through it and discards others to enforce the rules. The firewall needs to be in the path that is used for forwarding packets to and from the Internet. Cisco's firewall product is called a PIX firewall.

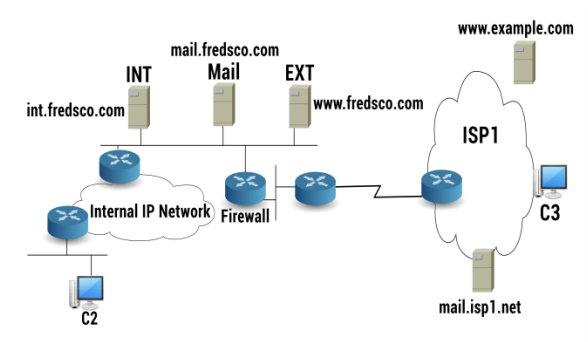


Figure 79.1: Putting Up a Wall Between the Dangerous Folks and Your Network

As a firewall watches the traffic entering the network, it knows the nature of the traffic that is allowed to flow through it. Also, it recognizes when a host is initiating a new flow. A host who is initiating a new flow can be recognized by looking at: The first TCP segment used to create a TCP connection SYN flag bit =1, and source IP address of the packet.

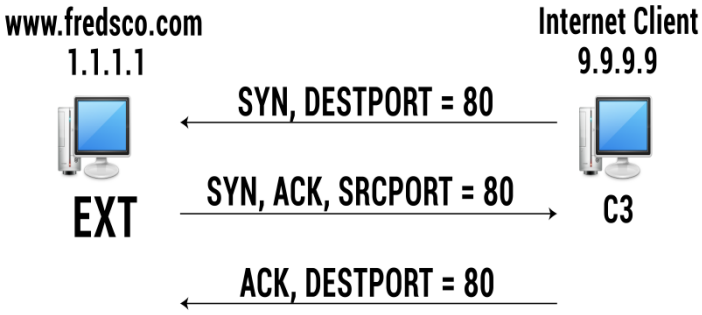


Figure 79.2: TCP Connections and Well-Known Ports

The scenario depicting the allowance of the TCP Connection is shown next.

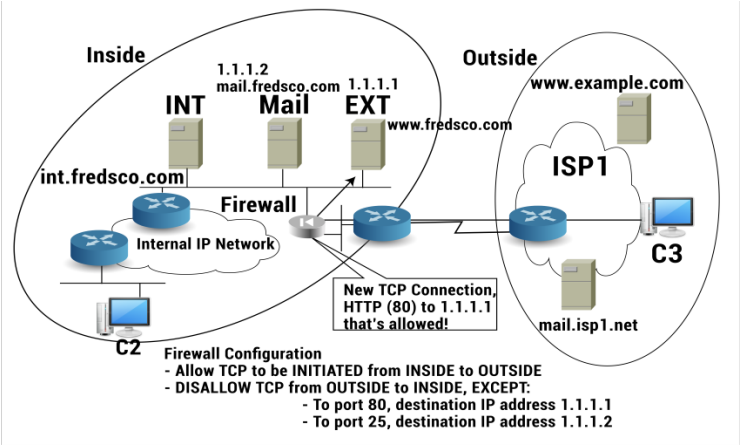


Figure 79.3: Allowing the TCP Connection from Figure 79.2

The firewall uses a similar logic to stop packets that should not be allowed. This is shown next.

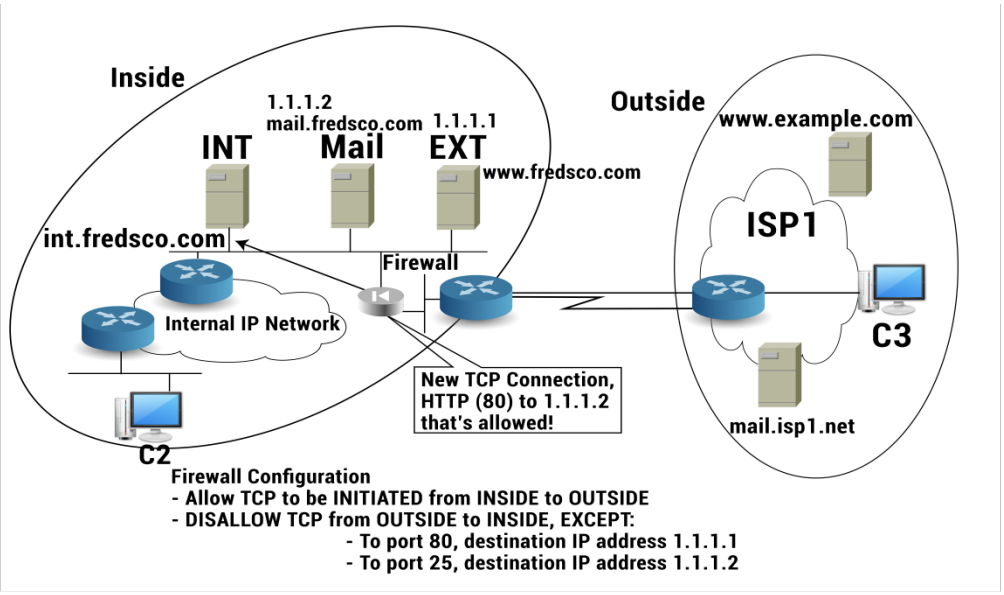


Figure 79.4: Disallowing a TCP Connection to an Inside Web Server

Firewalls are like routers. They forward packets based on destination IP address. They have at least two physical interfaces. They can have more than two interfaces. Outside interface connects to Internet. Inside interface connects to internal network.

A third interface connected to a LAN called a demilitarized zone (DMZ), somewhere bet inside & outside interfaces. With a DMZ, Internet-accessible servers can be placed on a different LAN. A stronger firewall rule: No TCP connections can be initiated from outside to the inside. The only flows allowed are for servers in the DMZ.

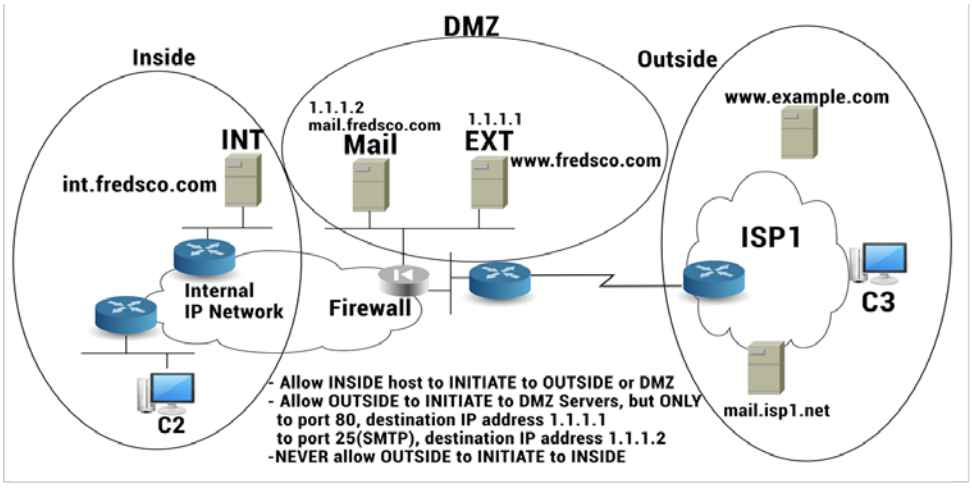


Figure 79.5: A Safe but Potentially Risky Place: The DMZ

Intrusion detection systems (IDSs): watch packets that a firewall allows through. They look for things in the packets to determine if someone is cheating firewall and do bad things to servers in network. Some IDS devices sit in the network, watching packets that pass over a LAN and are called network-based IDSs. Those IDS softwares that sit on the servers are called host-based IDSs. A network-based IDS is shown next.

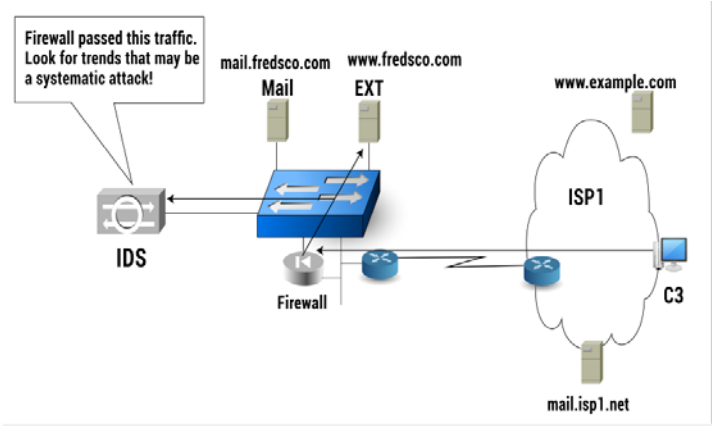


Figure 79.6: Watching for Patterns with a Network-Based IDS

Handouts for Part 2 (Topics 80 to 120) CS206: Introduction to Network Design and Analysis

Figures and Material used for this topic have been adapted from "Wireshark User's Guide", U. Lamping, R. Sharpe, and E. Warnicke, 2014, https://www.wireshark.org/docs/wsug_html/.

Topic 80: Introduction to Wireshark

This topic provides introduction to Wireshark.

Wireshark is a network packet analyzer which captures network packets and displays that packet data as detailed as possible. Wireshark is a free open source software program available at www.wireshark.org. G. Combs is the original creator of Ethereal (Wireshark's development name prior to May 2006). As an open source project, it's source code is open.

Intended Purposes: When run on a host connected to a wired or wireless network, Wireshark captures and decodes the network frames. People use it to learn network protocol internals. Network administrators use it to troubleshoot network problems. Network security engineers use it to examine security problems. Developers use it to debug protocol implementations.

Wireshark's Features

1- Available for UNIX and Windows.
2- Capture live packet data.
3- Display packets with very detailed protocol information.
4- Filter packets on many criteria.
5- Save packet data captured.

Wireshark's Installation

Get Wireshark installer from: www.wireshark.org/download.html and execute it.

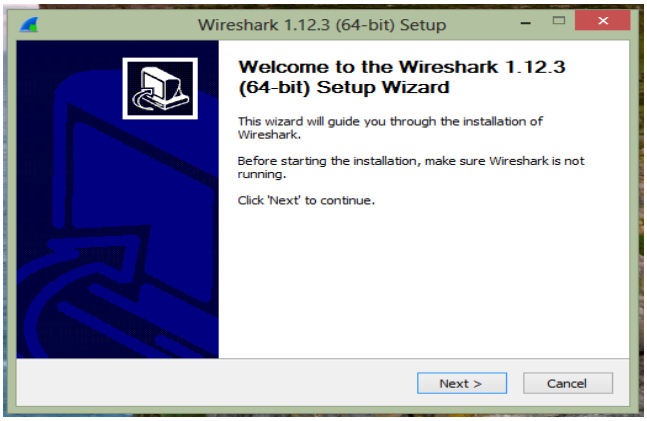


Figure 80.1: Wireshark's Installation wizard

Installation Components

- **Wireshark** - The network protocol analyzer.
- **TShark** - A command-line network protocol analyzer.
- **Plugins & Extensions** - Extras for the Wireshark and TShark dissection engines.
- **Tools** - Additional command line tools to work with capture files
- **User's Guide**

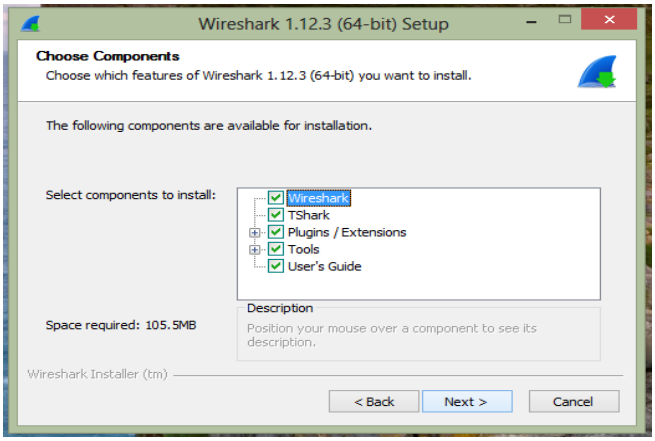


Figure 80.2: choose components

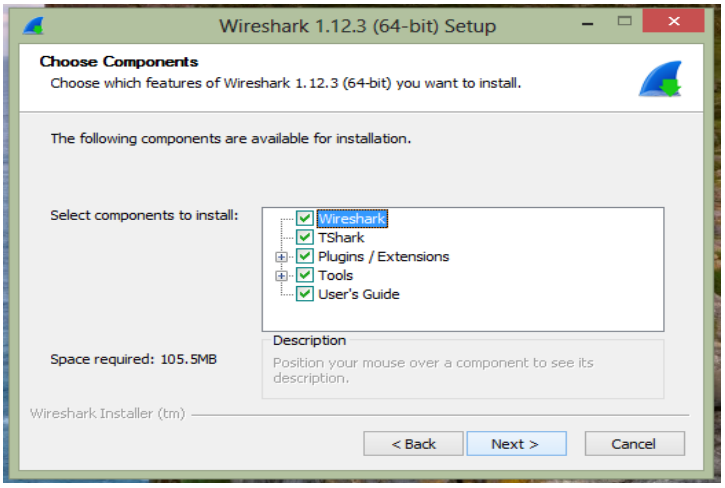


Figure 80.3: choose components

Installing WinPcap: With WinPcap installed you would be able to capture live network traffic.

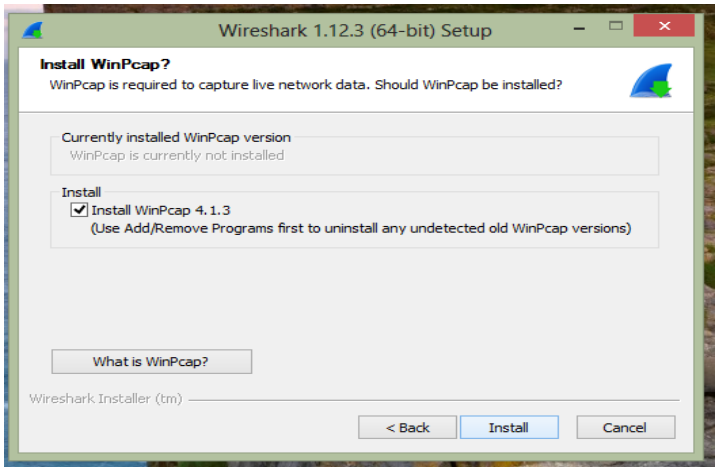


Figure 80.4: Installing WinPcap

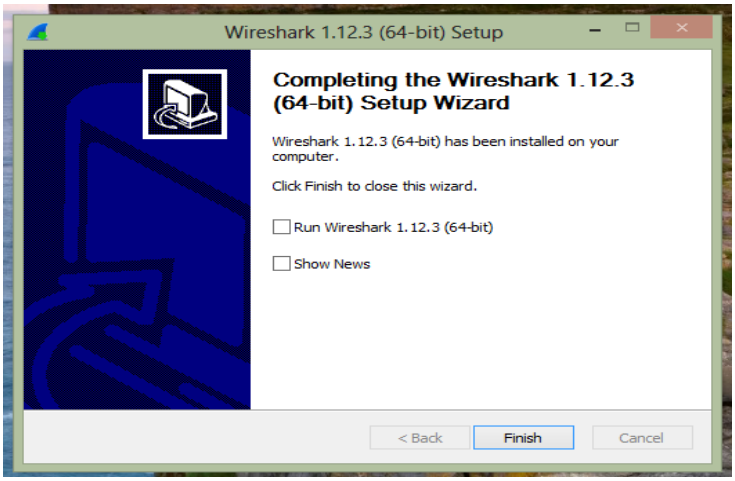


Figure 80.5: Installing WinPcap

The main window is shown next.

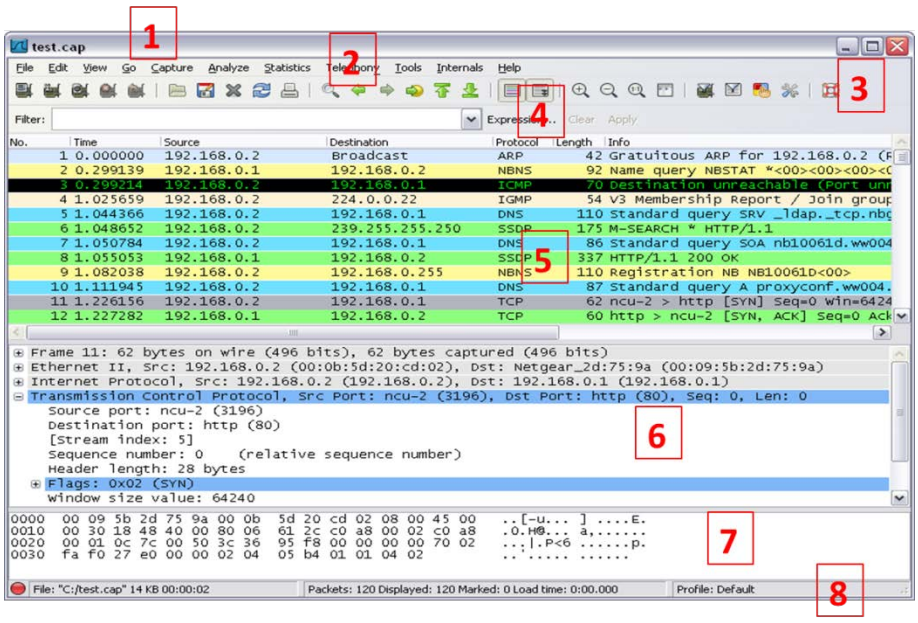


Figure 80.6: The Main window

Area 1 shows the Title bar — trace file name. Area 2 represents Main menu — standard menu. Area 3 is the Main toolbar — provides quick access to frequently used items from menu. Area 4 depicts Display filter area — reduce amount of traffic you see. Area 5 shows Packet List pane — summary of frames. Area 6 is the Packet Details pane — dissected frames. 7. Packet Bytes pane — hex/ASCII details. Area 8 represents Status Bar — access to the Expert, annotations, packet counts, and profiles.

Figures and Material used for Part2 (from Topics 81 to 172) have been adapted from "Troubleshooting with Wireshark: Locate the Source of Performance Problems", 2014, by L. Chappell.

Topic 81: Five Common Network Problems

This topic discusses 5 common Network problems.

TCP Connection Refused by Server

A service is not running on a server or perhaps a firewall is preventing the connection. TCP connection refusals may also be due to a closed port. Possible Symptoms: Client's SYN followed by Reset (RST)/ACK. Client SYN followed by an ICMP Destination Unreachable/Port Unreachable response from a host-based firewall.

Connection Blocked by a Host-Based or Network Firewall

Ideally, hosts would not even attempt to communicate with firewalled resources. Such an attempt could be due to a misconfiguration, malware, malicious user, or other issue. Possible Symptoms: No response to a SYN packet, RST/ACK response to a SYN packet.

Slow Application at Server

The good news is that the server did not refuse to provide a desired service. The bad news is that the server is slow. This may be due to: 1- lack of processing power at the server, 2-a poorly behaving application, or 3-even, in a multi-tiered architecture, a slow upstream server that actually provides the data. Possible Symptoms: TCP-based app: Large delay between the server ACK to a client request and the response data. UDP-based app: Large delay between a request and the response data.

Slow Load of Remote Content

Many networks are designed in a multi-tiered fashion. For example, consider a client that sends a request to Server 1. That server may need to obtain information from Servers 2 through 9 before answering the client. We need to capture this multi-tiered traffic to determine which server is actually responding slowly. Possible Symptoms: TCP-based app: Large delay between the server ACK to a client request and the response data. UDP-based app: Large delay between a request and the response data.

Topic 82: Next 5 Common Network Problems

This topic describes next 5 common Network problems.

Server Application Fault

The server is up and running, but not responding to requests. The server responds to a SYN with a SYN/ACK, but when the client makes a request, no response is received. When the TCP Retransmission Time Out is reached, client retransmits request. If no ACK is received, it continues to retransmit request using an exponential backoff time until it finally gives up and sends a TCP Reset. Possible Symptoms: Retransmissions.

Content Redirection

Upon arriving at a store to buy something, we might be told that the store does not have the item in the stock; please go to another store to get it. If an application supports redirection (such as HTTP) and the target knows where the information actually resides, it may send you a redirection response. Possible Symptoms: In HTTP communications, response codes 300-399. A sudden “name resolution process” and traffic to another host.

TCP Receive Buffer Full

When advertised TCP receive buffer value drops to zero, data transfer will stop. A low Window Size value can also cause data flow to stop. The only recovery is a Window Update. Possible Symptoms: Unusually high TCP delay before a Window Update and resumption of data flow.

TCP Send Buffer Full:

A limited send buffer space can negatively impact network performance even if network can handle a high data transfer rate and the receiver has plenty of buffer space. Possible Symptoms: High TCP delay for no apparent reason.

Altered TCP Attributes along a Path

Routers and other interconnecting devices can bring havoc on a network if they change the attributes of a TCP connection as they forward the traffic. Possible Symptoms: Low TCP calculated window size and significant delays before Window Update packets.

Topic 83: Next 6 Common Network Problems

In this topic, we provide description of next 6 Common Network Problems.

Mismatched TCP Parameters across a Proxy Device

Connection parameters on one side of a proxy device do not match the connection parameters offered in connection on other side of proxy device. Possible Symptoms: Delays in data forwarded through proxy (proxy queuing).

Routing Loops

Routing loops occur when a packet is routed back onto a network over and over again. Possible Symptoms: Identical packets listed but no TCP Retransmission indications (they are not identical packets—their TTL value decrements).

Weak Signal (WLAN)

If a wireless signal degrades substantially, it may not be interpreted properly when captured. Possible Symptoms: Low Signal Strength value.

Asymmetric Routing

This is a situation when traffic flowing from Host A to Host B flows along a different path than the traffic flowing from Host B to Host A. This can be a problem, if there are devices that must see every packet in order to function. For example, network path must be symmetrical from a client to a proxy host. An IDS box must see every packet. Possible Symptoms: ACKed segment that was not captured.

Packet Loss

Typically, this occurs at an interconnecting device such as a switch, a router, a NAT device, or a network firewall. If the number of packets dropped is small and the recovery process is quick, the packet loss may go unnoticed. If many sequential packets are lost, however, users will likely feel the impact and complain. Possible Symptoms: Fast Retransmission. Duplicate ACKs.

High Path Latency

A single low speed (high delay) link along a path or the delay between geographically disbursed peers can inject a level of path latency that affects performance. Possible Symptoms: Large delays between the outbound SYN and the inbound SYN/ACK of a TCP handshake.

Topic 84: Next 4 Common Network Problems

This topic discusses Next 4 Common Network Problems.

Lousy Routing Path:

When construction occurs in a major city, traffic is a nightmare as drivers are rerouted along less efficient and less direct routes. This is also true of network traffic. If a target is 10 blocks away and yet for some reason the packets must travel through 17 routers to get there, performance may be unacceptable. **Possible Symptoms:** Large delays between the outbound SYN and the inbound SYN/ACK of a TCP handshake.

Bandwidth Throttling

Transmitting data along a bandwidth throttling link is like driving a car during rush hour. You move along bumper-to-bumper at speeds below your lowest speedometer indications.

Delayed ACK

It is defined in RFC 1122 as a method to "increase efficiency in both the Internet and the hosts by sending fewer than one ACK segment per data segment received." This delay can cause issues for the host that is sending data if it times out waiting for an ACK or it cannot send another data packet until an ACK is received. Possible Symptoms: 200ms delay before ACK packets.

Queued Packets (Overloaded Router)

TCP peers and UDP-based applications may detect sudden queue delays and think packets have been lost. This may be caused by an overloaded router or perhaps prioritization at a router (e.g., video streaming first, email traffic last). Possible Symptoms: Decrease in throughput followed by equal increase in throughput.

Topic 85: Next 5 Common Network Problems

This topic studies Next 5 Common Network Problems.

Route Redirections

When a host sends packets to one local router when another local router exists with a preferred path, a route redirection may take place. The receiving router may respond with an ICMP packet that includes IP address of the recommended router. Rare - we see only one router on the local network. Possible Symptoms: ICMP Type 5 packets with either Code 0 (Redirect for Host) or Code 1 (Redirect for Network) indicate route redirection is taking place.

Broadcast or Multicast Storms

Broadcasts are typically not forwarded so you should be capturing on and dealing with hosts on a single network. Multicasts can be forwarded through an internetwork therefore they can cause a greater problem if something goes wrong and they storm the network. Possible Symptoms: High rate of packets addressed to the all nets broadcast (255.255.255.255). High rate of packets addressed to a multicast address (224-239.x.x.x).

Switch Loop

Older switches that have not been restarted or rechecked every once in a while may begin to malfunction. If there is a loop—network will become overwhelmed with looped packets. Possible Symptoms: High rate of identical packets.

Virus/Malware on Network Hosts

When a compromised host begins performing port scans on other network hosts or it begins broadcasting discovery packets, the overhead may be felt. Possible Symptoms: Local broadcasts. Unusual internal targets (such as a local client trying to connect to the Accounting server).

Network Name Resolution

This is imperative to connecting to a target. A user may receive an application error such as "Server not found" as in the case of a DNS Name Error when browsing. Possible Symptoms: No response to a name query. An error response to a name query (such as a DNS Name Error or Server Error).

Topic 86: Next 8 Common Network Problems

This topic studies Next 8 Common Network Problems.

Network Address Resolution

Incorrect subnet addressing can cause a client to send packets that are destined to a local device to a router. Possible Symptoms: ARP Requests are sent for remote targets. Traffic destined to local hosts are sent to the router.

Hardware Address Resolution

This allows obtaining MAC address of a local target or local router. Network address resolution problems may cause a host to think local devices are remote (or vice versa). Possible Symptoms: No response to an ARP query for a local host. No response to an ARP query for a local router.

No Support for Selective ACK

When packet loss is detected by a receiving TCP host that supports SACK, that host can acknowledge data received after the missing packet(s). Without SACK, the first packet lost and every subsequent data packet will be retransmitted even when those subsequent packets were received successfully. Possible Symptoms: No SACK Option in the TCP header of a SYN packet. No SACK Option in the TCP header of a SYN/ACK packet when there was a SACK Option in the TCP header of a SYN packet.

No Support for Window Scaling

Window Scaling is used to increase the advertised TCP receive buffer size past the 65,535-byte limit caused by the 2-byte Window Size field. During the TCP handshake, peers indicate that they support Window Scaling and provide a Window Scale Shift Count. Reduces the delays caused by a low window or Zero Window condition. Possible Symptoms: No Window Scaling Option in TCP header of a SYN packet. No Window Scaling Option in TCP header of a SYN/ACK packet when there was a Window Scaling Option in TCP header of a SYN packet.

Client Misconfiguration

A misconfigured client may have the wrong DNS address, the wrong router address, incorrect port numbers defined in a services file, or other problems. Possible Symptoms: The client sends traffic to the wrong target. The client receives service refusals or no answer. Numerous other symptoms may appear depending on the misconfiguration.

Low Packet Size/Low MTU Size

Amount of data that can be carried in a frame is limited by MTU, MSS, or even an inefficient application. Performance pains when sending large files. Possible Symptoms: The MSS value defined in the TCP SYN or SYN/ACK packet is illogically small.

TCP Port Number Reuse

Port numbers can be reused without any problem if previous TCP connection is terminated. Otherwise, the new connection is refused. Possible Symptoms: TCP RST sent in response to a SYN packet to a server port that is known to be open.

Slow Application

Slow applications can be due to poor or bloated coding, internal errors, or even man-made timers defining the application's performance speed. Possible Symptoms: Large delay in the application response time value.

Topic 87: A Four-Part Analysis Methodology

In this topic, we explain an analysis technique for the troubleshooting of networks.

A Network Analyst's Perspective includes Task 1: Define the problem, Task 2: Collect system, application and path information, Task 3: Capture and analyze packet flows, and Task 4: Consider tools.

Define the Problem

A common complaint from network users: "The network is slow". This is a vague description. Need more information from the user. Q1. What type of traffic will you be looking for? A file upload, file download, login, email send/receive or something else? Q2. What server target were you communicating with? Q3. What are the symptoms? Q4. Did you receive any error message? Q5. Is this happening all the time?

Collect System, Application and Path Information

Obtain as much system, network and infrastructure information as possible. Ask the customer about their configuration. Q1. What operating system is running on the client/server? Q2. What application (and version) is running? Q3. Describe the network path that the traffic must traverse.

Capture and Analyze Packet Flows

Capture Location Tips: Capture as close as possible to the complaining host so that you can observe the traffic from that host's perspective, examine the roundtrip time to the target(s) etc. Capture Tool Tips: Prefer using a tap or dedicated capture device rather than spanning a switch port for the capture process. Analysis Process Tips: Know what is "normal". Remove unrelated traffic from view. Focus on traffic related to the complaining user's machine etc.

Consider Other Tools

Once you have hit a Wireshark limitation, you may need to work with another tool. If size of trace files becomes larger than 100 MB, Wireshark becomes too slow.

Topic 88: Using a Troubleshooting Checklist

This topic describes the usage of a Troubleshooting Checklist.

Captured traffic is saved in a trace file. When you open a trace file, use a basic troubleshooting checklist. The order in which you go through the checklist may change depending on the troubleshooting issue.

Verify Trace File Integrity and Basic Communications

Look for ACKed Unseen Segment. Verify traffic from the complaining user's machine is visible. Verify resolution process completion such as DNS/ARP.

Focus on Complaining User's Traffic

Filter out unrelated traffic. Export related traffic to a separate trace file.

Detect and Prioritize Delays

Sort and identify high delta times. Measure path latency (Round Trip Time) using delta times in TCP handshake. This can be achieved by measuring delta from TCP SYN to SYN/ACK. Measure server response time. This can be obtained by measuring from request to response.

Look for Throughput Issues

Click on low throughput points to jump to problem spots in the trace file. Look at traffic characteristics at low throughput points.

Check Miscellaneous Traffic Characteristics

Check packet sizes during file transfer. Check for ICMP messages. Check for IP fragmentation.

TCP-Based Application: Determine TCP Connection Issues/Capabilities

Look for unsuccessful TCP handshakes. Examine the TCP handshake Options area, e.g. MSS, SACK.

UDP-Based Application: Identify Communication Issues

Look for unsuccessful requests.

Spot Application Errors

Filter for application error response codes.

Trace Files used in Topics from 89 to 172 are available at http://www.wiresharkbook.com/troubleshooting.html.

Topic 89: Wireshark Lab 1

This topic describes how to create a Troubleshooting Profile in Wireshark.

Until you create a new profile, you are working in Wireshark's Default profile. The profile you are working in is shown in the right side column of the Status Bar. This is shown next.

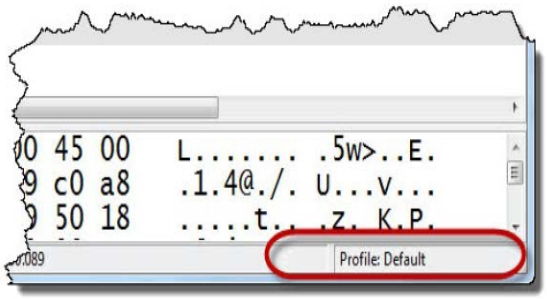


Figure 89.1: Create Your Troubleshooting Profile

You can create profiles to customize Wireshark with buttons, colors, and more. You can create separate profiles for different needs. For example, you may want to make a VoIP profile, a WLAN profile, and a general troubleshooting profile. You can quickly switch between profiles depending on your needs.

Step1: Right-click the **Profile** column on the Status Bar.

Step2: In the Configuration Profile window, select **New**.

Step3: Click the **arrow** in the **Create from** area, expand the **Global section** and select **Classic**. This profile uses the most vibrant colors.

Step4: Enter **Troubleshooting Book Profile** in the Profile Name area. Click **OK**.

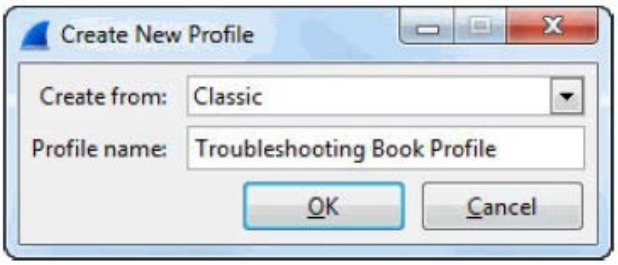


Figure 89.2: Troubleshooting Book Profile

As soon as you create your new profile, the Wireshark Status Bar indicates that you are working in the Troubleshooting Book Profile, as shown next.

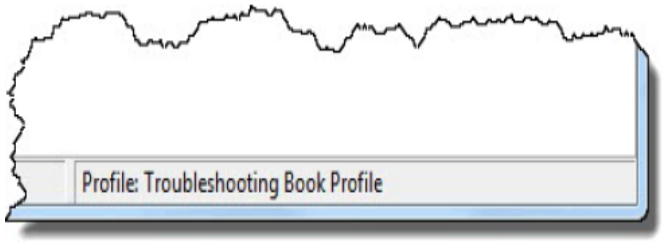


Figure 89.3: Wireshark Status Bar indicates the Troubleshooting Book Profile

You will be able to add capabilities and customization to this new profile. Wireshark also allows download/import a predefined profile for immediate use.

Topic 90: Wireshark Lab 2

This topic discusses how to enhance the Packet List Pane Columns in Wireshark.

By default, the Packet List pane contains: No. (number), Time, Source, Destination, Protocol, Length, and Info columns. This is shown next.

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	24.6.173.220	96.17.148.114	TCP	66	523
2	0.017118000	96.17.148.114	24.6.173.220	TCP	66	80-
3	0.017290000	24.6.173.220	96.17.148.114	TCP	54	523

Figure 90.1: Enhance the Packet List Pane Columns

You can add columns to display additional information about packets to speed up your analysis process.

Step 1: Open ***tr-httpdelta.pcapng***. This trace file contains traffic to/from a user's machine that is checking for Windows updates as well as virus detection updates.

Step 2: Packets 1-3 are TCP handshake packets. Packet 4 is an HTTP GET request for a file called *minitri.flg.* Packet 5 is an ACK for GET request. Packet 6 is the HTTP 200 OK. This is shown next.

1	0.000000000	24.6.173.220	96.17.148.114	TCP	66 52382→80 [SYN] Seq=0
2	0.017118000	96.17.148.114	24.6.173.220	TCP	66 80→52382 [SYN, ACK]
3	0.017290000	24.6.173.220	96.17.148.114	TCP	54 52382→80 [ACK] Seq=1
4	0.018186000	24.6.173.220	96.17.148.114	HTTP	343 GET /minitri.flg HTT
5	0.036422000	96.17.148.114	24.6.173.220	TCP	60 80→52382 [ACK] Seq=1
6	0.037222000	96.17.148.114	24.6.173.220	HTTP	317 HTTP/1.1 200 OK (te

Figure 90.2: Enhance the Packet List Pane Columns

Select Packet 6 in the Packet List pane and then, in the Packet Details pane, expand the Hypertext Transfer Protocol.

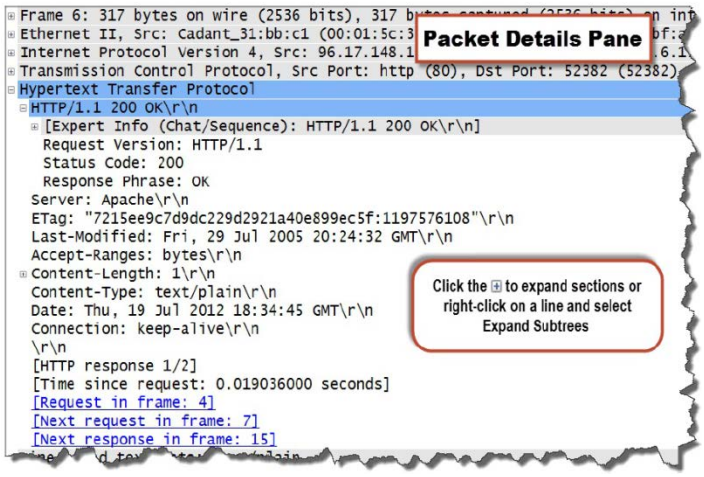
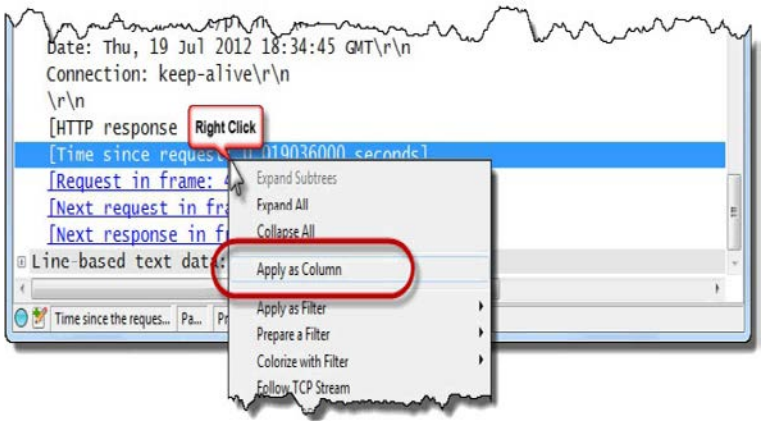
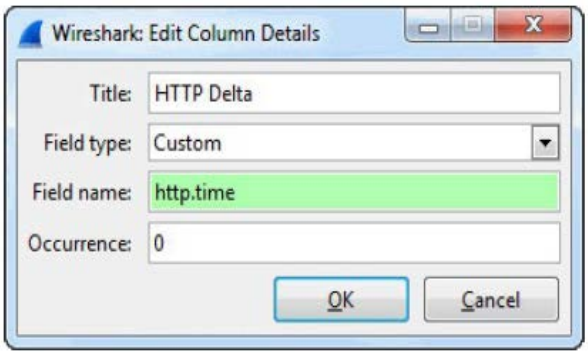


Figure 90.3: Add and Use a Custom Column to Locate HTTP Delays

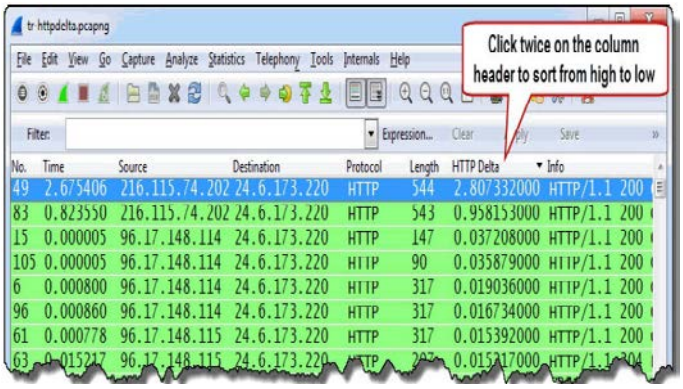
Step 3: Scroll to the bottom of the HTTP section and right-click on the [Time since request: 0.019036000seconds] line. Select Apply as Column.



Step 4: Wireshark places the new Time since Request column to the left of the Info column. Right-click on this new column heading and select **Edit Column Details**. Enter **HTTP Delta** in the Title area. Click **OK**.



Step 5: Click twice on your new **HTTP Delta** column header to sort the column data from high to low. Wireshark indicates there is a 2.807332 second delay before one of the HTTP 200 OK responses (Packet 49).



Step 6: Right-click on your **HTTP Delta** column heading and select **Hide Column**. You can restore this hidden column at any time. Right-click on any column header, select **Displayed Columns** and select column to restore.

Topic 91: Wireshark Lab 3

In this topic, we learn how to change the Time Column settings in Wireshark.

Packets are time stamped at the moment they are captured. By default, Wireshark sets the Time column to Seconds Since Beginning of Capture. In addition, the resolution is set to nanoseconds regardless of whether the packet timestamps contain that level of precision.

Step 1: Open ***tr-australia.pcapng***. This trace file contains a web browsing session and was captured at the client. We want to change the Time column setting so we can quickly measure the delta time between displayed packets.

Step 2: This trace file begins with a DNS query and response. TCP connection establishment begins in Packet 3. Select **View | Time Display Format | Seconds since Previous Displayed Packet**.

Step 3: To change the precision, select **View | Time Display Format | Milliseconds: 0.123**. Now, look at the time from the SYN (Packet 3) to the SYN/ACK (Packet 4). It appears the round trip time is 192 (ms).

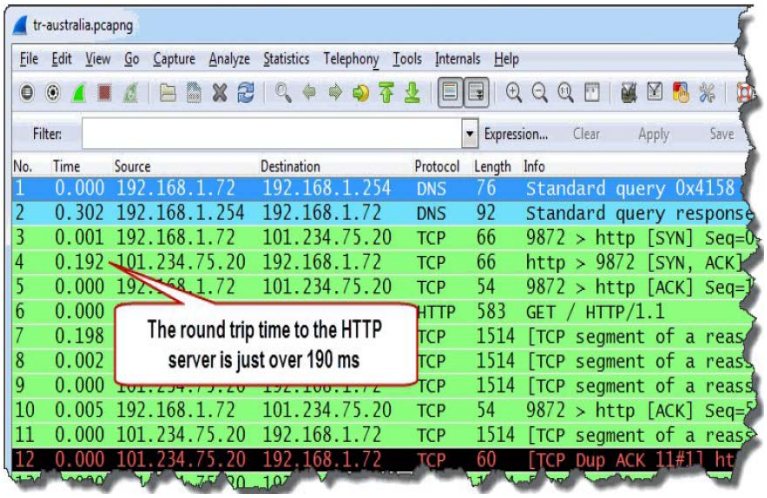


Figure 91.1: Set the Time Column to Detect Path Latency

Topic 92: Wireshark Lab 4

This topic describes how to apply a filter on a host, subnet or conversation in Wireshark. When you capture traffic at the server or inside the network infrastructure: your trace file may contain conversations between many hosts on the network. Are you interested in the traffic between a specific client and server? If yes, you can apply a display filter based on a host address, a subnet address or a conversation.

Step 1: Open ***tr-cnn.pcapng***.

Step 2: This trace file contains numerous conversations. Let's extract conversations between the local client and cnn.com servers. We begin with looking at the name resolution information that Wireshark extracted from the trace file. Select **Statistics | Show Address Resolution**.

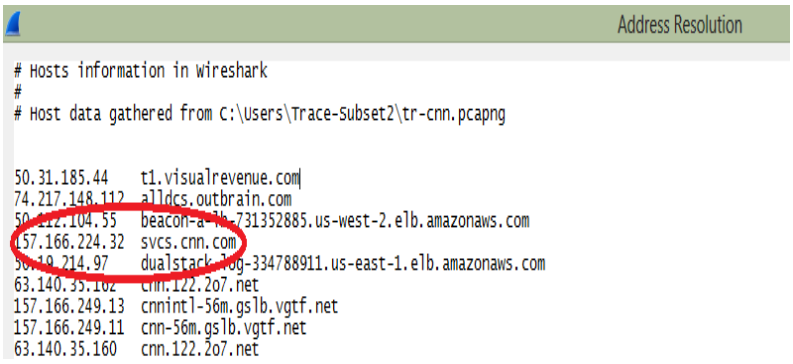
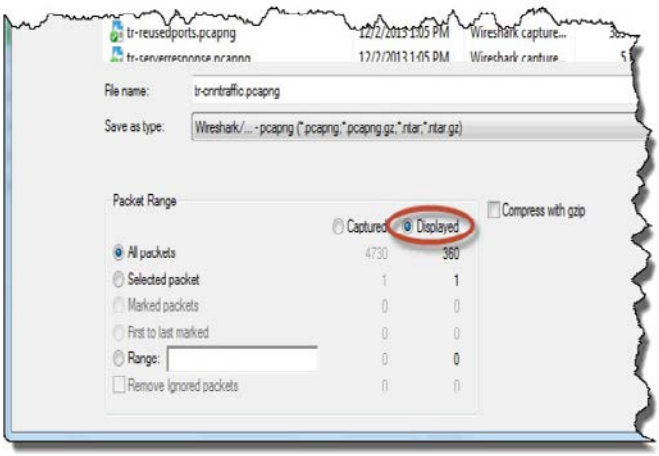


Figure 92.1: Extract and Save a Single Conversation

Servers in cnn.com domain all begin with 157.166. Click **OK** to close the Address Resolution window.

Step 3: In the display filter area, enter **ip.addr==157.166.0.0/16**. Click **Apply**. The Status Bar indicates that 360 packets match the filter. This lists all conversations to and from the cnn.com servers.

Step 4: Select **File | Export Specified Packets**. The **Displayed** radio button is selected by default, as shown next. Name your file ***tr-cnntraffic.pcapng***. Click **Save**.



Step 5: We can also use right-click method to apply a display filter to a single conversation. Let's do this on **Packet 3** in the Packet List pane. Select **Conversation Filter | TCP**. 55 packets appear.

Step 6: Select **File | Export Specified Packets**. Name your file ***tr-cnnconv1.pcapng***. Click **Save.**

Step 7: Click the **Clear** button to remove your display filter. Avoiding unrelated traffic and potential distractions makes analysis easier. Therefore, save the traffic from an interesting conversation to a separate trace file.

Topic 93: Wireshark Lab 5

This topic describes how to apply a filter using port number in Wireshark.

There are two ways to define a display filter on an application in a trace file—you can filter based on the application name (if known to Wireshark), or the port number in use.

Step 1: Open ***tr-twohosts.pcapng***. Let's look at the FTP data transfer connection established by 192.168.1.119.

Step 2: Enter **ip.addr==192.168.1.119** in the display filter area and click **Apply**. This filters all traffic to and from 192.168.1.119. Look for response to the PASV command (Packet 3,959). Expand FTP section in the Packet Details pane to see port no. that the server will be listening on for the FTP data channel (port 39,757).

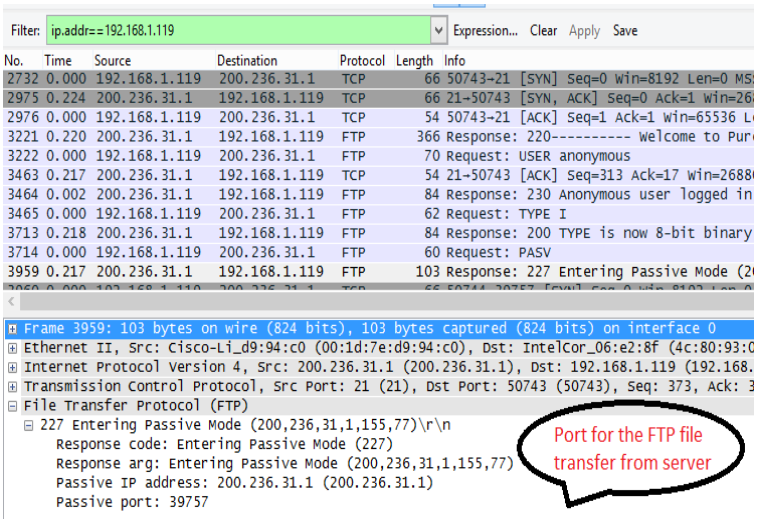
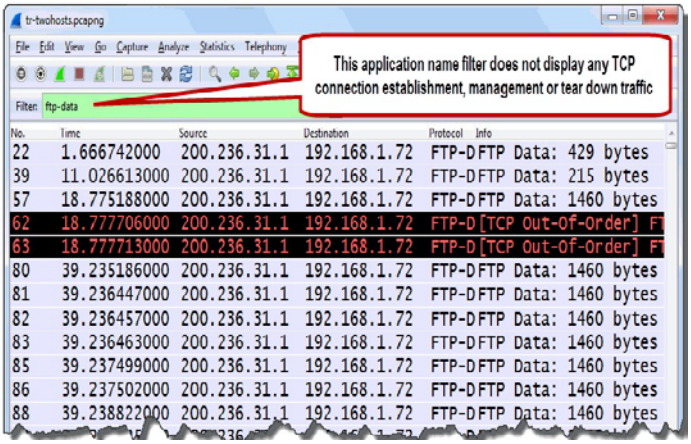


Figure 93.1: Filter Traffic Based on a Port Number

Step 3: Replace your address display filter with **tcp.port==39757**. Click **Apply**. The Status Bar indicates that 28,020 packets match this filter. Next, we contrast this with a display filter based on an application name.

Step 4: Replace your TCP port filter with **ftp-data** and click **Apply**. Now you won't see the TCP handshake, ACKs, or the connection teardown packets.



Step 5: Click the **Clear** button to remove your display filter.

Topic 94: Wireshark Lab 6

In this topic, we apply a filter using a field value in Wireshark.

We often need to identify packets that contain a specific field or a specific field value. For example, the display filter **http.request.method** can be used to view all HTTP client request packets using **http.request.method** field. **dns.flags.rcode > 0** is used to identify DNS error responses with code greater than 0. If you have a packet that contains the field name in which you are interested, you can right-click on the field and select **Apply as Filter**.

Step 1: Open ***tr-winsize.pcapng,*** HTTP clients send commands such as GET and POST in the HTTP Request Method field. Let's display all such packets.

Step 2: Right-click on the **Hypertext Transfer Protocol** section in the Packet Details pane in **Packet 4** and select **Expand Subtrees**. When you click on the **Request Method: GET** line, the Status Bar provides the name of this field—**http.request.method.**

Step 3: Type **http.request.method** in the display filter area and click **Apply**. One packet matches the filter. We can use this filter to determine how many HTTP requests were sent to a server. For example, **ip.addr==10.1.1.1 && http.request.method** would display all HTTP requests to or from 10.1.1.1. If 10.1.1.1 is a client, you would only see HTTP requests sent from this host.

Step 4: Click the **Clear** button to remove the display filter.

Topic 95: Wireshark Lab 7

This topic describes how to locate Buffer Problems using the Calculated Window Size Field in Wireshark.

Every TCP packet sent by a host contains that host's available receive buffer space in the Window Size field. If Window Scaling is in use, this field value is multiplied by a scaling factor. When the advertised buffer space becomes equal to zero, the host cannot accept any more data—a Zero Window condition. Even a low Window Size value can stop a TCP peer from transmitting data.

Step 1: Open ***tr-winsize.pcapng***.

Step 2: Expand any **TCP header** in the Packet Details pane. Right-click on the **Calculated window size** field and select **Prepare a Filter | Selected**.

Step 3: Change the display filter value to **tcp.window_size < 1000** and click **Apply**. This displays Packet 374 in which the client is advertising a 536-byte receive buffer. What will happen if the TCP peer has more than 536 bytes of data queued to transmit? This low Window size value will stop data transmission. Next, we look at this phenomenon.

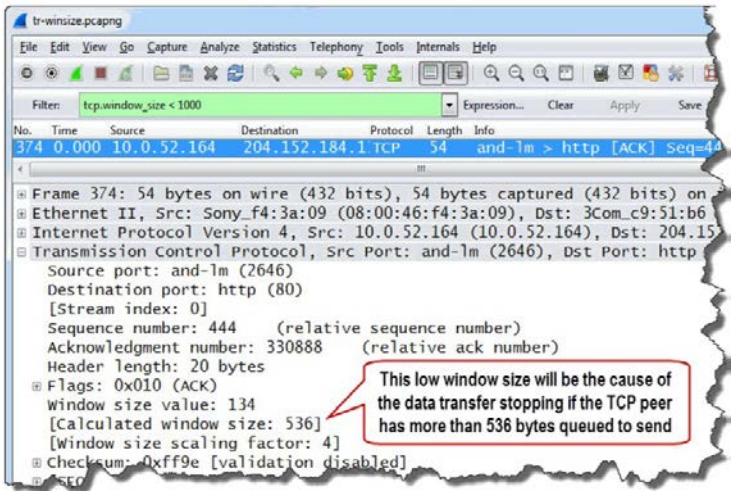
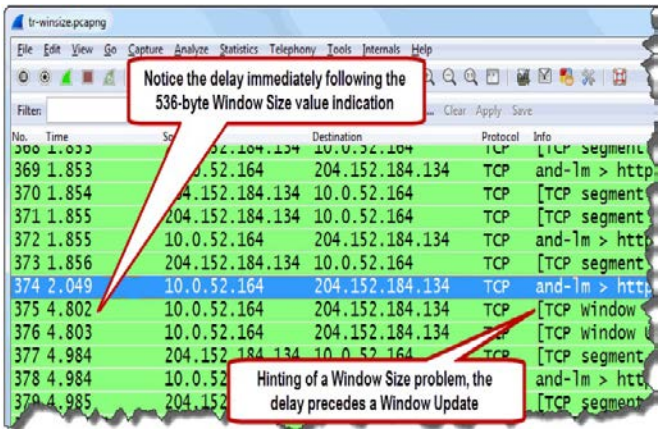


Figure 95.1: Filter on the Calculated Window Size Field to Locate Buffer Problems

Step 4: Click Clear to remove your filter. In this trace file, we next view the delay that occurs before the Window Update packet (Packet 375).



Essentially, the server could not transmit the full-sized packet because the client only had 536 bytes of buffer space available. The server had to wait until the client's buffer size increased.

Topic 96: Wireshark Lab 8

In this topic, we discuss how to filter OUT “Normal” Traffic to focus on anomalies in Wireshark.

To filter out traffic based on an application name, simply precede the application display filter name with an exclamation sign **(!)**. For example, to remove ARP from view, use **!arp**. There are two methods you can use to exclude traffic based on a field value. One method uses the **!** or **not** operator with **==** or **eq**. The other uses the **!=** or **ne** operator.

Examples

- **!ip.addr==10.10.10.10**
- **http.request.method != "GET"**

When to Use ! and == and When to Use !=

Use the first method when you filter on a field name that matches two fields such as **ip.addr**, **tcp.port**, or **udp.port**. Use the second method when you refer to a field name that only matches one field such as **dns.flags.rcode** or **tcp.dstport**.

Correct Display Filter

- !ip.addr==10.1.1.1
- dns.flags.rcode!=0

Incorrect Display Filter

- ip.addr != 10.1.1.1
- !dns.flags.rcode==0

This lab removes a set of applications and protocols from view to determine what other traffic is seen on this network.

Step 1: Open ***tr-general.pcapng***.

Step 2: In the display filter area, type **!tcp && !arp** and click **Apply**. There are 40 packets that match this filter.

Step 3: To remove DNS and DHCP from view, expand the filter by adding **&& !dns && !bootp.** Eight packets are displayed.

The displayed packets indicate that there are two hosts running Dropbox on the network and are sending packets to the broadcast address (255.255.255.255).

Topic 97: Wireshark Lab 9

This topic presents how to Create Filter Expression Buttons in Wireshark.

Filter Expression buttons are based on display filters. These buttons can be created and used to quickly apply display filters to your traffic to identify common network problems. Let's create a button to quickly identify TCP handshake packets that do not offer Selective Acknowledgment (SACK) or Window Scaling functionality. To do this, we need to combine an inclusion filter for the SYN bit set to 1 with an exclusion filter for the SACK and Window Scaling options.

Step 1: Open ***tr-smbjoindomain.pcapng***.

Step 2: Packet 11 is the first SYN packet in the trace file. Right-click on the TCP header of this packet and select Expand Subtrees. Let's first build the filter and then turn the filter into a filter expression button. Right-click on **SYN: Set** line and select **Prepare a Filter | Selected**. Wireshark places first part of filter in the display filter area.

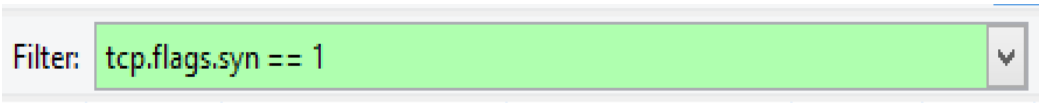
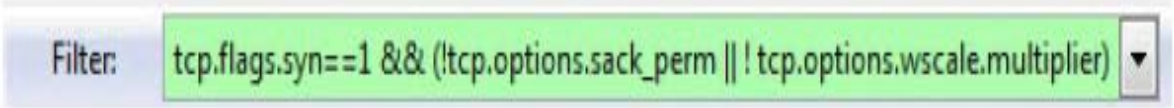


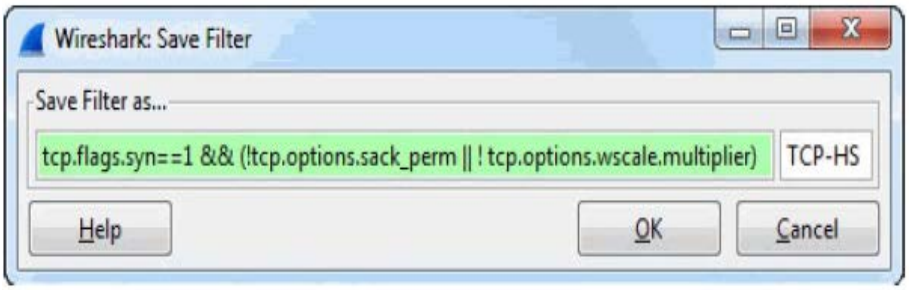
Figure 97.1: Create a Button to Detect Missing TCP Functionality

Step 3: Scroll down to the TCP Options area. Click on the **TCP SACK Permitted Option: True** line. This displays **tcp.options.sack_perm** in the Status Bar area. Expand the filter by typing **&& !tcp.options.sack_perm** so that TCP handshake packets that do not contain this value can be observed.

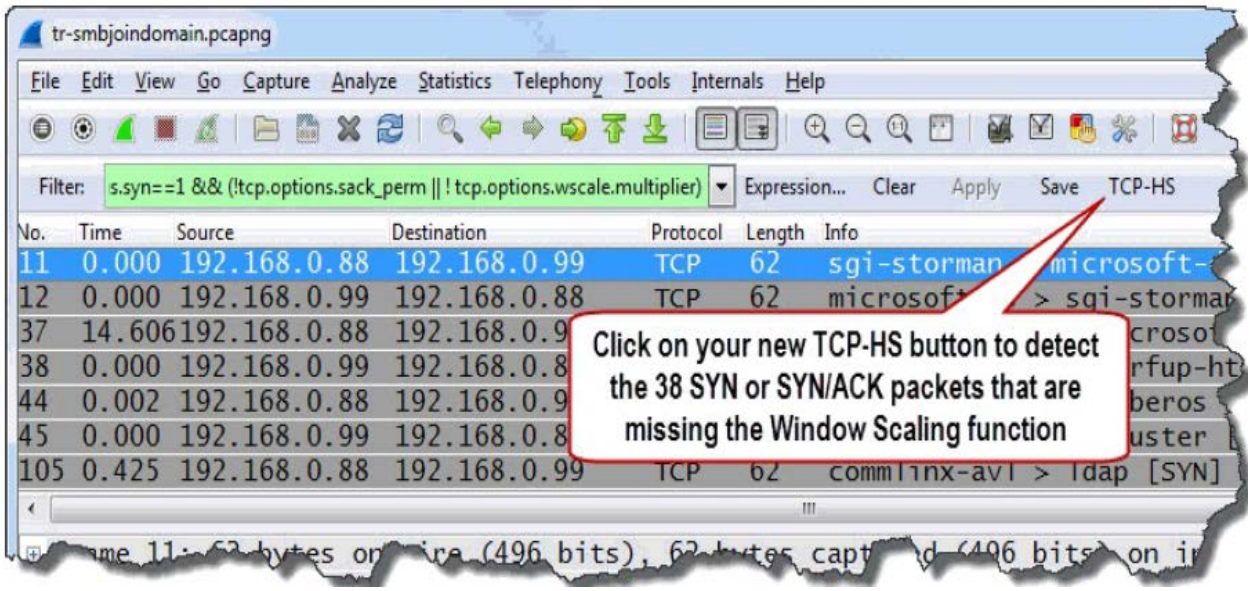
Step 4: Now add **|| ! tcp.options.wscale.multiplier** and put parentheses around the options, as shown next.



Step 5: Click the **Save** button and name your new button **TCP-HS** and click **OK**



Step 6: Click your new TCP-HS button. There are 38 packets that match the TCP-HS button filter. The connections established by these packets will not support all the desired TCP functions.



If you need to edit, reorder or delete Filter Expression buttons, select **Edit | Preferences | Filter Expressions**.

Topic 98: Wireshark Lab 10

This topic discusses how to launch and navigate through the Expert Infos. in Wireshark.

Wireshark's Expert Infos can help you quickly detect network problems as well as obtain basic information about network communications and view/jump to packet comments.

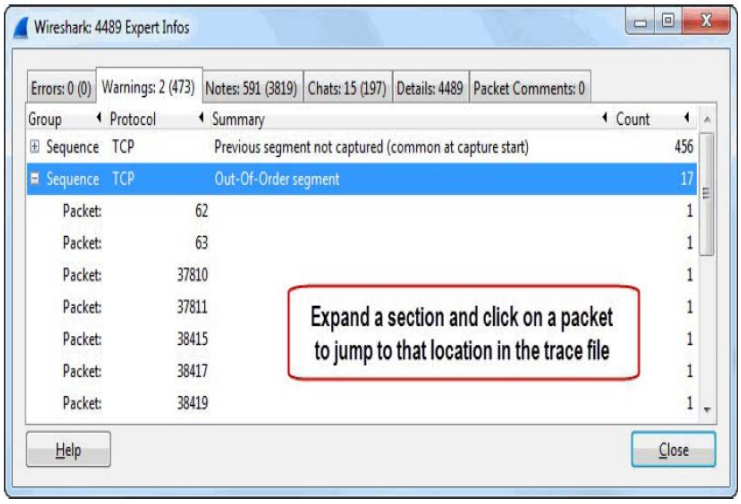
Step 1: Open ***tr-twohosts.pcapng***.

Step 2: Click the **Expert Infos** button in the bottom left corner of the Status Bar. This will open the **Expert Infos** window.

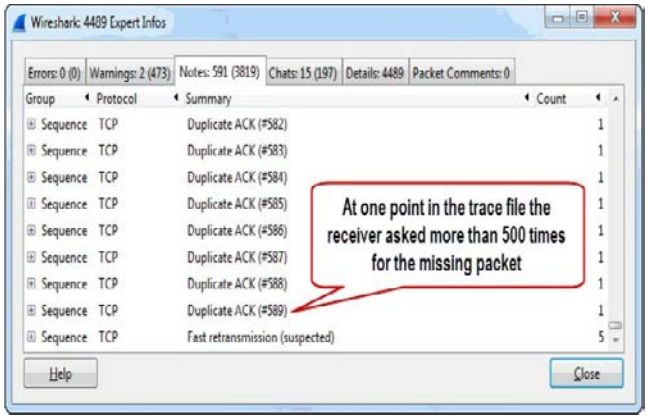
Figure 98.1: Use Expert Infos to Identify Network Problems

The Expert Infos window is divided into six tabs: **Errors**: Checksum errors, dissector failures. **Warnings**: Potential problems detected. **Notes**: Symptoms of problems; typically recovery processes. **Chats**: TCP connection overhead (handshake, Window updates, disconnects). **Details**: Summary of Errors, Warnings, Notes and Chats. **Packet Comments**: List of all packet comments in trace file.

Step 3: If IPv4 checksum validation is disabled, there are no Expert Infos Errors in this trace file. Otherwise, you will see 6,767 IPv4 Bad Checksum Errors. To disable IPv4 checksum validation, toggle back to Wireshark, rightclick on the **Internet Protocol Version 4** line in the Packet Details Pane, select **Protocol Preferences** and toggle off the ***Validate IPv4 checksum if possible***. Click the Warnings tab of **Expert Infos** window. Click on a packet to jump to that location in the trace file.



Step 4: Click the **Notes** tab. As you scroll the list, you will see 589 Duplicate ACKs sent by receiver to recover a missing packet. This can be caused by a very high latency path or a brief connection outage.



Step 5: Click **Close** to shut down the Expert Infos window.

Topic 99: Wireshark Lab 11

This topic describes how to change the Dissector Behavior in Wireshark.

Some of Wireshark's predefined preference settings are not ideal for troubleshooting. For example, the ***Allow subdissector to reassemble TCP streams*** preference setting.

Step 1: Open ***tr-youtubebad.pcapng***.

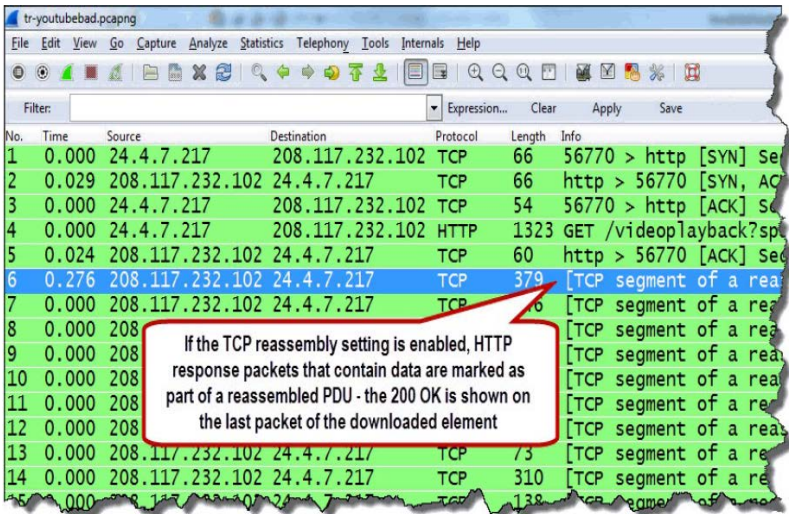
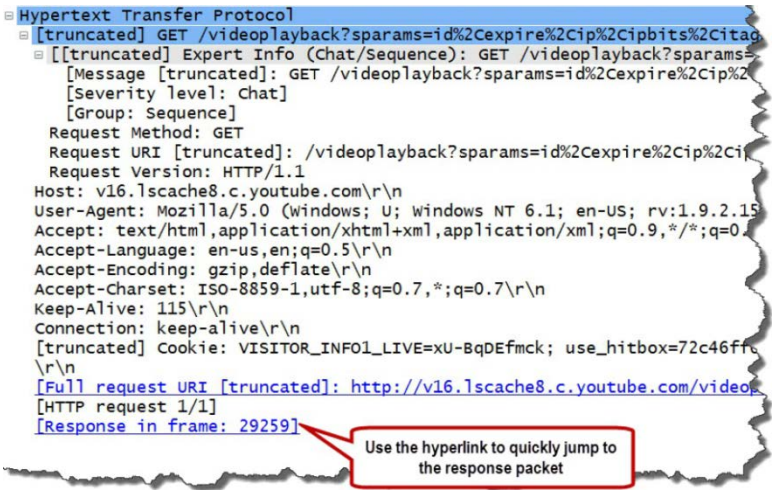


Figure 99.1: Change the TCP Dissector Reassembly Setting to Properly Measure HTTP Response Times

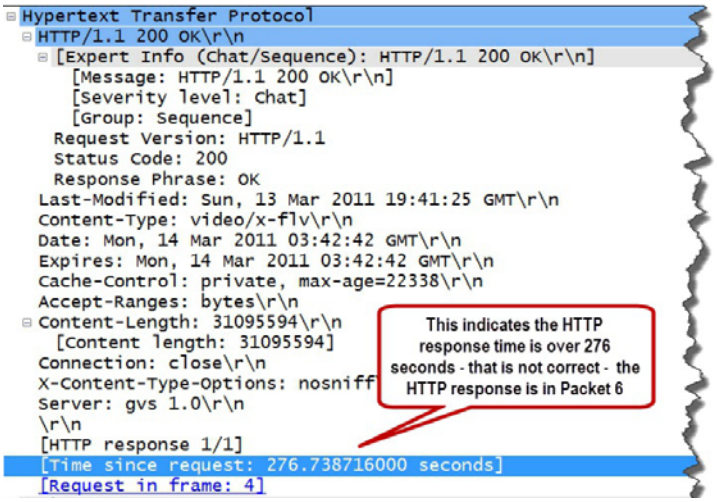
Response Code in the Info column for Packet 6 cannot be seen because the **Allow subdissector to reassemble TCP streams** preference setting is enabled.

Step 2: In the Packet Detail pane of **Packet 4**, right-click the **Hypertext Transfer Protocol** heading and select **Expand Subtrees**. A hyperlink to the response packet is

located at the bottom of the HTTP section. Double-click the **hyperlink** to jump to **Packet 29,259**.



Step 3: Scroll to the bottom of the HTTP header in Packet 29,259. The Time Since Request (**http.time**) field indicates the HTTP response time was over 276 seconds.



This is not correct. The HTTP response time is measured from the HTTP request packet to the HTTP response packet that contains the 200 OK response.

Step 4: To find the actual HTTP response time, in the Packet Details pane of any packet, right-click the **TCP header**, select **Protocol Preferences** and toggle off the ***Allow subdissector to reassemble TCP streams*** preference setting.

Step 5: Now click the Go to First Packet button. Notice we see that Packet 6 actually contains the 200 OK response. Examine the HTTP response time value in Packet 6. It is just over 300 ms.

Topic 100: Wireshark Lab 12

This topic provides a way to find the top talkers in Wireshark.

We can use the Conversations window to determine the most active conversation based on hardware address, network address, or even the port numbers in use.

Step 1: Open ***tr-general.pcapng***.

Step 2: Select **Statistics | Conversations**. The tabs indicate the number of each type of conversation seen in the trace file.

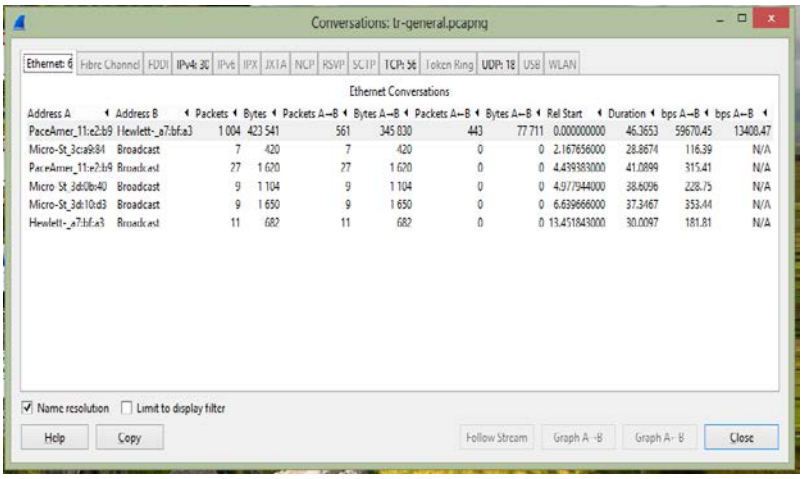
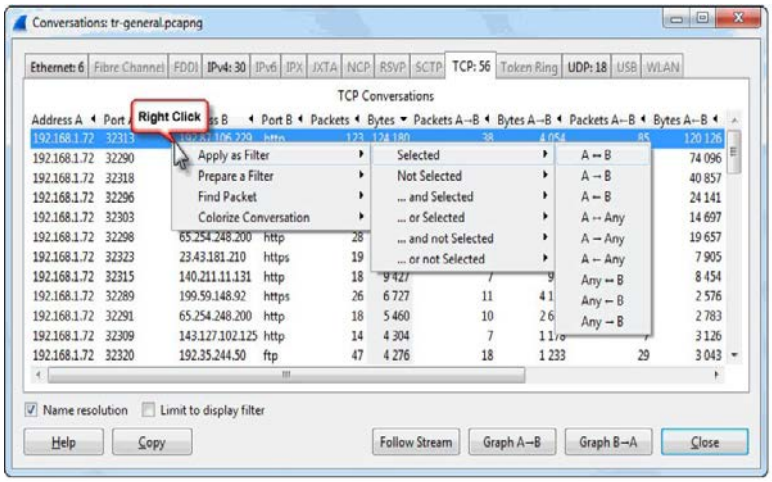


Figure 100.1: Find the Most Active Conversation (Byte Count)

Step 3: We are interested in the most active TCP conversation (in bytes) in this trace file. Click the **TCP** tab and then click the **Bytes** column heading twice to sort from high to low. The most active conversation is between 192.168.1.72 on port 32313 and 192.87.106.229 on port 80 (listed as *http*).

Step 4: Right-click on this **top conversation** and select **Apply as Filter | Selected A <->B.** Wireshark applies the filter and displays the 123 packets of this conversation.



Step 5: When you are done, click **Clear** to remove your display filter, toggle back to the Conversations window and click **Close**.

Topic 101: Wireshark Lab 13

This topic provides how to build a basic IO graph in Wireshark.

The basic IO Graph can be used to view throughput levels for all traffic in a trace file, or plot a subset of traffic (based on display filters). The IO Graph can help you prioritize your troubleshooting tasks.

Step 1: Open ***tr-winsize.pcapng***. This trace file contains a single TCP conversation. An HTTP client is downloading a large file from a web server.

Step 2: Select **Statistics | IO Graph**. By default, Wireshark displays the packets per second rate (packet per tick with a default tick rate of one second).

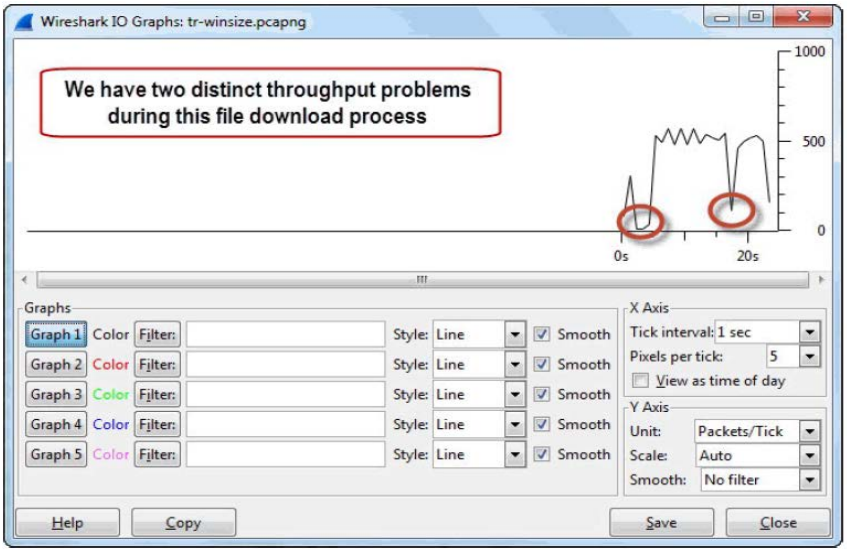
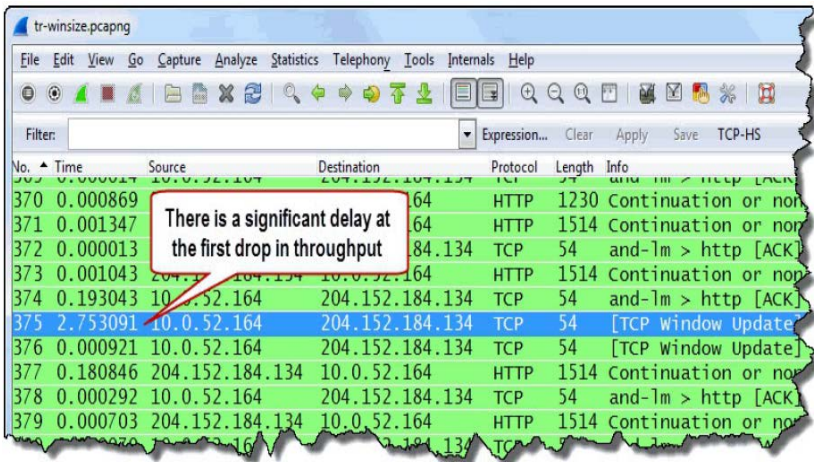


Figure 101.1: Quickly Spot a Throughput Problem in an IO Graph

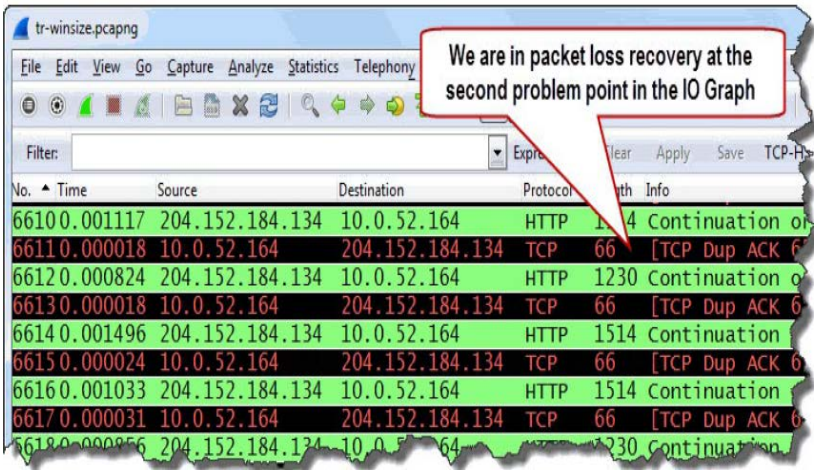
Let's investigate both of them.

Step 3: Click on the **first drop in throughput** in the graph. Wireshark jumps to that point in the trace file so we can investigate the problem further.



If your Time column is set to *Seconds Since Previous Displayed Packet* (**View | Time Display Format**), you will see a delay of over 2.75 seconds in the trace file. Packet 375 is marked as a TCP Window Update packet. This indicates that the delay may have something to do with the Window Size value advertised by the client (10.0.52.164).

Step 4: Go to the IO Graph. Click on the **second problem point** in the graph. From Wireshark's window, we can see what is happening at this point in the file download process.



The client appears to be in the middle of a packet loss recovery process.

Step 5: Go to the IO Graph and click **Close**.

Topic 102: Wireshark Lab 14

This topic discusses the addition of a coloring rule in Wireshark.

Coloring rules can be used to quickly identify packets in the Packet List pane. Let's build a coloring rule to highlight DNS errors.

Step 1: Open ***tr-chappellu.pcapng***.

Step 2: Type **dns** in the display filter area to capture all DNS traffic and then click **Apply**. Forty-three packets will match your filter. The client asks two DNS servers (75.75.75.75 and 75.75.76.76) to resolve www.chappellU.com nine times before receiving an answer (Packet 12).

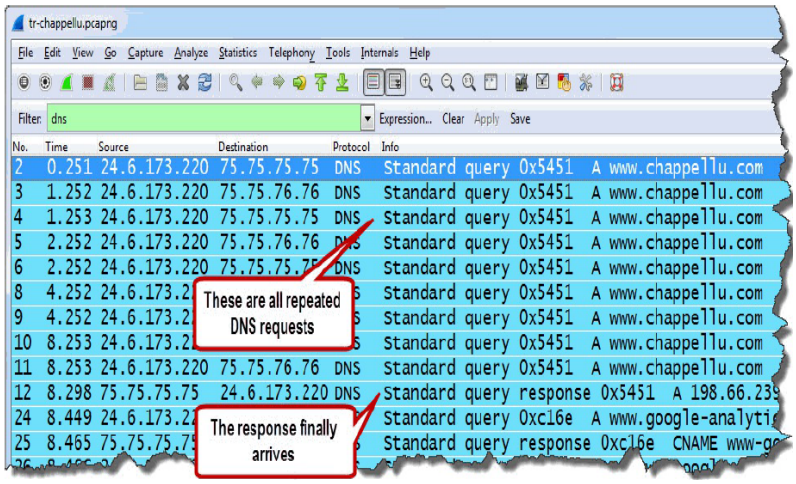
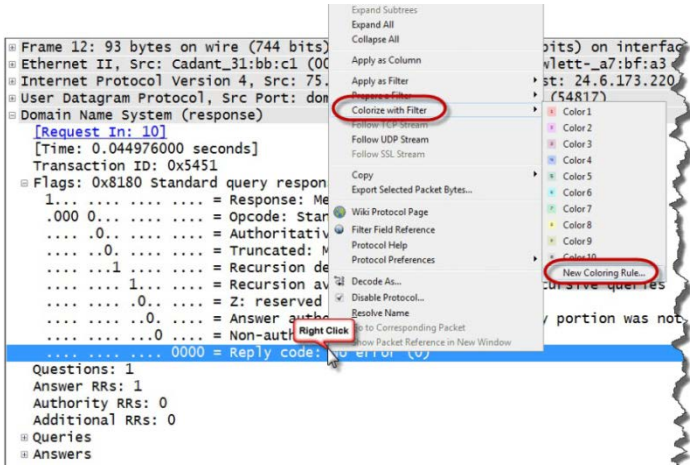


Figure 102.1: Build a Coloring Rule to Highlight DNS Errors

Step 3: Right-click on the **Domain Name System (query)** section in the Packet Details window of Packet 12. Select **Expand Subtrees**. When the Reply Code field inside the Flags section contains a 0, the DNS response was successful. If it contains any other value, the response indicates there is as DNS error.

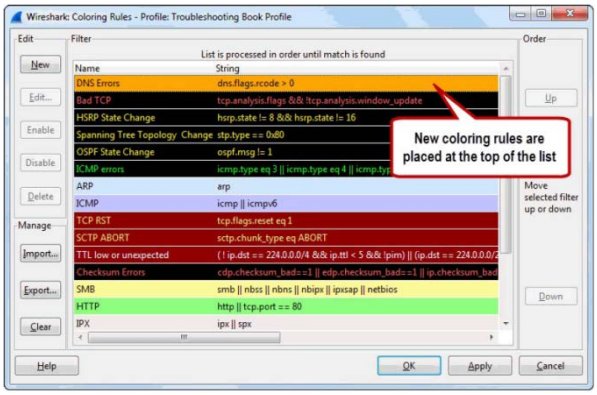
Step 4: Right-click on the **Reply Code** field and select **Colorize with Filter | New Coloring Rule**.

Step 5: Enter **DNS Errors** as the name of your new coloring rule. Change the String value to dns.flags.rcode > 0.



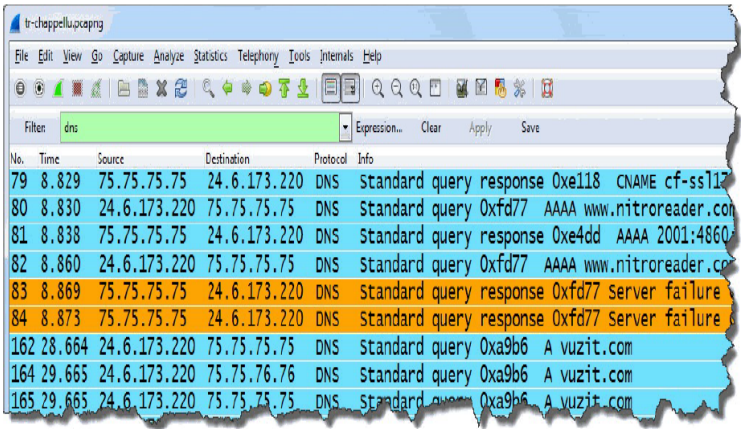
Step 6: Click the **Background Color** button and type **orange** in the Color Name field. When you tab away from the Color Name field, Wireshark changes the word "orange" to the hex value #FFA500. Then, Wireshark shows the new color in the color preview area. Click **OK** to close the background color window and click **OK** to close the Edit Color Filter window.

Your new coloring rule appears at the top of the list of color filters. Packets are processed in order through this list. Now, DNS errors will appear with an orange background.



Step 7: Click **OK** to close the Coloring Rules window.

Step 8: With **dns** filter still in place, scroll through the packets to see if you notice the two DNS errors in the trace file. Packets 83 & 84 appear with orange.



Step 9: Expand the **Frame** section in the Packet Details pane of Packet 83. You will see your Coloring Rule Name and Coloring Rule String listed in this area.

Topic 103: Capture Options for a Switched Network

This topic explains tips on choosing a capture location for a switched network.

These days, almost all network clients are connected to the network through a switch. Four types of packets are forwarded by a switch. Broadcast multicast, traffic to your hardware address and traffic to an unknown hardware address.

Because of this, when you connect a system running Wireshark directly to a switch port, you cannot listen to other users' traffic. In order to capture the traffic between the client and the upstream switch (and ultimately a remote host), you need to either

(a) Install Wireshark or another capture tool on the user's machine,

(b) Make the switch send a copy of the traffic down your analyzer port, or

(c) Tap in and obtain a copy of the traffic between the client and the switch.

Install Wireshark on User's Machine: This is a great option—if you possible.

Switch Port Spanning: The next option to consider is to make the switch send a copy of the traffic down to your analyzer port (aka "spanning"). Not all switches support this feature. If there are corrupt frames traveling from the user's host, those corrupt frames won't be forwarded down the spanned port by the switch. Furthermore, avoid "oversubscribing" your switch port – spanning a level of traffic that cannot "fit" down the pipe to your Wireshark system. Switch will drop excess packets and trace file will be incomplete.

Use a Test Access Port ("Tap"): A tap is a simple device that copies all the traffic flowing through it (including those corrupt packets) out to a monitor port.

Topic 104: Wireshark Lab 15

In this topic, we describe the Wireless Capture Options in Wireshark.

You are lucky if your native WLAN adapter can capture WLAN Management and Control traffic. In Monitor Mode, you should be able to see traffic from any network as well. To test the capture capabilities of your WLAN Native Adapter, follow the given steps.

Step 1: Launch Wireshark and click the **Interface List** button on the Main Toolbar.

Step 2: Select the checkbox in front of your WLAN adapter and click **Start**.

Step 3: Go to a browser window and visit www.wireshark.org. Go to Wireshark and examine the packets you have captured. If your native adapter is suitable for network capture, you should see some WLAN management and Control traffic (such as Beacon packets and Probe Request/Probe Response packets).

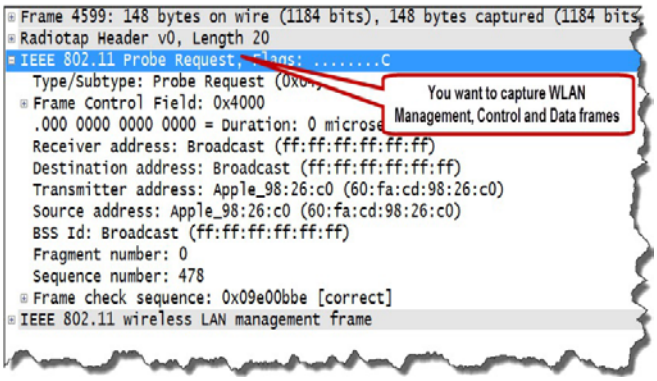


Figure 104.1: Test Your WLAN Native Adapter Capture Capabilities

Also, when you look at the data packets you should see an 802.11 header on the data packets. If your adapter strips off the 802.11 header, Wireshark will apply an Ethernet header. In case, you do not see these traffic types or characteristics, consider another solution for WLAN capture.

Visit: wiki.wireshark.org/CaptureSetup/WLAN for additional options for WLAN capture.

Topic 105: Wireshark Lab 16

This topic provides how to capture to a File Set in High Traffic Rate Situations in Wireshark.

Capturing to file sets is an important task when you are working in high traffic situations. File sets are groups of trace files that are linked based on their file name. In this lab exercise, we will use an autostop condition to only capture three files.

Step 1: Click the **Capture Options** button on the Main Toolbar.

Step 2: In the Capture Options window, set **path and file name** for your file set. Enable **Use Multiple Files**. Set **Next file every 1 Minute(s)**. Set **Stop capture after 3 Files**. Click **Start**.

Step 3: Open a browser and visit several web sites. Browse for at least **3 minutes** and go to Wireshark. Your capture process will automatically stop after 3 minutes. The third file will be displayed.

Step 4: To move from one file to the next file in a file set, select **File | File Set | List Files**, select a file in the list and Wireshark will load that file. You can quickly locate specific packets in the file set by applying a display filter to one of the files and then clicking subsequent files in the file list. The display filter will remain in place as you open each file. When you are finished navigating through files, click **Close** on the File Set window.

Topic 106: Wireshark Lab 17

This topic describes how to create and apply a MAC address filter in Wireshark.

Capture filters can reduce the traffic that you need to examine. Here, we will create and use a capture filter based on the MAC address. This will enable us to see all of the traffic to or from our machine.

Step 1: Obtain the MAC address of your host using either ***ipconfig*** or ***ifconfig*** as supported by your machine's OS.

Step 2: Click the **Capture Options** button on the Main Toolbar.

Step 3: Enter **ether host xx:xx:xx:xx:xx:xx** (replacing the **x** indications with your MAC address). Uncheck **Use multiple files**. Click **Start**. If you need this filter again, then click the **Capture Filter** button. Click **New** and name your filter ***MyMac*** and click **OK**.

Step 4: Open a browser window and visit www.wireshark.org.

Step 5: Go to Wireshark and click the **Stop Capture** button on the Main Toolbar.

Step 6: Your trace file will contain the HTTP traffic from your browsing session to www.wireshark.org.

Step7: Clear the display filter when you are finished.

Topic 107: Verify the Target Host Traffic

This topic describes how to verify the capture process in Wireshark.

The first step of any analysis process is to verify that the hosts are able to communicate and you can see their traffic in the trace file. If hosts are not able to communicate, there can be several reasons for this.

Check Your Capture Process: If you do not see any traffic, something may have gone wrong during the capture process. A) Wireshark had a capture filter in place and the complaining user's traffic did not match the capture filter. B) If you are using a tap, the user's network cable isn't plugged into the tap. C) If you are spanning a switch port, the switch is not spanning the traffic down your analyzer port.

Consider the TCP/IP Resolution Process: All applications must go through a basic resolution process to build the packet to communicate with another host on a TCP/IP network.

1. Port Resolution: The user specifies Port number in the URL, in the application code.

2. Name Resolution: Examine local cache to locate the information or send a name resolution request on the network.

3. Location Resolution – Local or Remote: Compare target address to local host subnet mask.

4. MAC Address Resolution – Local Target: Examine local cache to locate the target MAC address or send an ARP Request.

5. Route Resolution: Examine local cache to locate the best route for target host.

6. MAC Address Resolution – Remote Target: Examine local cache to locate the target MAC address or send an ARP Request.

Topic 108: Wireshark Lab 18

This topic describes how to identify name Resolution Problems in Wireshark.

If a client does not know the IP address of a target (either in cache or a local hosts file), the client can send a DNS query to obtain this information. What if the client does not know of a DNS server to ask, the client cannot send out a DNS query. The resolution process ends there. If a client sends a DNS query and does not get a response or receives an error in the DNS response, the client can't talk to the target.

Step 1: Open ***tr-nameresolution.pcapng***.

Step 2: Type **dns** in the display filter area and click **Apply**. You can observe from the Status Bar that 32 packets match this filter. From the Info column, you can see a number of **No Such Name** responses indicating the name resolution process failed. This can be due to DNS issues or user issues. In this trace file, the user typed the wrong URL.

Step 3: Clear the display filter when you are finished.

Topic 109: Wireshark Lab 19

This topic describes how to identify local address Resolution Problem in Wireshark.

Before a client can send a packet to a local target or a local router, it must obtain the MAC (Media Access Control) address of that local target or router. If the client does not have the MAC address information in cache, the client sends out an Address Resolution Protocol (ARP) request. If no response is received when trying to acquire the local target's MAC address, the client is done. It cannot send out a packet to the target.

Step 1: Open ***tr-localresolution.pcapng***.

Step 2: Scroll through this trace file. Look at the ARP requests sent to discover the MAC address of 192.168.1.45. There are no responses.

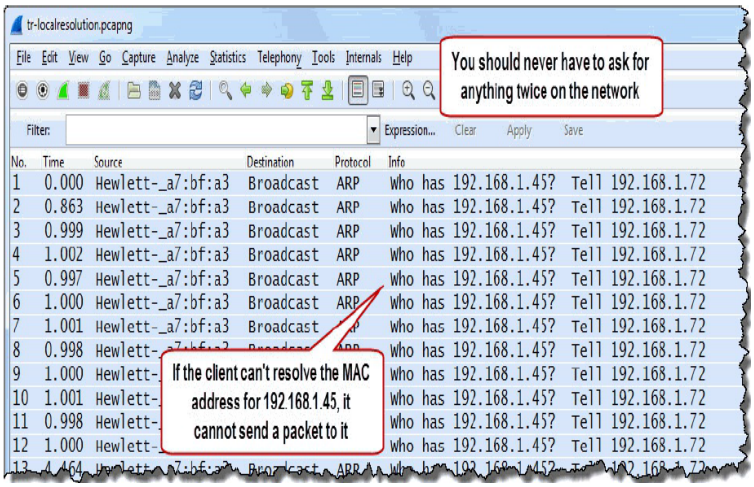


Figure 109.1: Find Local Address Resolution Problems

Without resolving MAC address issue, 192.168.1.72 will not be able to communicate with 192.168.1.45. Maybe 192.168.1.45 is not currently up. Maybe that is the wrong IP address. We can't tell.

Topic 110: Wireshark Lab 20

In this topic, we describe the “No server Response to TCP Connection Request” situation in Wireshark.

There are several reasons why a server may not respond to a TCP connection attempt. The TCP handshake request packet (SYN) may not arrive at the server. Maybe the SYN packet was lost. A firewall along the path dropped the SYN packet, or a host-based firewall on the server blocked access to the port. Alternately, the response (SYN/ACK) may not arrive at the client. The SYN/ACK packet was lost along the path, or a firewall along the path blocked the SYN/ACK.

Step 1: Open ***tr-noserver.pcapng***.

Step 2: Scroll through this trace file. This trace file contains only SYN packets from 192.168.1.72 to 192.168.1.66. None of the SYN packets have received SYN/ACK responses. Expand the TCP header in Packet 1. Right-click on the **[Stream index: 0]** line and select **Apply as Column**. Wireshark shows that there are 6 separate connections (TCP Stream Index: 0-5).

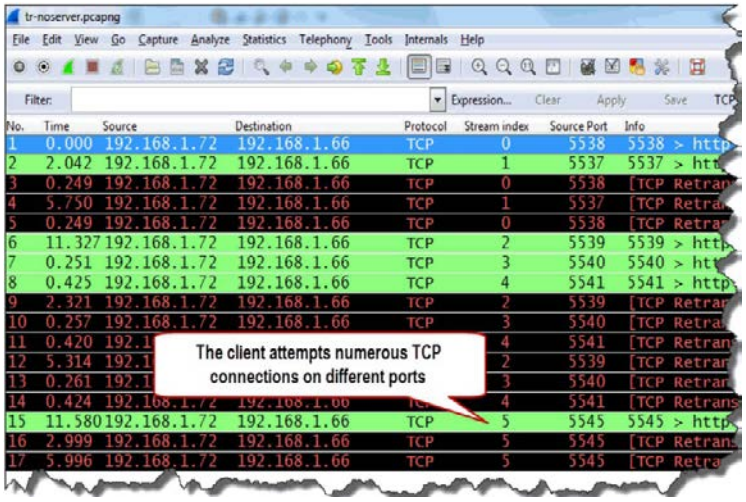


Figure 110.1: No Response to TCP Connection Request

Step 3: Right-click on the TCP **Source Port** field in any packet and select **Apply as Column**. This shows that the client has set up numerous ports for these connections.

Step 4: Some of these SYN packets match the HTTP coloring rule while others match the Bad TCP coloring rule because the SYN packets are Retransmissions.

Topic 111: Wireshark Lab 21

This topic discusses how to analyze the "No Response to Service Request" situation in Wireshark.

Step 1: Open ***tr-serverresponse.pcapng***.

Step 2: Scroll through this trace file to get familiar with the traffic pattern. Use the Stream Index column to differentiate the separate connections bet. 24.6.173.220 and 50.62.146.230. Right-click on Packet 1 in the Packet List pane and select **Conversation Filter | TCP**.

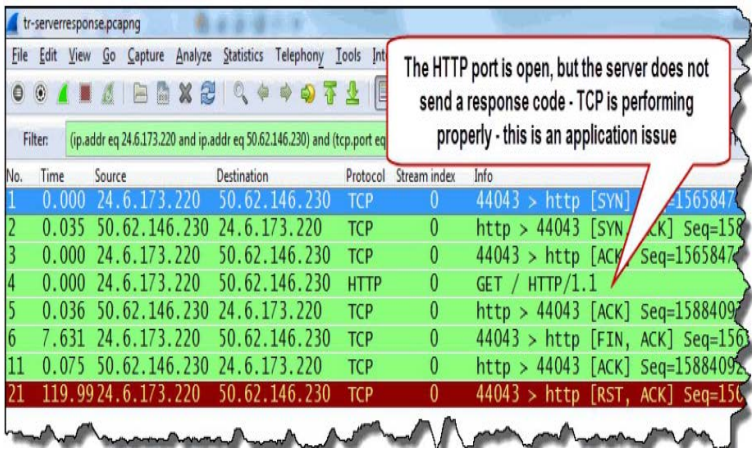


Figure 111.1: No Response to Service Request

The TCP handshake completes successfully in Packets 1-3. The client requests the default file from the web site's root directory in Packet 4. Packet 5 contains acknowledgment no. 288, which indicates that the server has received every sequence no. up to 287, and it expects sequence no. 288 next. So, server received the request. Packet 5 contains acknowledgment no. 288, which indicates that the server has received every sequence no. up to 287, and it expects sequence no. 288 next. So, server received the request. The client's browser appears to time out and sends a FIN/ACK after almost 8 seconds. The client begins an implied connection termination. The server sends an ACK. We would expect the server to begin closing its side of the connection, but it does not. The client waits almost 120 seconds before sending a RST/ACK. TCP appears to be functioning properly in this trace file. The symptoms indicate the application has failed at the server side.

Topic 112: Do not Focus on Acceptable Delays

This topic discusses the worth of normal delays.

You can safely ignore some delays in your trace files. For example, a delay before a TCP RST packet would likely not be felt by the end user. Such acceptable delays should not raise an alarm.

Delays before DNS Queries

A DNS query will be triggered when we enter a URL in a browser and then press Enter. When we see an interesting link on a web page and we click on it. Open ***tr-delays.pcapng***.

You will find that the delay before Packet 29 is caused by an eventual time out of a connection. Packet 32 is a DNS query and the delay before it is because the user did not straightaway click on www.wireshark.org.

Delays before TCP FIN or Reset Packets

Delay introduced by an application, which sends TCP FIN/RST packets to close the connection after waiting for specified time or some task is completed.

Delays before a Client Sends a Request to a Server

Filling out a form and pressing the Submit button, or clicking the next link on a web page. In all such cases, an application requires user interaction.

Delays before Keep-Alive or Zero Window Probes

Keep-Alives and Zero Window packets are sent during a Zero Window situation to determine if more buffer space is available at the target. Hosts also send “Keep-Alives” periodically to maintain a TCP connection.

Delays before TLS Encrypted Alert

An application sends a Transport Layer Security (TLS) Encrypted Alert to eventually close an encrypted connection; we can't see the Close command.

Delays before a Periodic Set of Packets in a Connection that is Otherwise Idle

Applications can define their own keep alive packet types to keep the connection active.

Topic 113: Watch for the Delays that DO Matter

This topic describes various delays that do matter for networks.

On your network, knowing what "normal" delay times are will help you identify unusually high delay times. We next provide a list of delays that should be examined.

Delays before a Server Responds with a SYN/ACK

A client can use the time between the SYN and SYN/ACK in the TCP handshake to determine the round trip time between the hosts. A large delay before the SYN/ACK is an indication of a high round trip time between the hosts.

Delays before a Client Completes the 3-Way TCP Handshake

Time between SYN/ACK and client’s ACK to finish TCP handshake can be used by server to determine the round trip time.

Delays before a Server Sends a Response

In a trace file, if you observe that a server quickly sent an ACK to a client's request, but there is a long delay before server’s response, then this is not path latency issue. We need to consider why a server might be slow. For example, let’s look at the case given in ***tr-http-pcaprnet101.pcapng.*** The client's GET request (GET /home) in packet 18 followed by the server ACK takes 17 ms. We can see a delay of almost 1.8 seconds before the requested data begins. The trace was taken at the client. The round trip time between the hosts is acceptable, but the server response time is not.

Delays before the Next Packet in a Data Stream

There can be several reasons for delays that occur during a file download or file upload process. The sender became busy with other processing. There can be a

device along the path, which may be buffering the data for higher priority traffic. Lack of receive buffer space at a receiver.

Delays before an ACK from a TCP peer

This situation arises when ACKs from a receiver get delayed because of the path latency or delayed ACK function. Delayed ACK timers are often set at 200 ms.

Delays before a Window Update

A host must wait for a Window Update before sending a packet, if it finds that Window Size advertised is too small to fit a full-sized data segment.

Topic 114: Wireshark Lab 22

In this topic, we discuss how to detect delays in UDP Conversations in Wireshark.

The User Datagram Protocol (UDP) is a connectionless transport layer protocol with an 8-byte header. Unlike TCP, UDP has no sequencing or acknowledgement capability. Delays between requests and responses are a measure for UDP-based applications. UDP conversation statistics such as packet rate, bps rate etc. can be obtained with Conversations Window.

Step 1: Open ***tr-voip-extensions.pcapng***.

Step 2: Select Statistics | Conversation.

Step 3: Click the UDP tab. Uncheck the Name Resolution option, if you are interested in seeing port numbers rather than port names.

Step 4: Click twice on the **bps A –> B** column heading. This will sort UDP conversations based on traffic flowing from Address A/Port A to Address B/Port B. In the list, Wireshark will view the conversation between 192.168.5.11/port 25426 and 192.158.5.10/port 8000 first.

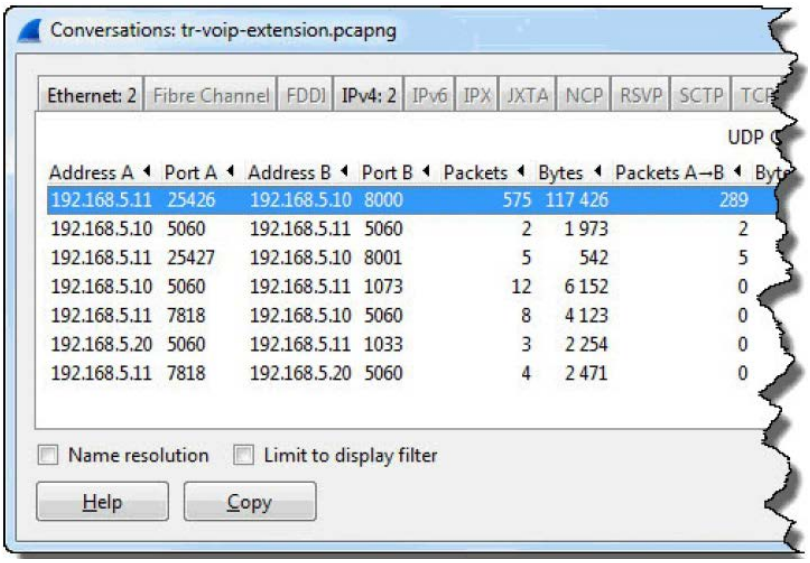


Figure 114.1: Obtain UDP Conversation Statistics and Filter on a UDP Conversation

Step 5: This conversation is also the most active UDP conversation in terms of the Bytes column value. Right–click on this conversation line and choose Apply as **Filter | Selected | A <–> B**.

Step 6: Select File | Export Specified Packets and name your new file ***udpconv1.pcapng*****.** When you are done, clear the display filter and close the Conversations window. Removal of unrelated traffic from view, allows Wireshark to list down statistics related to that traffic set. This makes identification of performance issues easier.

Topic 115: Wireshark Lab 23

This topic describes how to Add/Sort a Delta Time Column in Wireshark.

In Wireshark, the default Time column setting is **Seconds Since Beginning of Capture**. It becomes easier to locate delays when a time column displays delta times. We can locate the largest delays in a trace file by sorting the delta time column.

Step 1: Open ***tr-malaysianairlines.pcapng***

Step 2: Expand the Frame section of any packet.

Step 3: Right-click on the "Time delta from previous captured frame" line and select **Apply as Column**. This will create a **frame.time_delta** column.

Step 4: The new column appears to the left of the Info column. Click and drag it to the right of the existing Time column.

Step 5: Rename the column by right-clicking on the column heading and selecting **Edit Column Details**. Let's change the Title to **Delta**. Click **OK**.

Step 6: Click your new Delta column heading twice to sort from high to low. Go to the first packet. You can see packets with the largest delays at the top of the list.

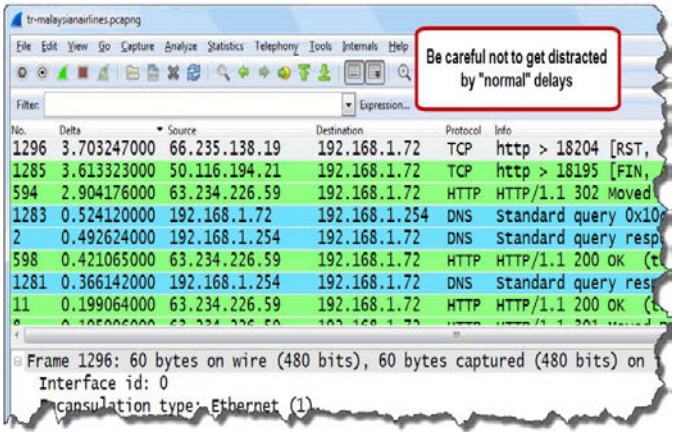


Figure 115.1: Add/Sort a Delta Time Column

In this trace file, delays such as delays before DNS queries, TCP RST packets, or TCP FIN packets are “normal”. We do not care about them. Focus on delays before DNS and HTTP responses.

Topic 116: Wireshark Lab 24

This topic describes how to add/sort a delta displayed time column in Wireshark.

Delays between displayed packets can be identified by using a delta displayed time column. Let’s create such a time column to show the delta times of DNS traffic only.

Step 1: Open ***tr-malaysianairlines.pcapng***.

Step 2: Click the **Preferences** button on the Main Toolbar and then select Columns.

Step 3: Click the **Add** button. In the drop-down “Field Type” list, select ***Delta time displayed***. Click on the column name and update the name to **Delta Displayed**.

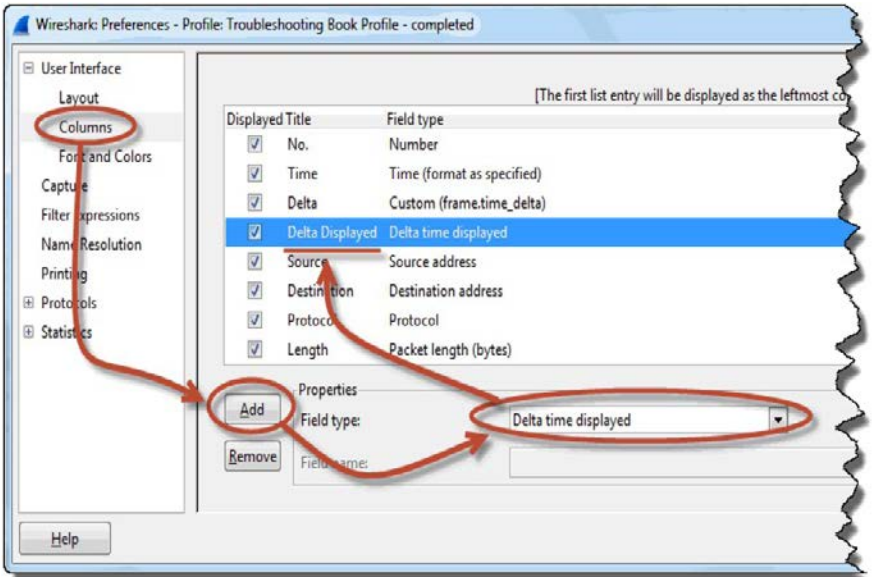
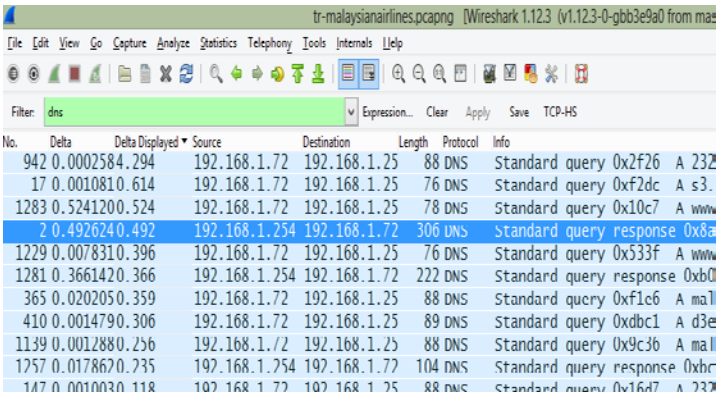


Figure 116.1: Add/Sort a Delta Displayed Time Column

Step 4: Click and drag your **Delta Displayed** column above the "Source" column. Click **OK**. If desired, right click on your newly created column heading to set left alignment.

Step 5: Now apply a filter for DNS traffic. For this purpose, enter **dns** in the display filter area. Click **Apply.**

Step 6: Clicking twice on your new **Delta Displayed** column will sort from high to low. Let's not focus on delays before DNS queries, and care about delays before DNS query responses.



We find that two packets (Packet 2 and Packet 1,281) are really very slow. **Cause for Delays:** If a local DNS server does not have these names in its cache, it needs to perform recursive queries to obtain the data.

Topic 117: Wireshark Lab 25

In this topic, we describe how to plot UDP Delays in Wireshark.

Using Wireshark's Advanced IO Graph with a filter and a reference to the maximum **frame.time_delta_displayed** value, we can have a pictorial idea about the delays in a trace file.

Step 1: Open ***tr-queuing.pcapng***.

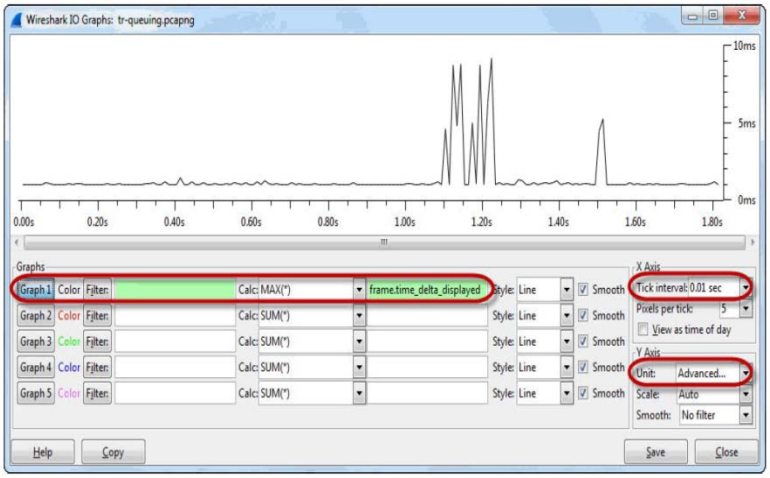
Step 2: Select **Statistics | IO Graph**.

Step 3: In the Y Axis Unit area, select **Advanced...**

Step 4: As this trace file contains less than 2 seconds of traffic. Select **0.01 sec,** in the X Axis Tick Interval area.

Step 5: Select the **MAX(*)** Graph 1 Calc option and enter **frame.time_delta_displayed** in the Calc area.

Step 6: Click the **Graph 1** button to plot the results. If your trace file contains both UDP and TCP-based traffics and you want to plot UDP delays, then enter **udp** in the Graph 1 filter area before you click the Graph 1 button.



There is a sudden increase in the delta time at approx. 1.2 seconds of the trace file. On clicking these points, Wireshark jumps to that point in the trace file and enables to do additional analysis.

Topic 118: Wireshark Lab 26

This topic describes how to obtain TCP conversation statistics in Wireshark.

Transmission Control Protocol (TCP) is a connection-oriented protocol. TCP is a stream based communication. Each separate TCP conversation is numbered by Wireshark with a TCP Stream Index (**tcp.stream**) value starting with 0. Let's find the

most active TCP conversation. If you have a large trace file, you can apply a filter from within Conversations window.

Step 1: Open ***tr-chappellu.pcapng***.

Step 2: Select **Statistics | Conversations** and click the **TCP** tab.

Step 3: Click twice on the **Bytes** column to sort from high to low.

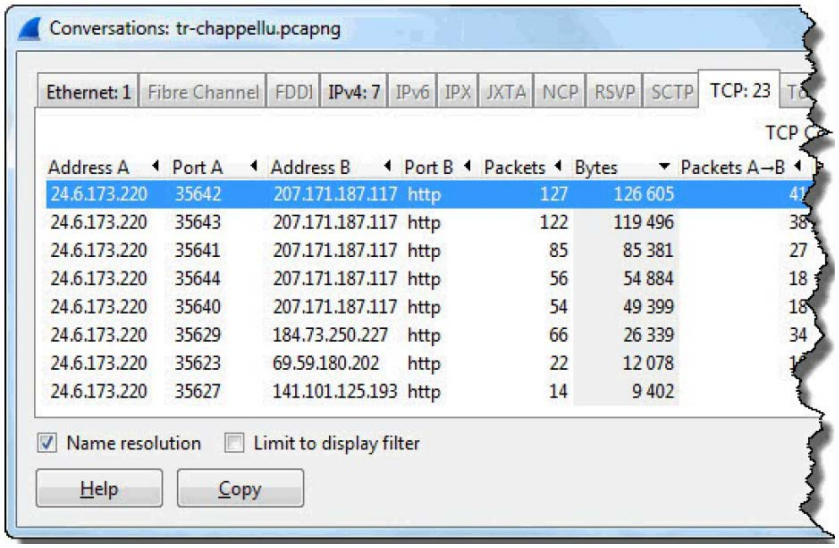
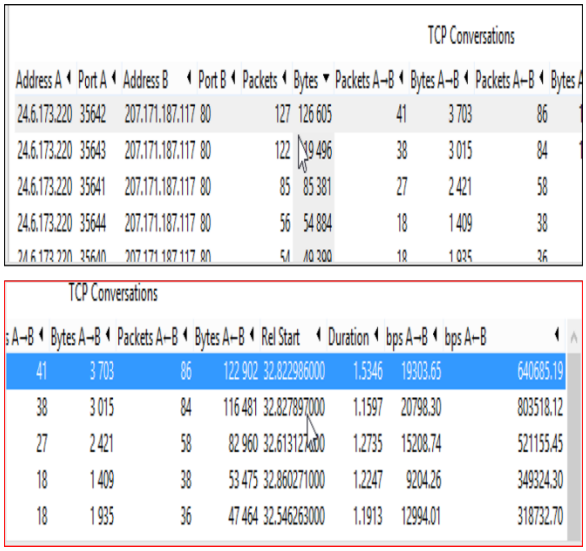
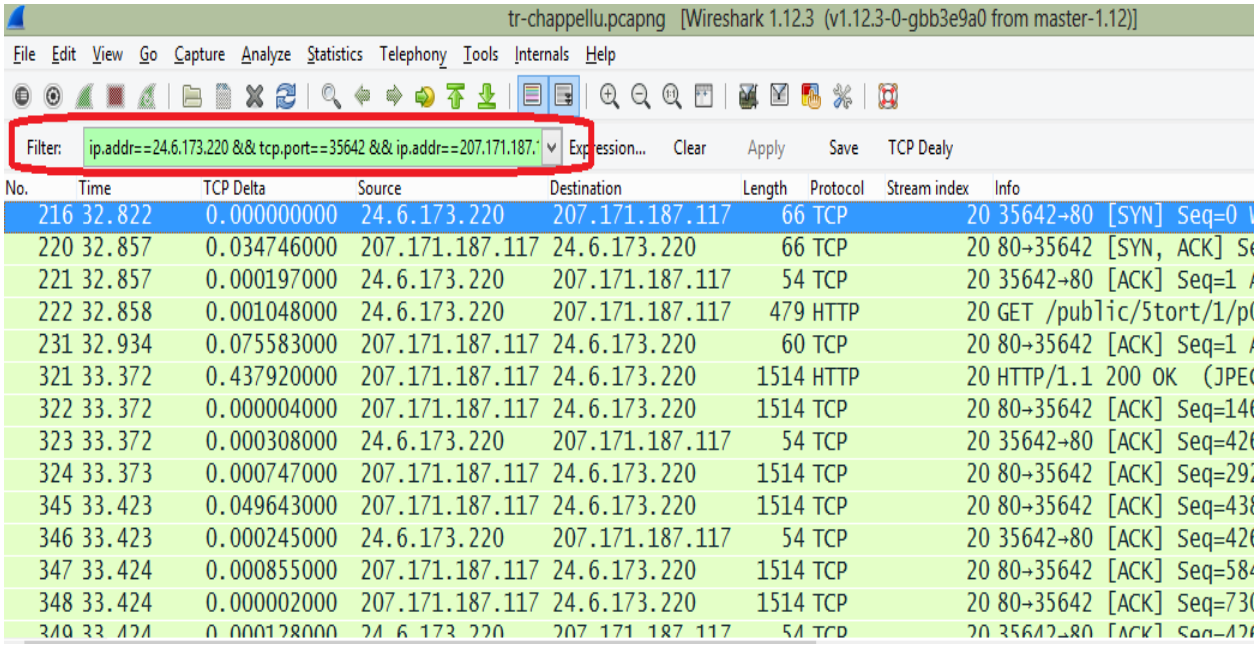


Figure 118.1: Obtain TCP Conversation Statistics

Step 4: Right-click on the top entry and select **Apply as Filter | Selected | A <–> B.** Wireshark creates a filter based on the source/destination address and source/destination port fields.





Step 5: Click **Clear** to remove your filter when you are finished. If there are many TCP conversations contained in your trace file, the method we learnt in this topic can be used to find the most active conversation and then quickly apply a filter on that conversation.

Topic 119: Wireshark Lab 27

In this topic, we describe how to filter TCP conversation with the stream index field in Wireshark.

What is a Stream?

Wireshark assigns each unique TCP connection attempt a separate TCP stream based on the source/destination addresses and source/destination port numbers. Let's create a filter based on the **tcp.stream** field.

Step 1: Open ***tr-chappellu.pcapng***.

Step 2: Expand the TCP header in Packet 59.

Step 3: Right-click on the **[Stream index: 7]** field in the TCP header. Select **Apply as Filter | Selected**.

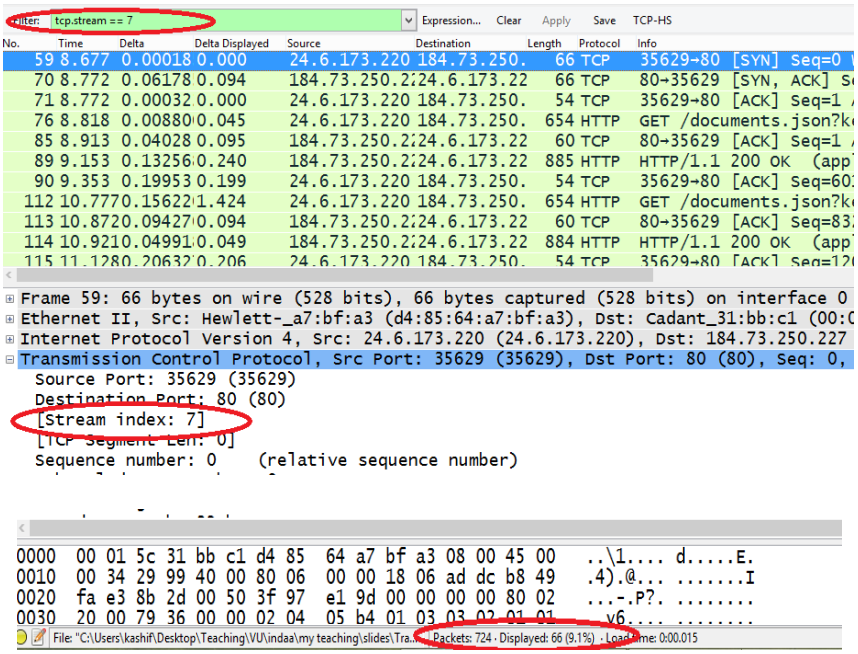


Figure 119.1: Filter on a TCP Conversation Using the Stream Index Field

We can see that Wireshark creates a filter for **tcp.stream==7** in the filter display area and applies it to the trace file. There are 66 packets matching this filter as indicated on the Status Bar. You can save this TCP conversation in a separate trace file. Select **File | Export Specified Packets** and provide a file name.

Step 4: Once you are finished, click **Clear** to remove the filter.

Topic 120: Wireshark Lab 28

This topic shows how to add a TCP stream index column in Wireshark.

There can be numerous TCP conversations in a trace file. Wireshark calls each unique connection attempt a TCP stream. To differentiate the TCP conversations, Wireshark assigns each unique connection attempt a separate TCP stream index based on the source/destination addresses and source/destination port numbers. Wireshark numbers each separate TCP conversation with a TCP Stream Index (**tcp.stream**) value starting with 0. Next, we show that packet, which is part of the first TCP conversation in a trace file.

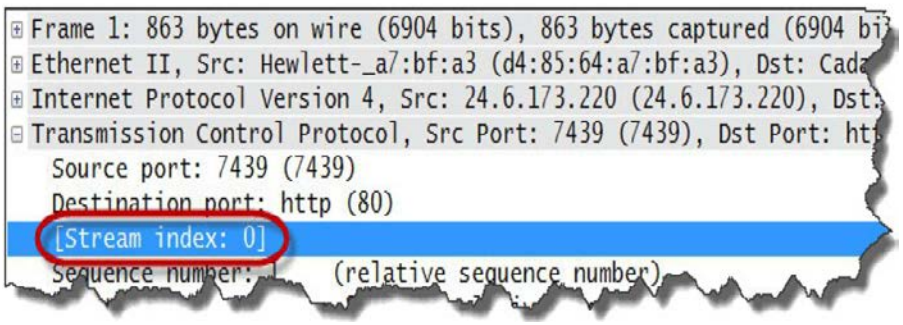
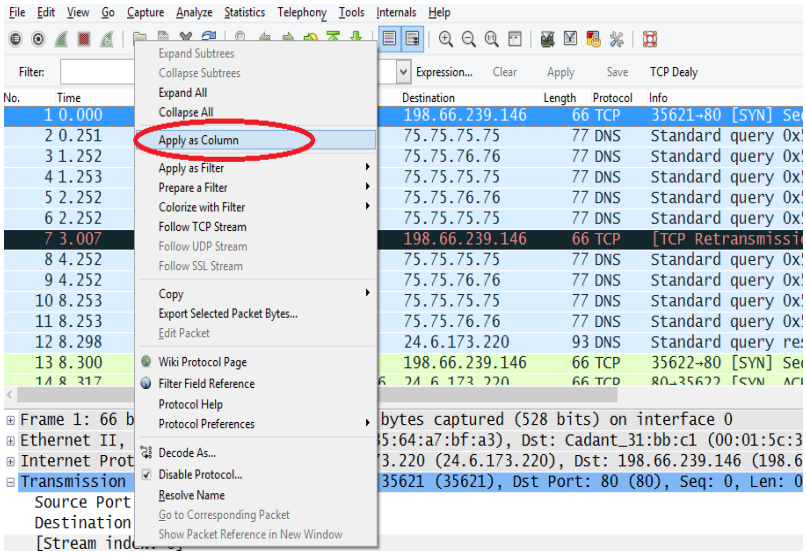


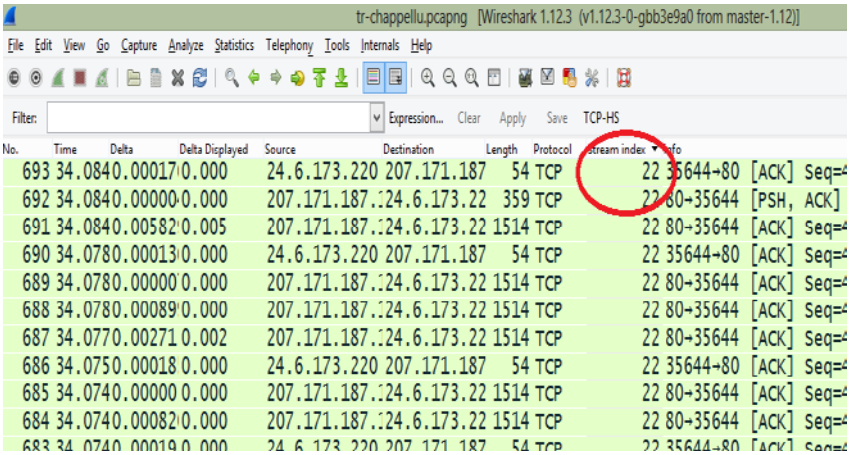
Figure 120.1: Add a TCP Stream Index Column

Step 1: Open ***tr-chappellu.pcapng***.

Step 2: Expand the TCP header in Packet 1. Right-click on the **[Stream index: 0]** line and select **Apply as Column**.



Step 3: Click on your **Stream index** column once to sort the trace file by conversations. Jump to the end of the trace file and you find that there are 23 TCP conversations. Counting TCP streams starts at 0.



Figures and Material used for Part2 (from Topics 121 to 172) have been adapted from "Troubleshooting with Wireshark: Locate the Source of Performance Problems", 2014, by L. Chappell.

Topic 121: Wireshark Lab 29

This topic describes how to add/sort a TCP Delta Time column in Wireshark.

The **tcp.time_delta** shows the time from the end of one packet in a TCP stream to the end of the next packet in that same TCP stream. To add the **tcp.time_delta** column, you must enable the TCP ***Calculate conversation timestamp*** preference. Click the **Preferences** button, expand **Protocols** and choose **TCP**.

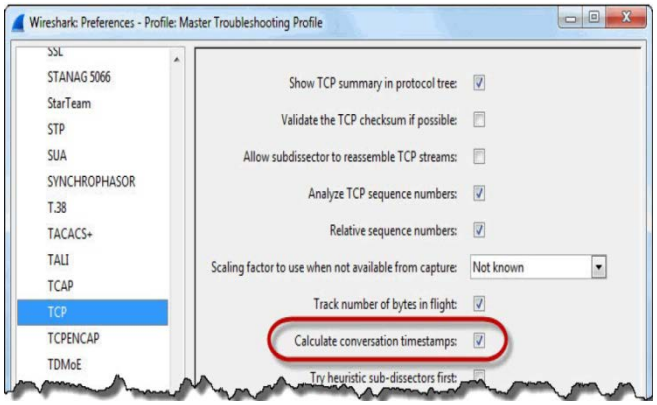


Figure 121.1: Add/Sort a TCP Delta Time Column

Step 1: Open ***tr-chappellu.pcapng***.

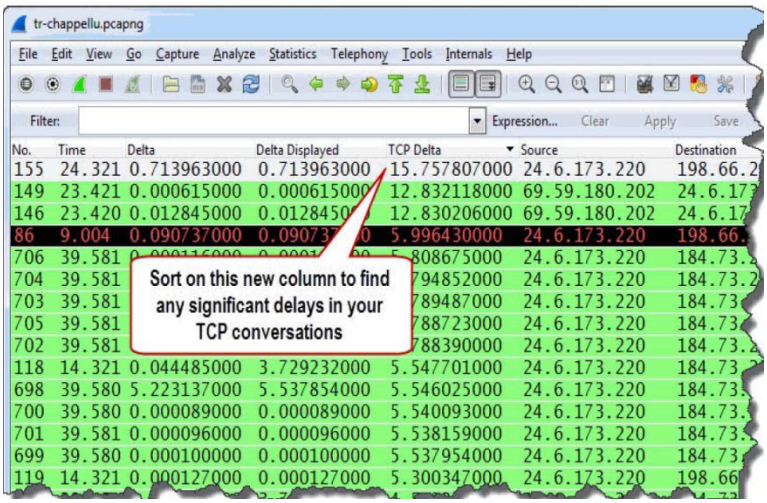
Step 2: Expand the **TCP header** in Packet 1. Right click anywhere on the TCP header, select **Protocol Preferences** and ensure that *Calculate conversation timestamps* is enabled.

Step 3: At the end of the TCP header, go to the **[Timestamps]** section, locate and right-click on the **Time since previous frame in this TCP stream** field. Select **Apply as Column**.

Step 4: The newly created column appears to the left of the Info column. Click and drag your new column to the right of the existing **Delta Displayed** column.

Step 5: Update the column name to **TCP Delta** by right-clicking on the column heading and selecting **Edit Column Details**. Click **OK**.

Step 6: Click the new **TCP Delta** column heading twice to sort from high to low. The packets with the largest delays before them in a TCP conversation appear at the top of the list.



Step 7: Scroll through the packets to determine where delays have incurred in this communication.

Topic 122: Wireshark Lab 30

This topic describes how to add a TCP Delay Button in Wireshark.

Using a “TCP Delay" button (filter expression) will allow us to efficiently locate delays. By pressing button TCP packets that are preceded by a noticeable delay will be displayed.

Step 1: Open ***tr-chappellu.pcapng***.

Step 2: In the display filter area, enter the following filter: **tcp.time_delta > 1**

Step 3: Click the **Save** button on the display filter toolbar. Enter **TCP Delay** as the label when prompted. Click **OK** to save your new button.

Step 4: Click your new **TCP Delay** button. You will find that 37 packets match the filter. There are numerous TCP FIN packets in the list – we do not care about it.

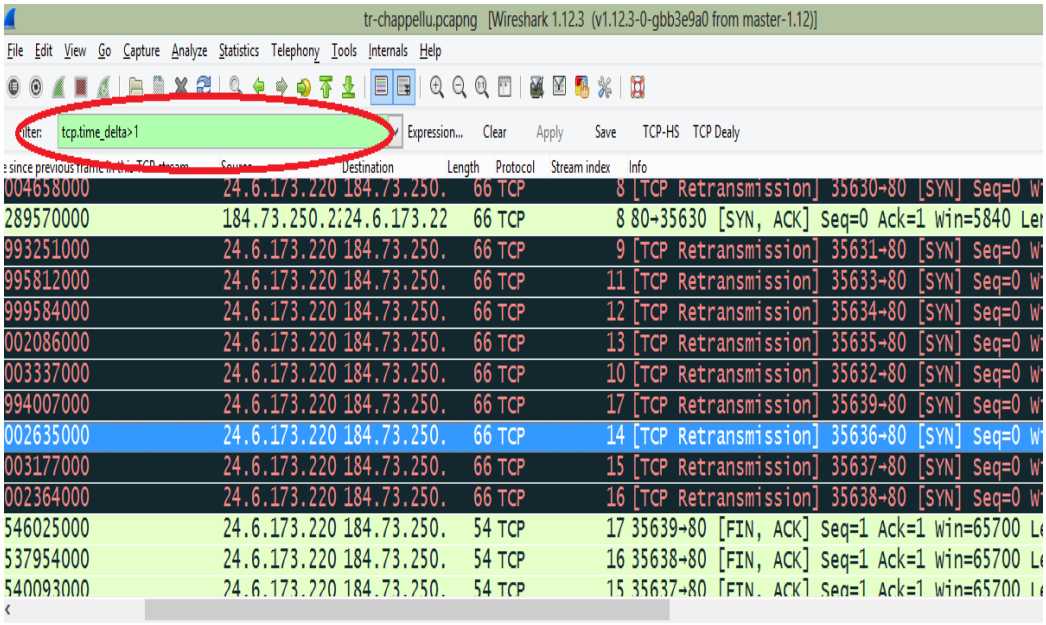
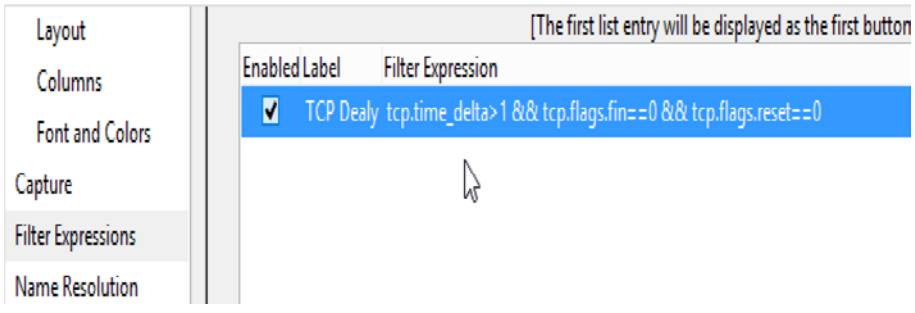
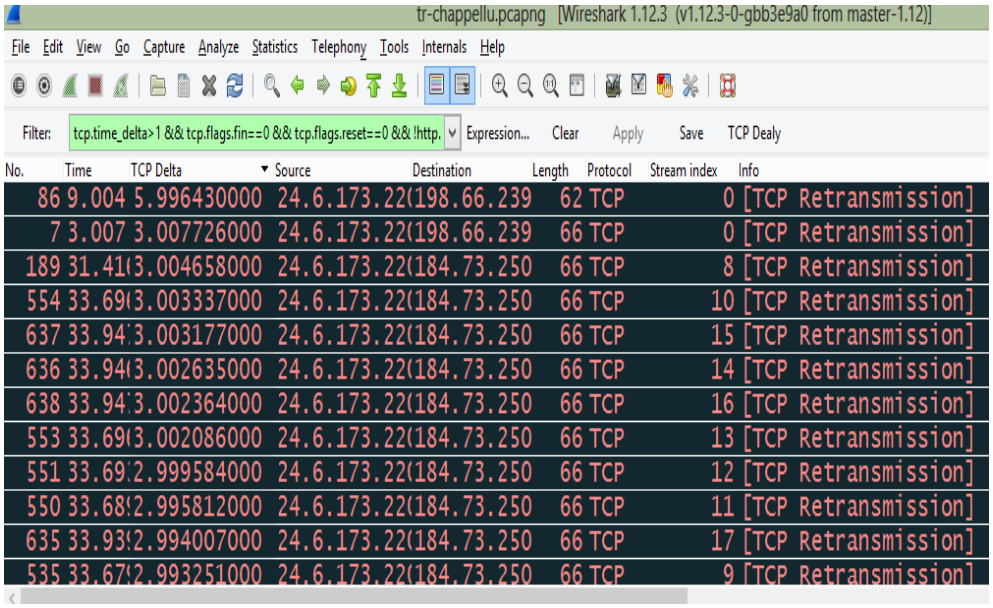


Figure 122.1: Add a "TCP Delay" Button

Step 5: Select **Edit | Preferences | Filter Expressions** , update TCP Delay filter expression to: **tcp.time_delta > 1 && tcp.flags.fin==0 && tcp.flags.reset==0** and then Click **OK**.



Step 6: Click your TCP Delay button again. 23 packets are displayed because TCP FIN and RST packets have been removed. Let's further remove HTTP GET requests from the TCP Delay button. Add the following string to the end of your filter: **&& !http.request.method=="GET".** The highest TCP Delta delay is under 6 seconds and is a SYN retransmission pkt. There are 12 SYN retransmissions between the client and 184.73.250.227. There is one SYN/ACK as the RTT is 1.28957 seconds.



Topic 123: Wireshark Lab 31

This topic discusses how to obtain the round trip time (RTT) using TCP handshake in Wireshark.

A file transfer process will be very slow if RTT is extremely high and everything else is functioning properly. Wireshark allows us to estimate the RTT by looking at the **tcp.time_delta** value. We can capture at client side and look at the **tcp.time_delta** value between the client's TCP SYN packet and the server's TCP SYN/ACK response.

Step 1: Open ***tr-cnn.pcapng***

Step 2: Enter **tcp.flags.syn==1** in the display filter area and then click **Apply**.

Step 3: Click your TCP Delta column heading twice to sort from high to low. We are interested in the delays preceding SYN/ACK packets.

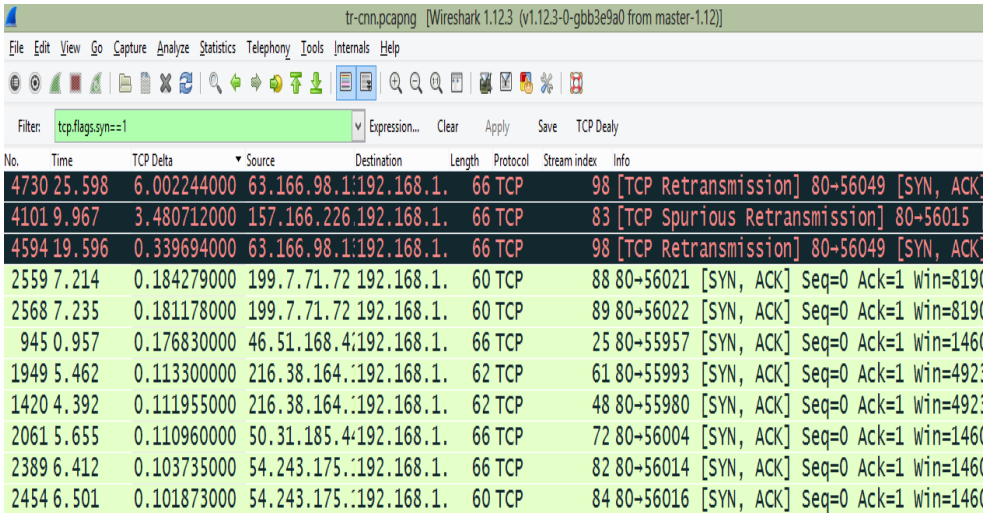


Figure 123.1: Obtain the Round Trip Time (RTT) Using the TCP Handshake

We can see that there are three packets that are marked as Retransmissions. These are because of connection establishment problems. We can also observe at the RTT to various servers.

Topic 124: RTT: Packets 2 and 3 of TCP Handshake

This topic describes how to use Packets 2 & 3 of TCP handshake for obtaining RTT in Wireshark.

Packets 2 and 3 of the TCP handshake can be used to measure the path latency or round trip time (RTT). We need to run a packet capturing tool such as Wireshark on the server host, and look at the **tcp.time_delta** value between the server's TCP SYN/ACK packet and the client's TCP ACK response. The SYN/ACK packet is easy to locate with a display filter, but the ACK (third packet of the handshake) is a bit trickier. The second (the SYN/ACK) packet of the TCP handshake can be detected by applying the filter: **tcp.flags.syn==1 && tcp.flags.ack==1.**

Detection of the third packet of the handshake is difficult. Use the following characteristics:

- **a) tcp.seq==1** (Required) TCP Seq. Number 1 (Relative Seq. Number)
- **b) tcp.ack==1** (Required) TCP Ack. Number 1 (Relative Ack. Number)
- **c) tcp.len > 0** (Optional) data in the third packet of the handshake
- **d) tcp.push==1** (Optional) PUSH bit set

The filter then becomes **(tcp.flags.syn==1 && tcp.flags.ack==1) || (tcp.seq==1 && tcp.ack==1).**

Topic 125: Wireshark Lab 32

This topic obtains the round trip time (RTT) using Display Filters in Wireshark.

Step 1: Open ***tr-chappellu.pcapng***.

Step 2: Enter the filter **tcp.flags.syn==1** in the display filter area and then click **Apply**. You will find that 58 packets match this filter. The first two packets are sent from the client port 35,621. Packet 3 and Packet 4 are the first two packets of a new TCP connection. The TCP Delta column indicates the time from the TCP SYN from port 35,622 and the SYN/ACK to that same port, RTT is about 17 ms.

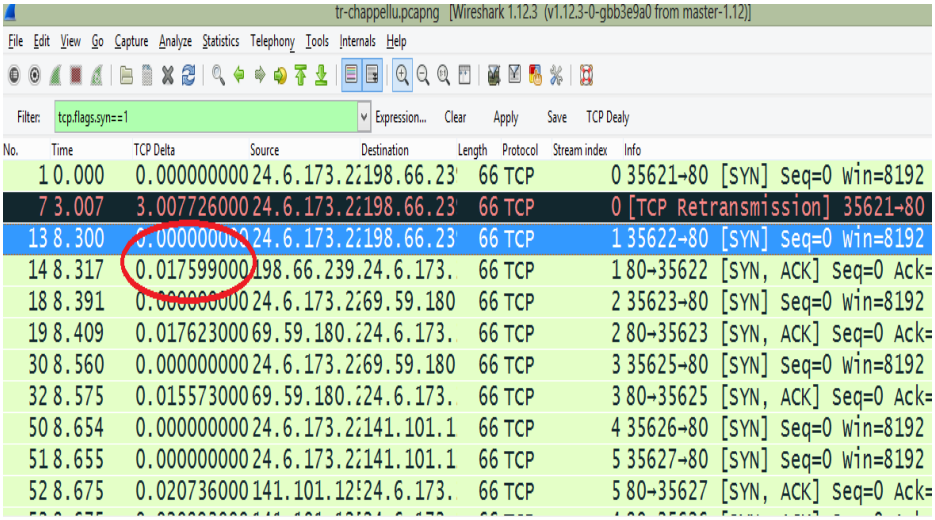
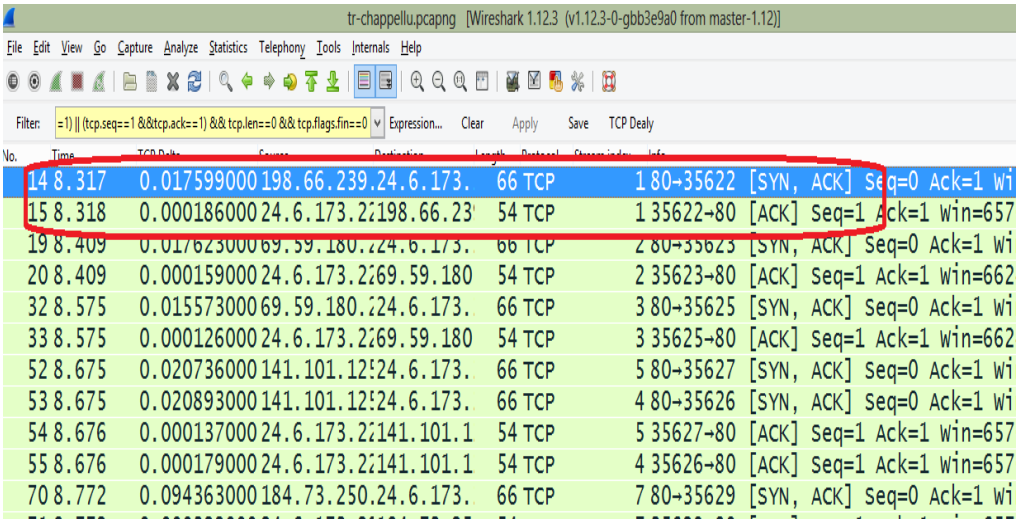


Figure 125.1: Obtain RTT using Display Filters

This trace file, which was captured at the client can be used to locate the second and third packet of the TCP handshake. These packets can be used to determine RTT when capturing at the server.

Step 3: Enter the following filter in the display filter area: **(tcp.flags.syn==1 && tcp.flags.ack==1) || (tcp.seq==1 && tcp.ack==1).** Click **Apply** and let's examine the results. There are 69 packets match this filter. Several packets from this set are not of interest to us.

Step 4: Let's enhance the filter with the following conditions: **(tcp.flags.syn==1 && tcp.flags.ack==1) || (tcp.seq==1 && tcp.ack==1) && tcp.len==0 && tcp.flags.fin==0.** Click **Apply**.



We now see only the SYN/ACK and ACK packets of the handshakes in the trace file. Using the TCP Delta column, we can determine the time between each of these packets in each of TCP conversations. For future use, we can save the filter expressions as buttons so that high path latency can be identified.

Step 5: Click **Clear** to remove the filter.

Topic 126: Wireshark Lab 33

In this topic, we discuss how to plot TCP delays in Wireshark.

Wireshark's advanced IO Graph can be used to plot the maximum **tcp.time_delta** value to locate TCP conversation delays in a trace file.

Step 1: Open ***tr-chappellu.pcapng***.

Step 2: Select **Statistics | IO Graph**.

Step 3: In the Y Axis **Unit** area, select **Advanced...**

Step 4: Select the **MAX(*)** Graph 1 Calc option and enter **tcp.time_delta** in the Calc area.

Step 5: Click the **Graph 1** button to graph your results.

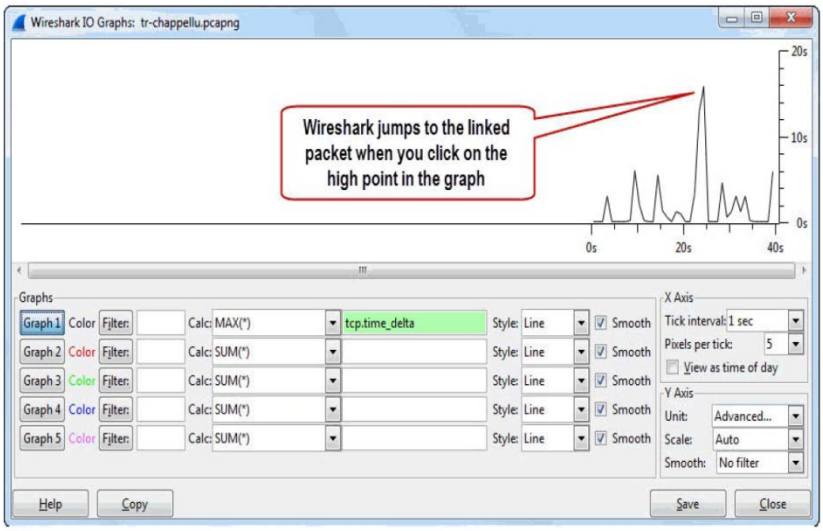
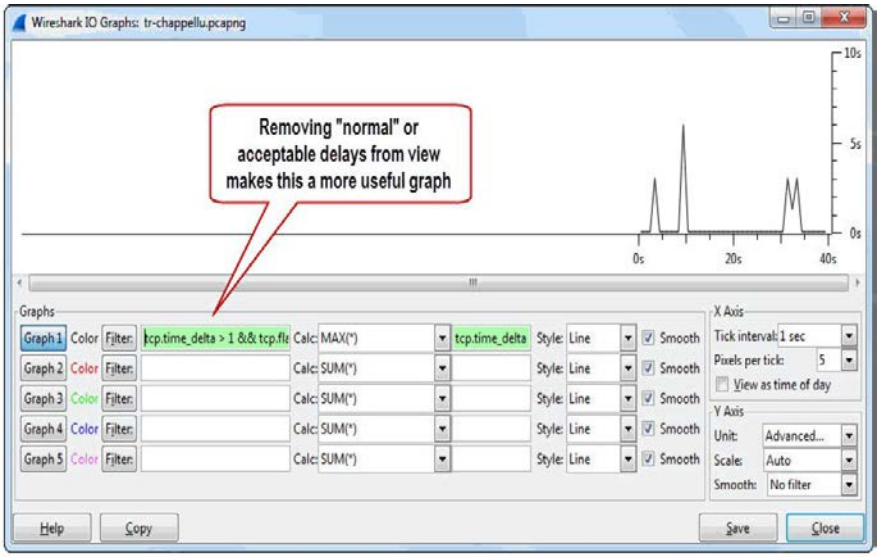


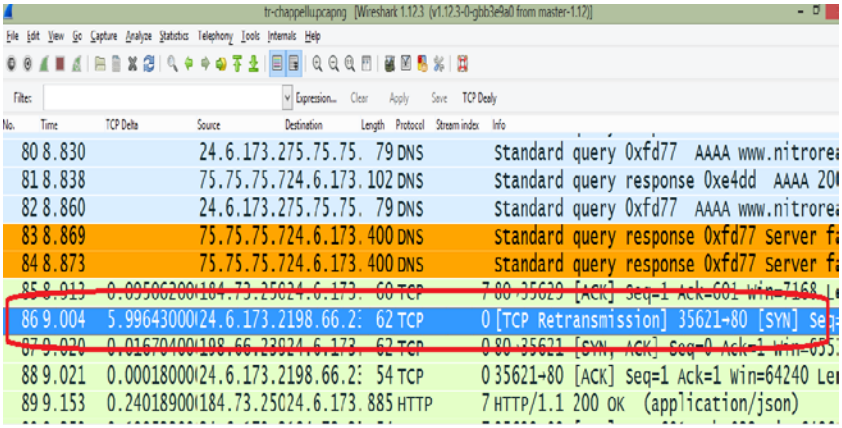
Figure 126.1: Graph TCP Delays

From the graph of this trace file traffic, we can observe that there is a spike in the RTT values around 25 seconds. As you click on this high point in the graph, Wireshark will jump to that packet in the main window. Wireshark takes us to packet number 155. The TCP Delta column value is 15.757807 seconds. This is a TCP FIN. For such a delay, we don't care much. Let's add a filter to remove such normal delays.

Step 6: Enter the following expression in the Filter area of Graph1: **tcp.time_delta > 1 && tcp.flags.fin==0 && tcp.flags.reset==0 && !http.request.method=="GET".** Click the **Graph 1** button again to so that the filter can be applied.



Now when you click on the largest delay point in this graph, Wireshark jumps to Packet 86.



We can see that this is a TCP SYN retransmission packet. It took almost 6 seconds after the previous packet. Thus, indicating a connection request that is not receiving responses.

Topic 127: Wireshark Lab 34

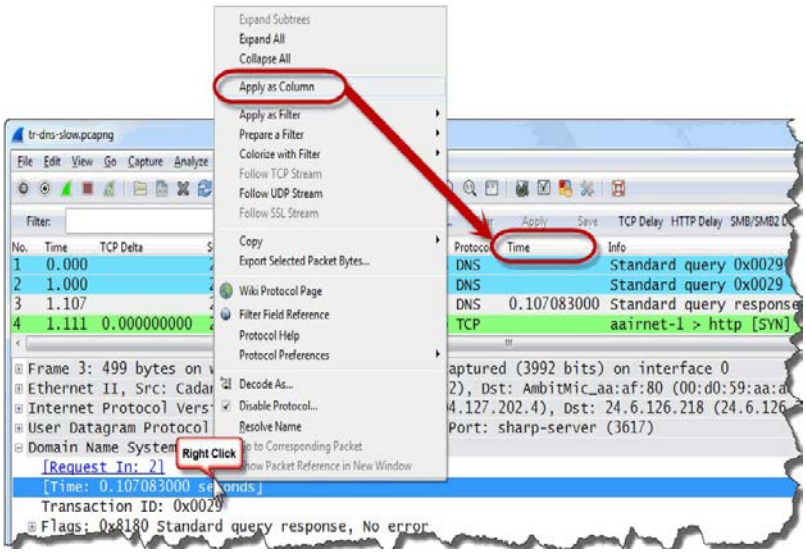
This topic how to find DNS response times in Wireshark.

Domain Name Service (DNS) provides the network IP address of a machine for a network name such as (such as www.wireshark.org). Applications protocols such as SMTP, HTTP generate DNS queries when a user provides a network name to them. DNS, which is a request/response protocol, employs UDP.

Step 1: Open ***tr-dns-slow.pcapng.***

Step 2: The **dns.time** field exists only in DNS response packets. In this trace file, Packet 3 is the first DNS response packet. Let's use this packet to create a **dns.time** column. Expand Packet 3's the **Domain Name System (response)** section.

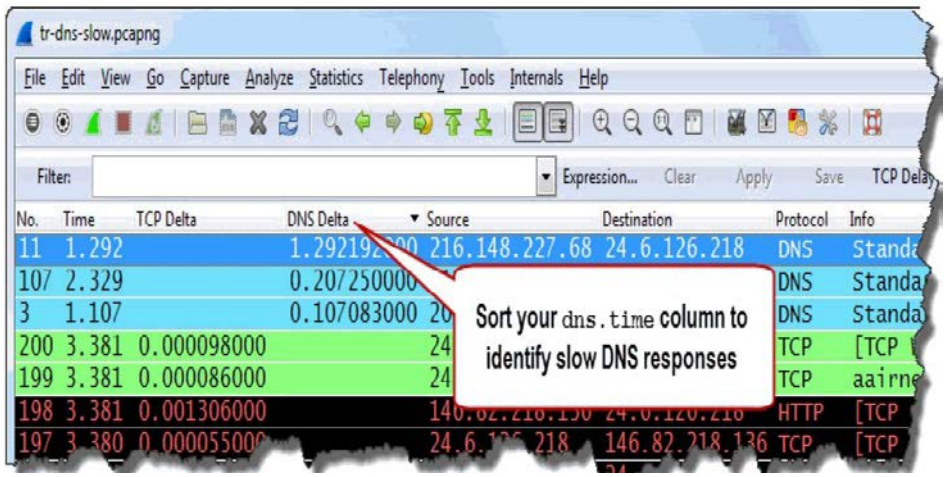
Step 3: Right-click on the **[Time: 0.107083000 seconds]** line and click **Apply as Column**.



Step 4: The newly created column appears to the left of the Info column. You can click and drag your new column to the right of the existing **TCP Delta** column.

Step 5: Right-click on the new column heading and selecting **Edit Column Details**. Rename the new column to **DNS Delta**. Click **OK**.

Step 6: By clicking the new **DNS Delta** column heading twice, it gets sorted from high to low.



A significant delay preceding Packet 11 of this trace file can be observed —almost 1.3 seconds. We need to investigate further to determine why the DNS server is working slowly.

Topic 128: Wireshark Lab 35

This topic describes how to create a Button to detect High DNS response times in Wireshark.

Domain Name System is a distributed database implemented in a hierarchy of many DNS servers. It is an application-layer protocol that allows hosts to query the distributed database and to resolve names (address/name translation). Consider a browser (i.e. an HTTP client) running on some a host A, who requests www.wireshark.org. In order for host A to be able to send an HTTP request message, host A must first obtain IP address of server. The host A runs the client side of the DNS application. The browser extracts the hostname from the URL and passes it to the client side of the DNS application. The DNS client sends a query using UDP to the DNS server listening at port 53. The DNS client eventually receives a reply which includes the IP address for the host name. Once the browser receives the IP address from DNS, it can initiate a TCP connection to the HTTP server process located at port 80 at that IP address.

Let's create a button to detect DNS response times larger than 1 second.

Step 1: Open ***tr-dns-slow.pcapng***.

Step 2: Type **dns.time > 1** in the display filter area and then click **Save**.

Step 3: Name your button **DNS Delay** and click **OK**.

Step 4: Click your new **DNS Delay** button. We observe that Packet 11 is the only packet that matched this filter i.e Packet 11 contains the largest DNS delay time.

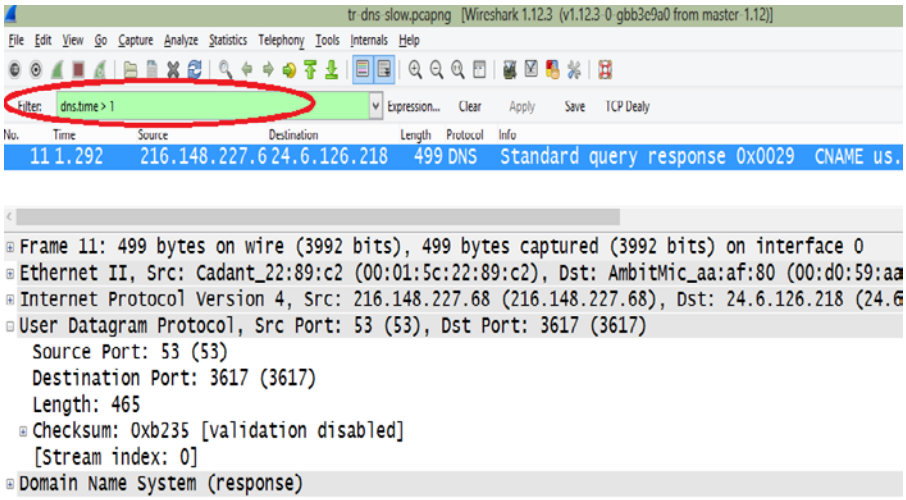


Figure 128.1: Create a Button to Detect High DNS Response Times

Topic 129: Wireshark Lab 36

In this topic, we describe how to plot DNS response times in Wireshark.

To highlight DNS delays in a trace file, let's create a graph.

Step 1: Open ***tr-dns-slow.pcapng***.

Step 2: Select **Statistics | IO Graph**.

Step 3: In the Y Axis Unit area, select **Advanced...**

Step 4: Select the **MAX(*)** Graph 1 Calc option and enter **dns.time** in the Calc area.

Step 5: Click the **Graph 1** button to plot results.

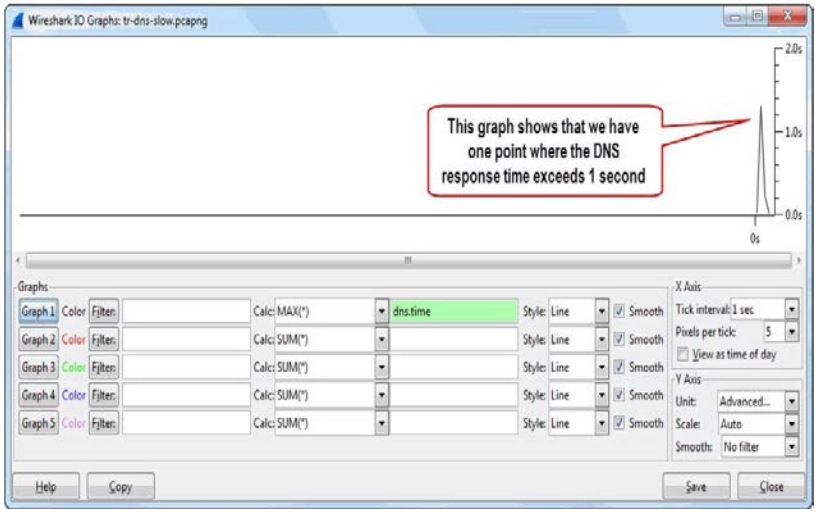
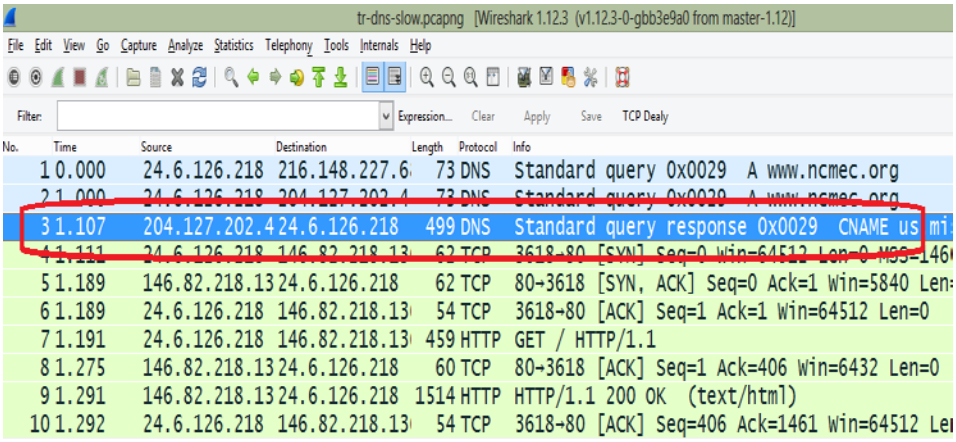


Figure 129.1: Graph DNS Response Times

Step 6: Click the highest point in the graph. Wireshark takes us to that packet.



We can see it is packet 3. It is a DNS query response packet has caused the largest delay. Sorting **dns.time** column can help us to detect delays more quickly.

Topic 130: Wireshark Lab 37

This topic discusses how to reassemble TCP streams by disabling the Allow Subdissector in Wireshark.

The delta time between an HTTP request (e.g. GET) and the response (e.g. 200 OK) is the HTTP response time. In Wireshark, HTTP response time can be estimated with **http.time** field. If a web server is overloaded with the connection, or requests, or needs to consult another server to answer client's requests. This can result in high HTTP response times. If enabled, Wireshark measures time from HTTP Request to the final data packet of the response. If you want to estimate the total time taken by downloading an object, then enable this setting. By disabling it, we can learn how quickly the server responded. There are two methods to change this TCP preference setting.

Step 1: Open ***tr-http-pcaprnet101.pcapng***.

Step 2: Right-click on the **TCP header** in the Packet Details of Packet 5. Select **Protocol Preferences.** Then, uncheck ***Allow subdissector to reassemble TCP streams***.

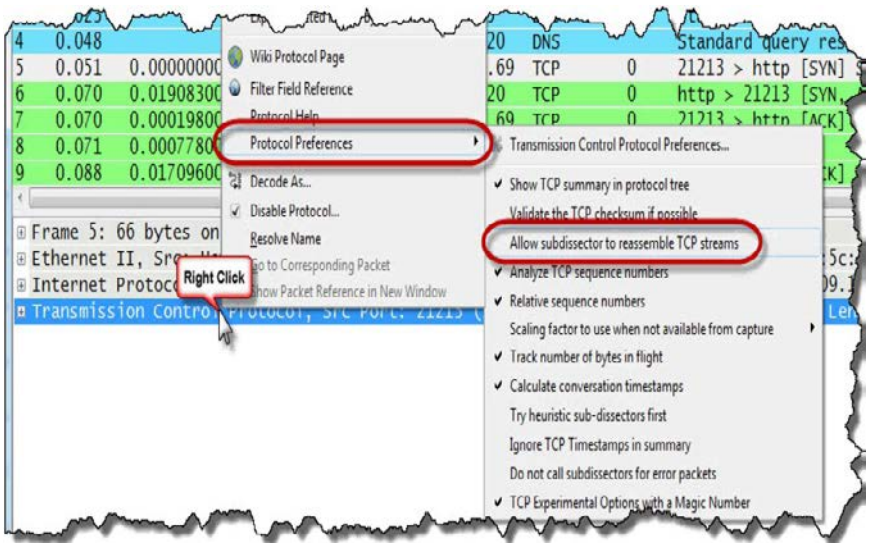
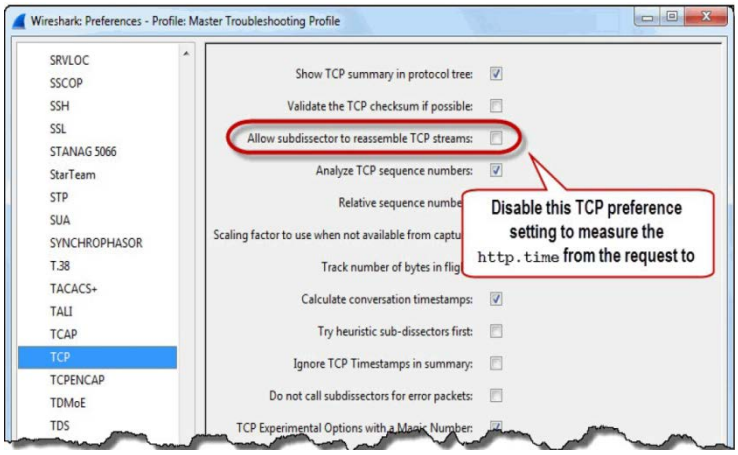


Figure 130.1: Disable the *Allow Subdissector to Reassemble TCP Streams* Preference Setting

Step 3: The 2nd method is: Select **Edit | Preferences | (+) Protocols | TCP**.



Topic 131: Wireshark Lab 38

This topic describes how to locate HTTP response times in Wireshark.

Step 1: Open ***tr-http-pcaprnet101.pcapng***.

Step 2: Only the HTTP response packets contain the **http.time** field. In this trace file, the first HTTP response packet is Packet 10 (HTTP 303 See Other).

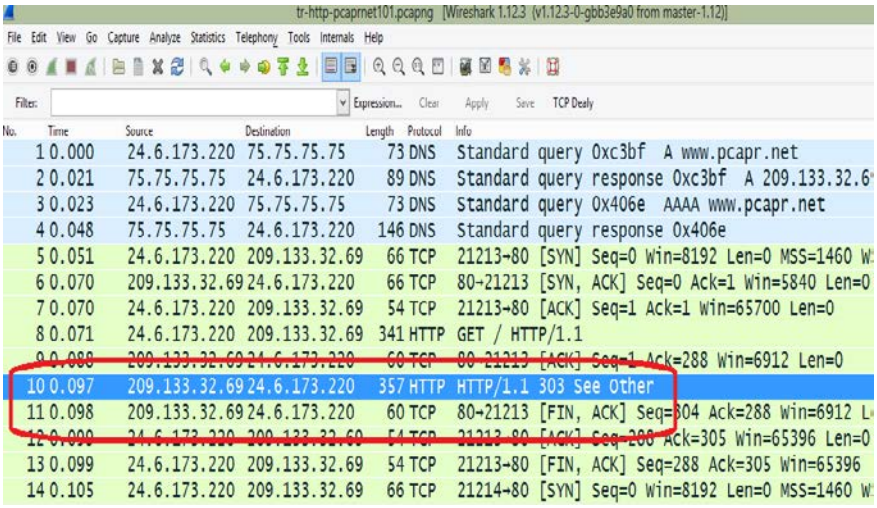


Figure 131.1: Add/Sort an HTTP Response Time Column to Find HTTP Response Times

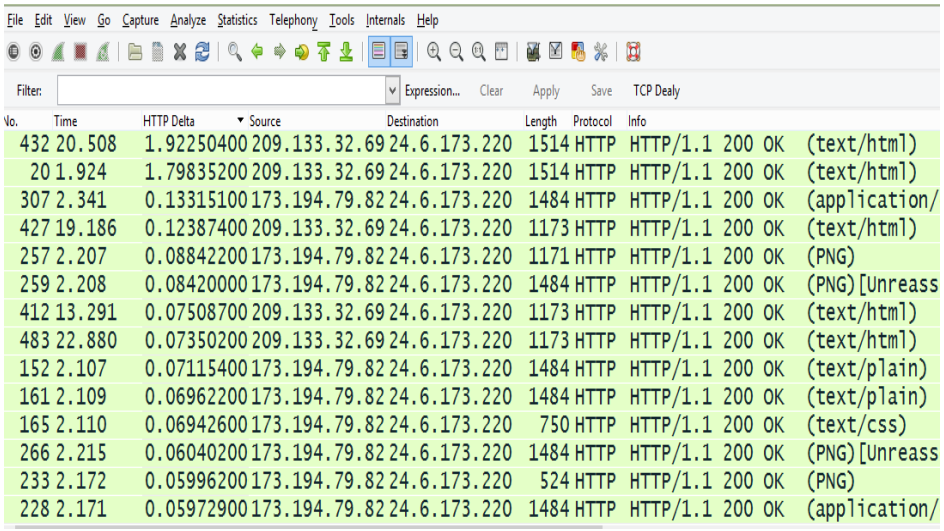
Let's use this packet to create our **http.time** column. In the Packet Details pane of Packet 10, right-click on the **Hypertext Transfer Protocol** section and select **Expand Subtrees.**

Step 3: Locate the **[Time since request: 0.026416000 seconds]** line and right-click on it and select **Apply as Column**.

Step 4: Your newly created column appears to the left of the Info column. Click and drag your new column to a place with better visibility.

Step 5: Right-click on the column heading and select **Edit Column Details**. Rename this new column to **HTTP Delta**. Click **OK**.

Step 6: Sort HTTP responses from high to low by clicking your new **HTTP Delta** column heading twice. Packets with the largest delays will appear at the top of the list.



We can observe that HTTP response time from the HTTP server (209.133.32.69) is over 1.7 seconds twice in this trace file. Those packets are bearing numbers 432 and 20.

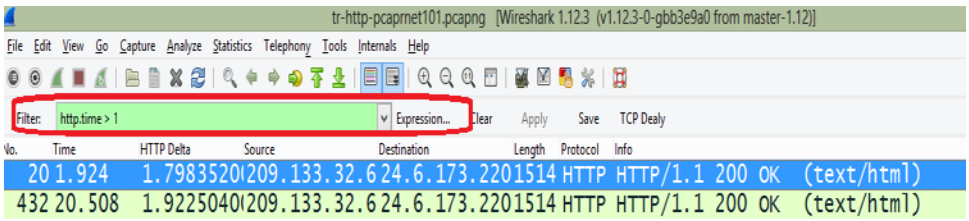
Topic 132: Wireshark Lab 39

In this topic, we create a button to quickly detect high HTTP response times in Wireshark.

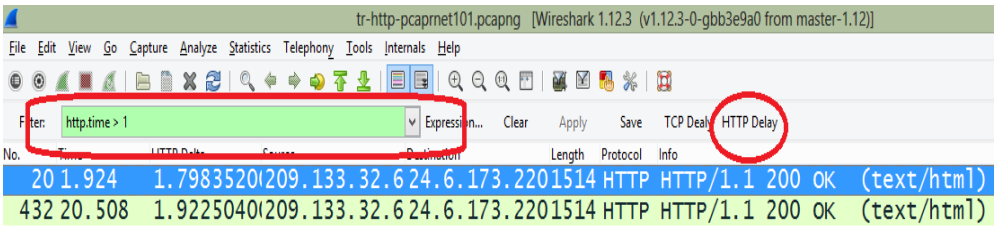
Wireshark allows us to create buttons based on filter expressions. It is one of the most powerful features to improve your efficiency in locating network problems.

Step 1: Open ***tr-http-pcaprnet101.pcapng***.

Step 2: Type **http.time > 1** in the display filter area and then, click **Save**.



Step 3: When you click **save**, Wireshark prompts to name the button. Name it **HTTP Delay** and then click **OK**.



Always remember to clear your display filter when you are done reviewing the results.

Step 4: As you click your new **HTTP Delay** button, you will find two packets of this trace file matching the filter—Packet 20 and Packet 432.

Topic 133: Wireshark Lab 40

In this topic, we plot HTTP response times in Wireshark.

Wireshark allows a user to define up to five differently colored graphs. We can make the following configurations:

Graphs

- **Graph 1-5:** enable the specific graph 1-5 (only graph 1 is enabled by default).
- **Color:** (cannot be changed)
- **Filter:** a display filter for this graph
- **Style:**(Line/Impulse/FBar/Dot)

X Axis

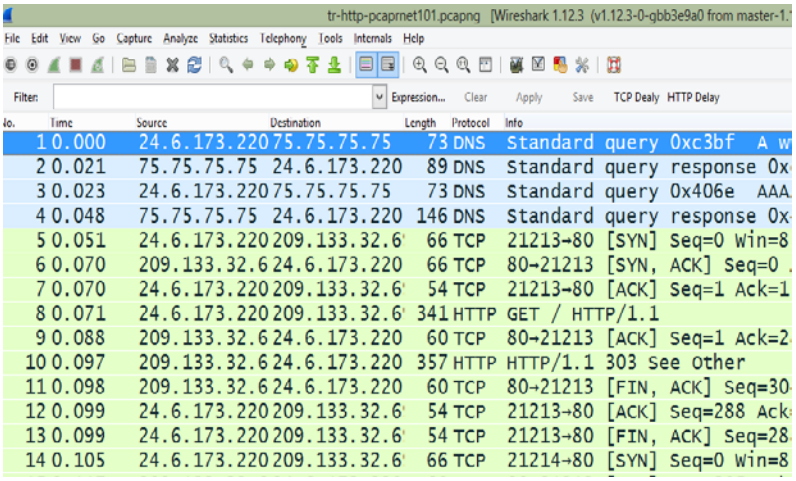
- **Tick interval:** an interval in x direction lasts (10/1 mins or 10/1/0.1/0.01/0.001s)
- **Pixels per tick:** use 10/5/2/1 pixels per tick interval
- **View as time of day:** instead of sec or mins, view x as time of day

Y Axis

- **Unit:** the unit for y direction (Packets/Tick, Bytes/Tick, Bits/Tick, Advanced…)
- **Scale:** the scale for the y unit (Logarithmic,Auto,10,20,50,100,200,500,…)

Let's Graph HTTP Response Times.

Step 1: Open ***tr-http-pcaprnet101.pcapng***.

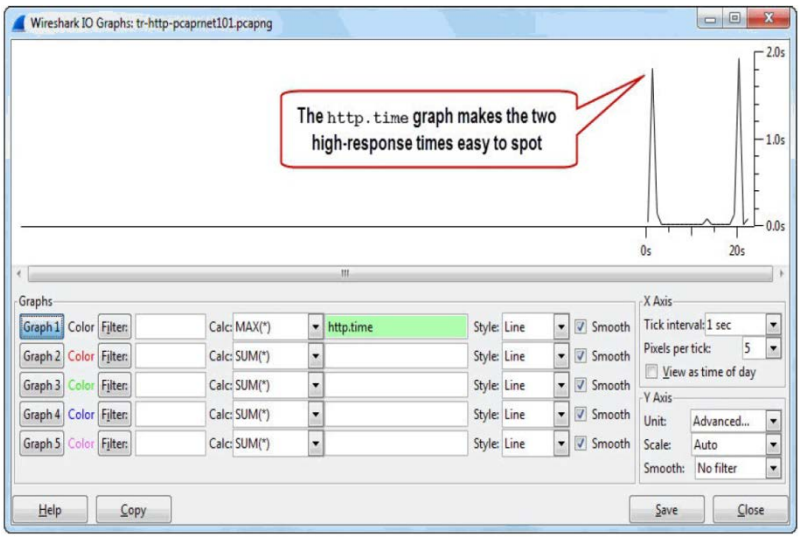


Step 2: Select **Statistics | IO Graph**.

Step 3: In the Y Axis Unit area, select **Advanced...**

Step 4: Select the **MAX(*)** Graph 1 Calc option and then, enter **http.time** in the Calc area.

Step 5: To plot your results, click the **Graph 1** button.



If you click the highest points in the graph, Wireshark will take you to those packets which have encountered highest delays. Packet 20 and Packet 432 show that the HTTP response time from the HTTP server (209.133.32.69) was over 1.7 seconds

Topic 134: Wireshark Lab 41

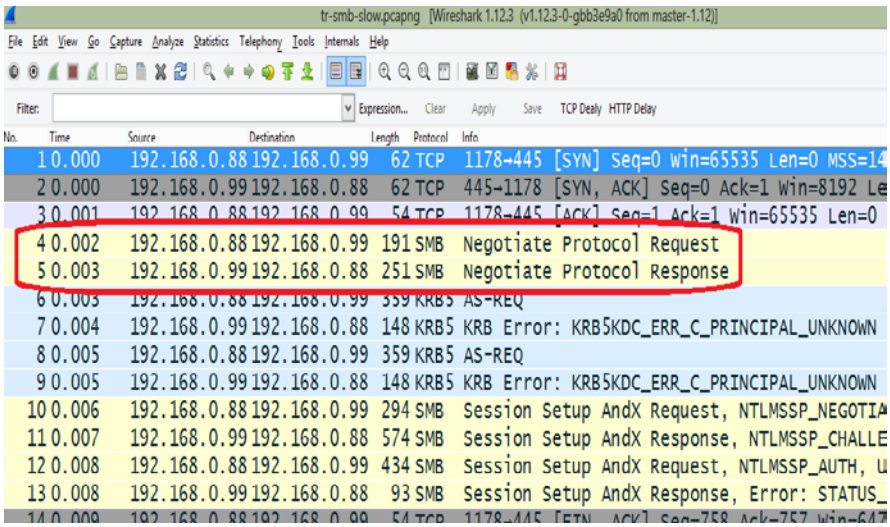
In this topic, we add Server Message Block (SMB) response time column in Wireshark.

What is a Server Message Block (SMB)?

On Windows-based networks, Microsoft employs a file sharing protocol called Server Message Block (SMB). SMB and SMB version 2 are the two versions that are commonly employed on Windows-based networks. SMB is a request/response protocol. Its response codes are available on Microsoft's Open Specification site www.microsoft.com/openspecifications/. SMB delays can be estimated by looking at the **smb.time** field in the SMB response packets.

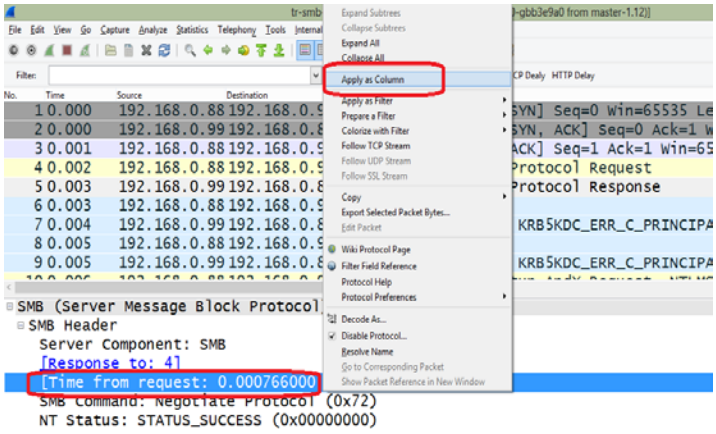
Step 1: Open ***tr-smb-slow.pcapng***.

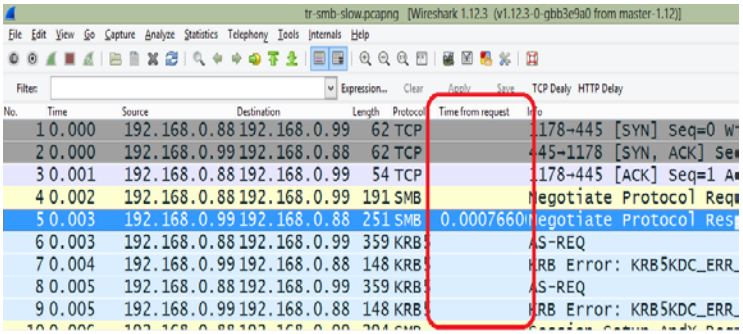
Step 2: The first SMB response packet is Packet 5 (Negotiate Protocol Response).



The **smb.time** field exists only in SMB response packets. Let's use packet 5 to create a **smb.time** column. Expand the **SMB** section and the **SMB Header** section of Packet 5 in the Packet Details pane.

Step 3: Right-click on the **[Time from request: 0.000766000 seconds]** line and click **Apply as Column**.

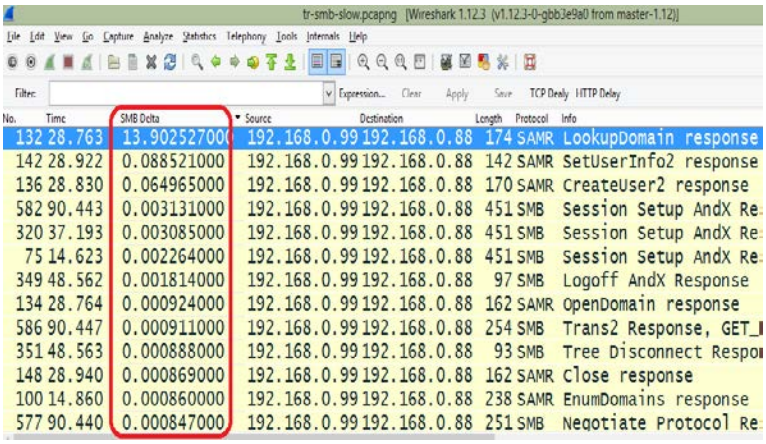




Step 4: The newly created column appears to the left of the Info column. Click and drag your new column to a suitable location where visibility is much better.

Step 5: Wireshark assigned the new **smb.time** column the label *Time from request*. On column heading click right and then, select **Edit Column Details**. Rename it's title to **SMB Delta**. Click **OK**.

Step 6: To examine the SMB response packets with the largest delays, click the newly created **SMB Delta** column heading twice. This will sort packets from high to low.

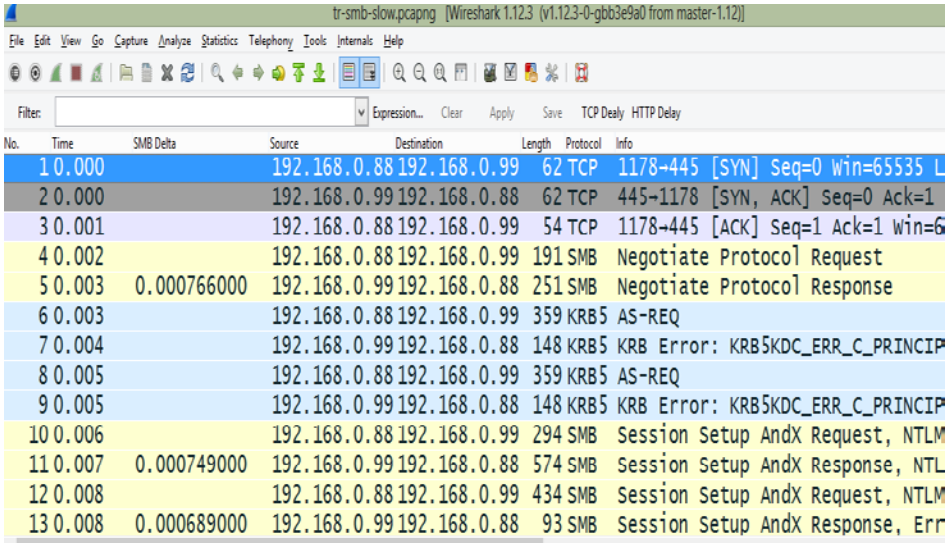


Topic 135: Wireshark Lab 42

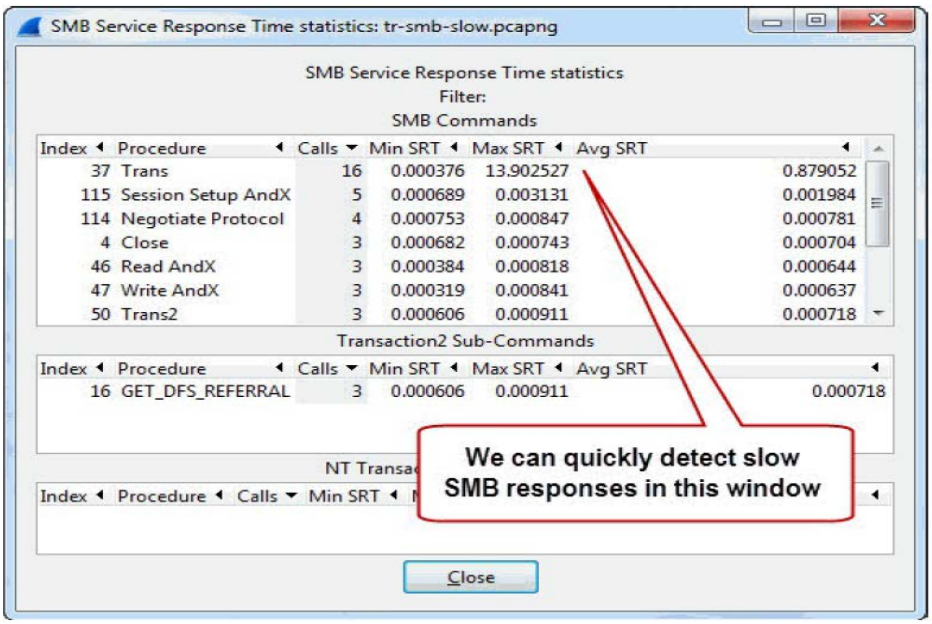
In this topic, we examine Server Message Block (SMB) statistics in Wireshark.

Service response times, including SMB and SMB2 response times are created and tracked by Wireshark.

Step 1: Open ***tr-smb-slow.pcapng***.



Step 2: Select **Statistics | Service Response Time | SMB.** As Wireshark prompts you, Click **Create Stat**. For a trace file, the SMB Service Response Time statistics window shows the minimum, maximum and average Service Response Time (SRT).



This SMB Service Response Time statistics window provides a list of all the request procedures.

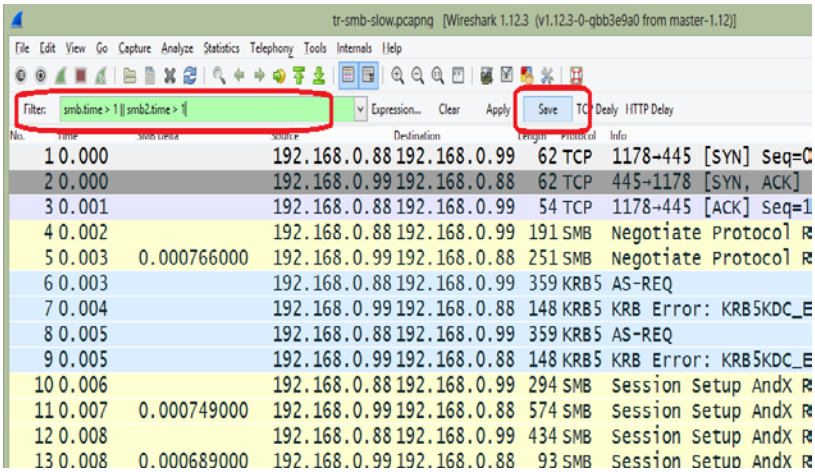
Topic 136: Wireshark Lab 43

In this topic, we create a button to detect Server Message Block (SMB) Response Times in Wireshark.

In Wireshark, SMB and SMB2 response times can be estimated by using **smb.time** and **smb2.time.** Let's learn how to create a button to detect SMB and SMB2 response times larger than 1 second.

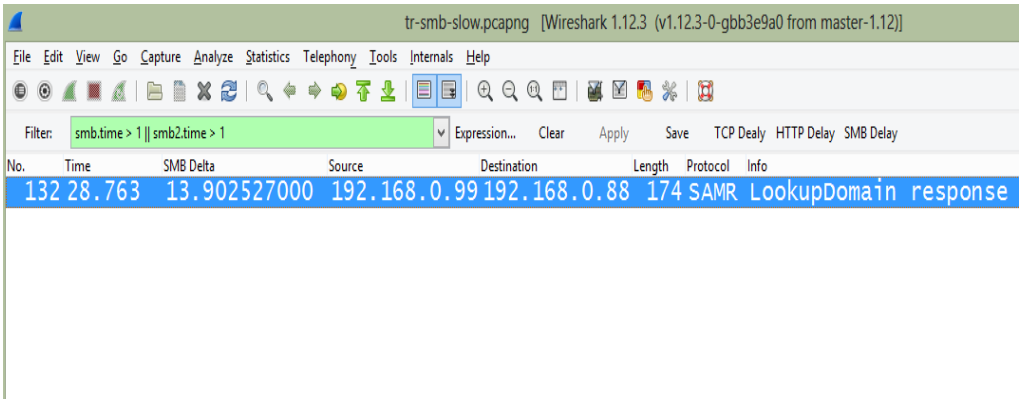
Step 1: Open ***tr-smb-slow.pcapng***.

Step 2: Type **smb.time > 1 || smb2.time > 1** in the display filter area. Click **Save**.



Step 3: You can name your button **SMB/SMB2 Delay** and then, click **OK**.

Step 4: Click your newly created **SMB Delay** button. We find that Packet 132 is the only packet that matched your filter.



Topic 137: Wireshark Lab 44

This topic plots Server Message Block (SMB) Response Times in Wireshark.

Let's learn how to plot SMB response times in Wireshark.

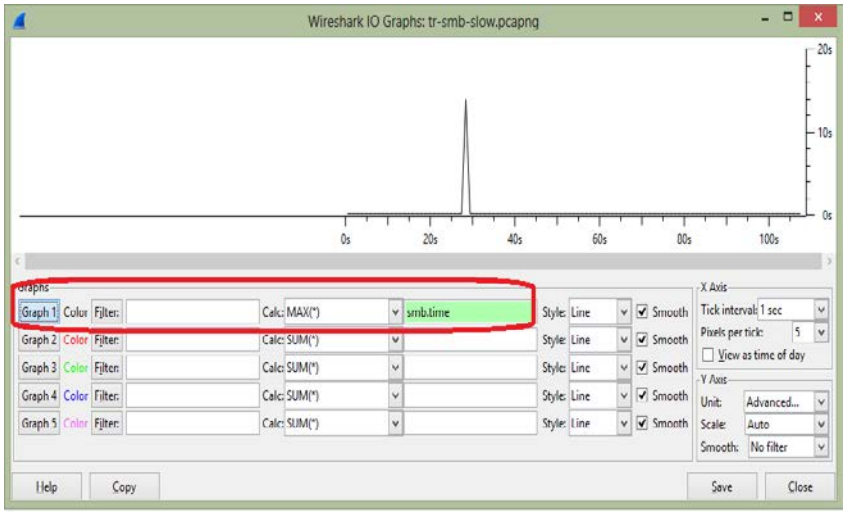
Step 1: Open ***tr-smb-slow.pcapng***.

Step 2: Select **Statistics | IO Graph.**

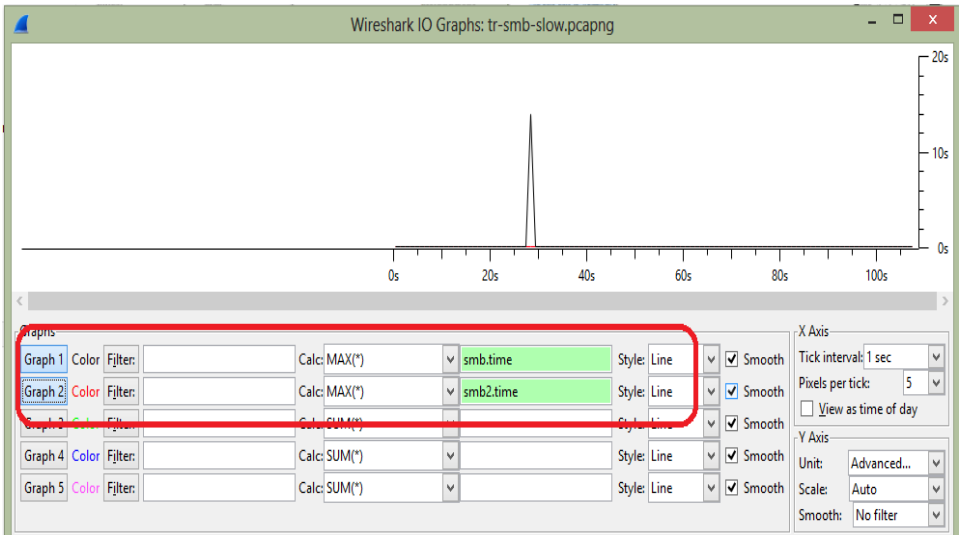
Step 3: In the Y Axis **Unit** area, select **Advanced...**

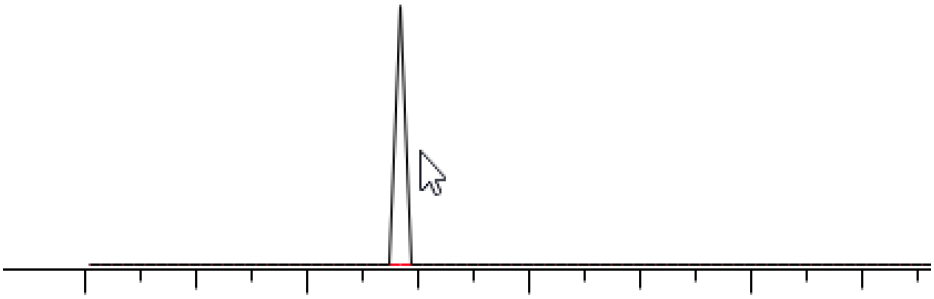
Step 4: Select the **MAX(*)** Graph 1 Calc option and enter **smb.time** in the Calc area.

Step 5: Click the **Graph 1** button to plot the SMB response times.



Step 6: Since SMB and SMB2 use different time fields, we have to create two graphs; one for each delta time.





Step 7: As you click on the highest points in the graph, Wireshark will jump to those packets in the main window for further analysis.

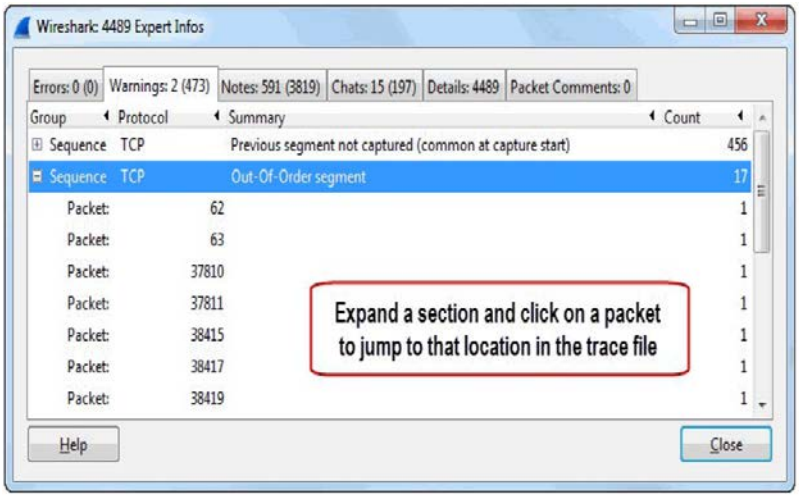
Topic 138: Wireshark's Expert Infos System

This topic provides an overview of Wireshark's Expert Infos System.

There are two buttons and three columns in Wireshark's Status Bar. The first button is named the **Expert Infos** button. Wireshark generates alerts for you to numerous network concerns seen in the trace file as well as packet comments in the Expert Infos window. Expert infos are only a hint and help both novice and expert users to find probable network problems a lot faster, compared to scanning the packet list "manually". The Expert classifies information into 6 categories:

- Errors: red
- Warnings: yellow
- Notes: cyan
- Chats: blue
- Details: grey
- Packet Comments: green

When you click the **Expert Infos** button in the bottom left corner of the Status Bar, the Expert Infos window will open.



If we understand the causes of the errors, warnings, and notes, then this will help us to figure out what is affecting the network performance. We next look at examples of various commonly occurring Expert warnings, notes, and chats.

Chats: information about usual workflow: e.g. a TCP packet with the SYN flag set

Notes: notable things: e.g. an application returned an "usual" error code like HTTP 404

Warnings: e.g. application returned an "unusual" error code like a connection problem.

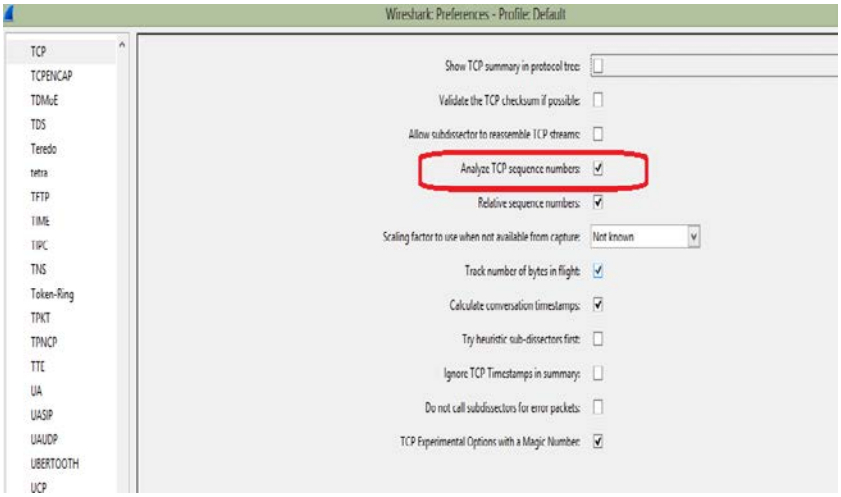
Topic 139: Wireshark's Packet Loss Detection

This topic provides an overview of Wireshark's Packet loss detection process.

Most of the time packets are dropped by interconnecting devices such as a switch, a router, a firewall i.e. anything that makes forwarding decisions.

What Causes Packet Loss: The common reasons are a switch or router is overloaded. It is unable to keep up with the required packet forwarding rate. The device is simply faulty.

How Wireshark's detects Packet Loss: The TCP sequencing process is used by Wireshark to detect lost packets. You can also turn off this feature by disabling the ***Analyze TCP Sequence Numbers*** TCP Preference setting. Click the Preferences button, then expand **Protocols** and choose **TCP**.



Wireshark creates a value called *nextseq* (displayed in the Next Sequence Number field). Its value is determined by adding together the Sequence Number field value of each packet to the number of data bytes in it. Therefore, the next expected sequence number from the sender is available in *nextseq*. Wireshark assumes that one or more packets have been lost when it sees sequence number jump beyond the *nextseq* value.

Topic 140: Packet Loss Recovery Methods

In this topic, we understand Fast Recovery and Retransmission Timeout (RTO) methods for Packet loss. An Internet application developer has two choices for the transport layer protocol: Transmission Control Protocol (TCP), or User Datagram Protocol (UDP). TCP provides a packet loss recovery mechanism while UDP does not. Based on this feature, there are applications which can and which cannot tolerate data loss. File transfer, e-mail, and Web documents, instant messaging are examples of those applications which cannot tolerate loss. Loss-tolerant apps include real-time audio/video, stored audio/video, and interactive games.

Packet Loss Recovery Method #1—Fast Recovery

This method can be used only if the receiver supports Fast Recovery. In this method, when the receiver observes a jump in the sequence number value, it will immediately begin sending Duplicate Acknowledgments. Upon receipt of four identical ACKs (the original and three Duplicate ACKs), the sender will retransmit the packet that has been lost.

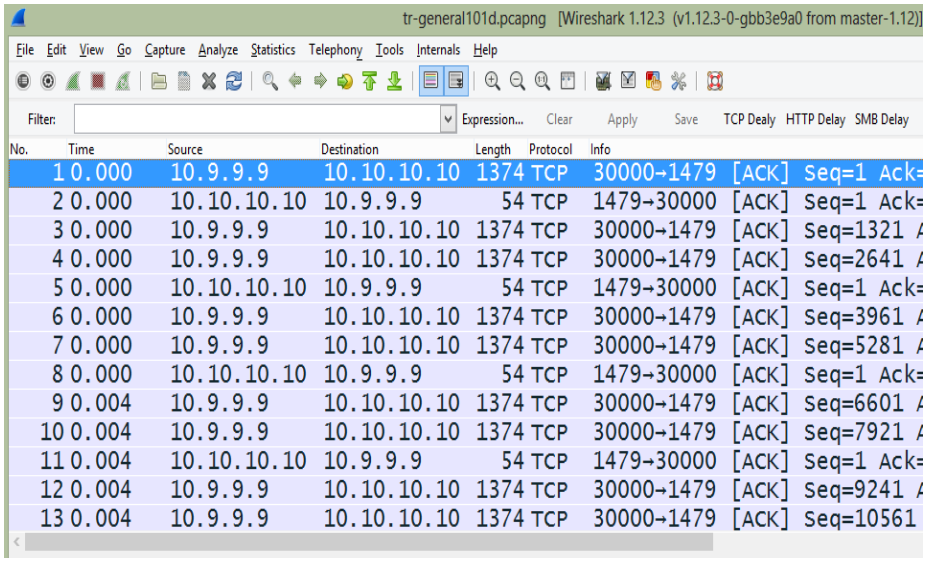
Packet Loss Recovery Method #2—Sender Retransmission Timeout (RTO)

In this method, a sender maintains a timer for a packet. If the packet has not been acknowledged within Retransmission Timeout (RTO) value, the sender retransmits the packet.

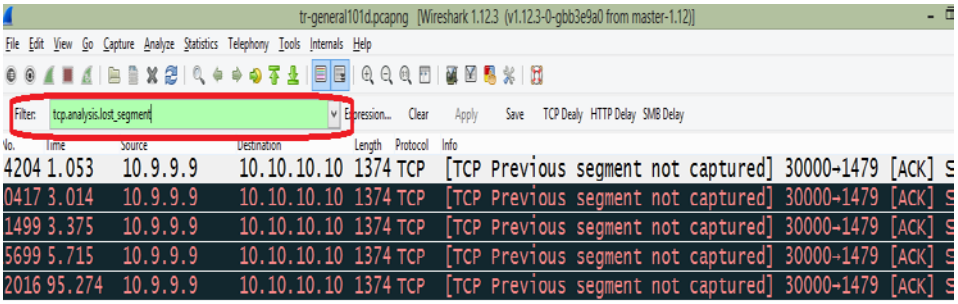
Topic 141: Wireshark Lab 45

In this topic, we apply a Filter to count previous segments in Wireshark.

Step 1: Open ***tr-general101d.pcapng.***



Step 2: In the display filter area, enter the filter **tcp.analysis.lost_segment**. Click **Apply**.



From the Status Bar, we can observe that Wireshark has detected packet loss five times in this trace file. In the Info column, we can see “Previous Segment Not Captured”. This warning means that Wireshark was not able to see the previous packet(s) in a TCP communication. Wireshark keeps a track of the packet ordering using TCP Sequence Numbers. From this, it can easily detect when packets are missing.

Step 3: As you finish analyzing the trace file, click **Clear** to remove your filter. Applying the filter **tcp.analysis.lost_segment** on the traffic of a trace file, we easily found that packet loss is occurring. To determine how many packets were actually lost, we need to examine the TCP sequence numbers.

Topic 142: Wireshark Lab 46

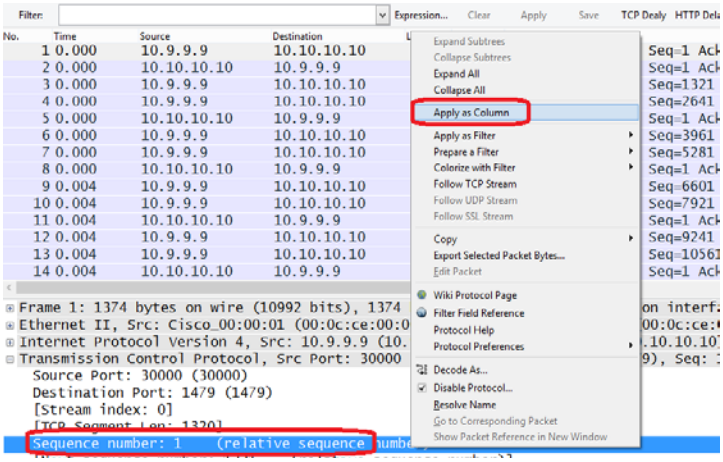
In this topic, we add TCP sequencing columns in Wireshark.

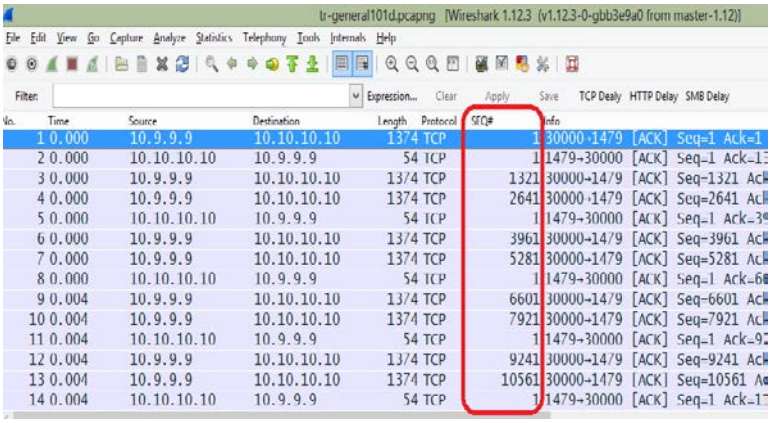
In this lab exercise, we will create three columns to help understand how TCP sequencing works in a trace file. Using these columns, we will be able to determine how many packets are actually lost when Wireshark displays ***Previous Segment Not Captured***.

Step 1: Open ***tr-general101d.pcapng***.

Step 2: Expand the **TCP header** in Packet 1.

Step 3: Right-click on the **Sequence Number** field and select **Apply as Column**. Rename this column **SEQ#** by right-clicking on your new **Sequence Number** column and selecting **Edit Column Details**.

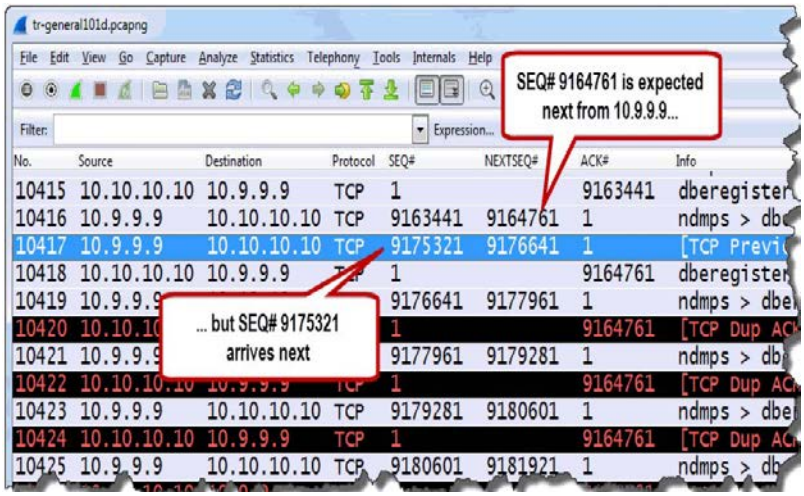




Step 4: Select **Apply as Column** after right-clicking on the **Next Sequence Number** field. Rename this column **NEXTSEQ#** by right-clicking on this newly created column and selecting **Edit Column Details**.

Step 5: Create the 3rd new column by right-clicking on the **Acknowledgment Number** field and select **Apply as Column**. Rename this column **ACK#** as we did in the previous step.

Step 6: Click the **Go To Packet** button on the Main Toolbar. As packet 10417 is one of the packets tagged with the *Previous Segment Not Captured* Expert indication. Enter 10417 and click **Jump To**. From the NEXTSEQ# column, we find that the next packet (after Packet 10,416) from 10.9.9.9 should use sequence number 9,164,761. But SEQ# is equal to 9,175,321 for the next packet from 10.9.9.9.



Because of the mismatch, Wireshark tags Packet 10,417 with *Previous Segment Not Captured*. 9,175,321 - 9,164,761 = 10,560 bytes have been lost. The TCP header of Packet 10,417 indicates that it contains 1,320 bytes of data. Assuming all the lost packets to be of 1,320 bytes long, 10,560/1,320 = 8 packets were lost prior packet 10,417.

Topic 143: Wireshark Lab 47

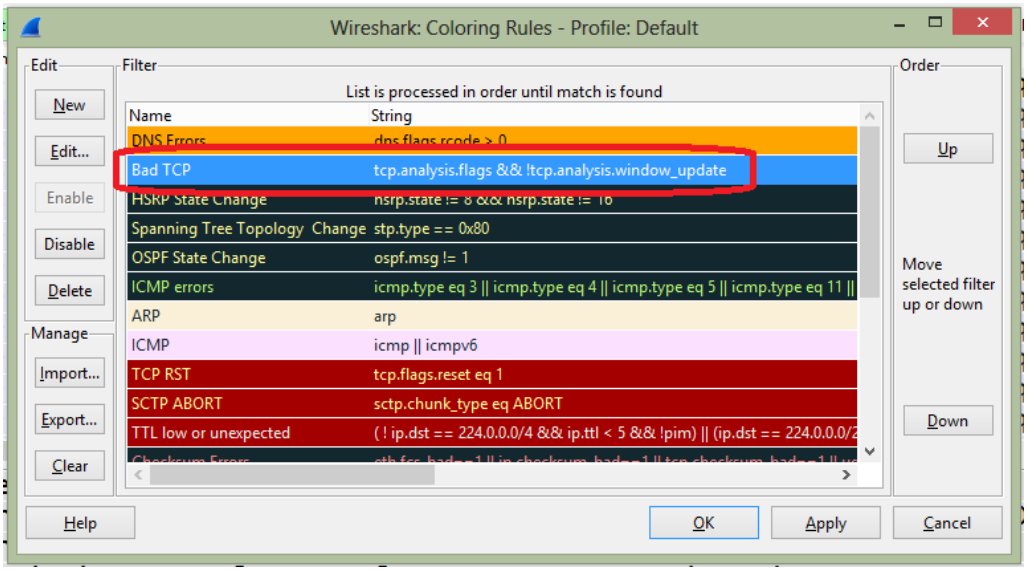
In this topic, we build a bad TCP Filter expression in Wireshark.

We would like to create a button, which when clicked once will view many of the key TCP problems in a trace file.

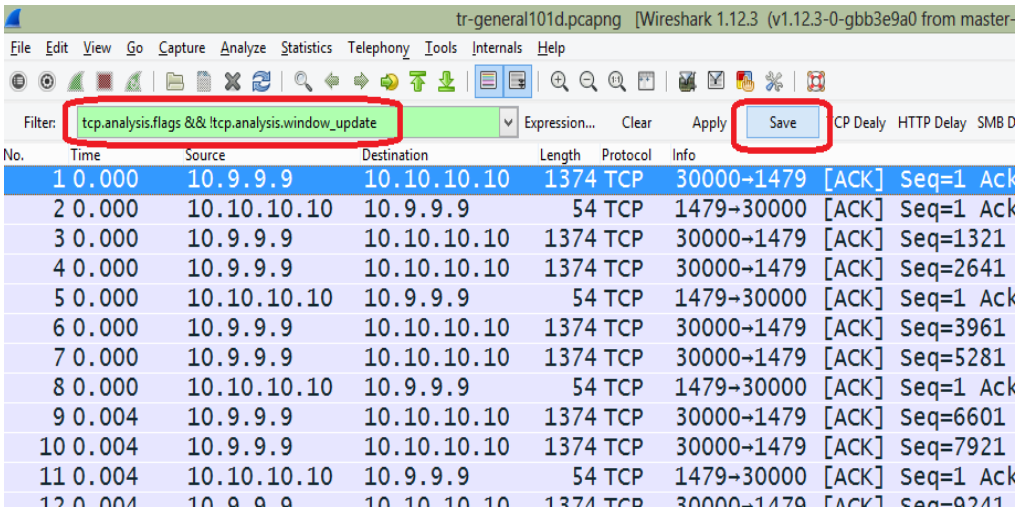
Step 1: Open ***tr-general101d.pcapng***.

Step 2: Type the following expression in the display filter area: **tcp.analysis.flags && !tcp.analysis.window_update.** Click the **Coloring Rules** button and then, look for

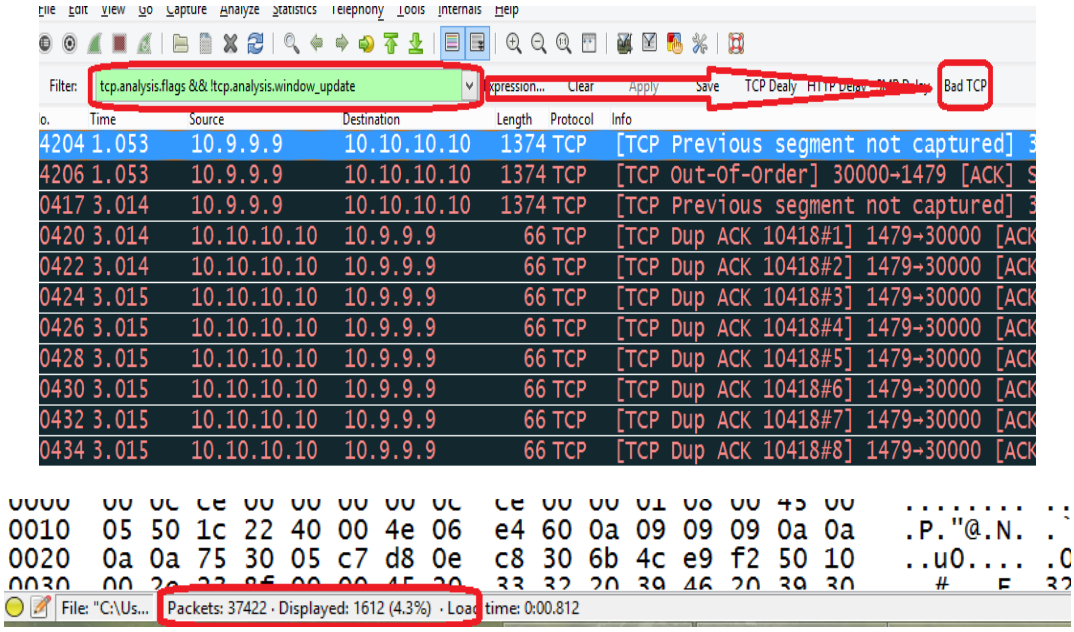
the **Bad TCP coloring rule**. The filter expression we typed in Step 2 is the same as the **Bad TCP coloring rule** string.



Step 3: Click **Save** on the display filter toolbar to create a new button. Name this new button **Bad TCP**.



Step 4: Click the newly created **Bad TCP** button.



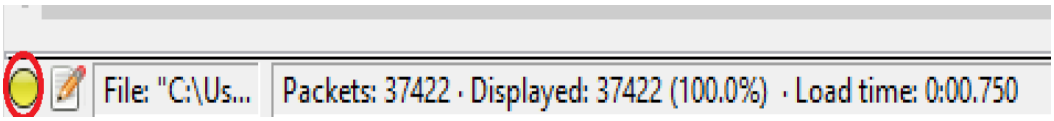
There are 1,612 packets (4.3% of the traffic) matching our Bad TCP button. These packets can badly affect e.g. a file transfer process to a noticeable extent. Click **Clear** to remove your filter when you are finished.

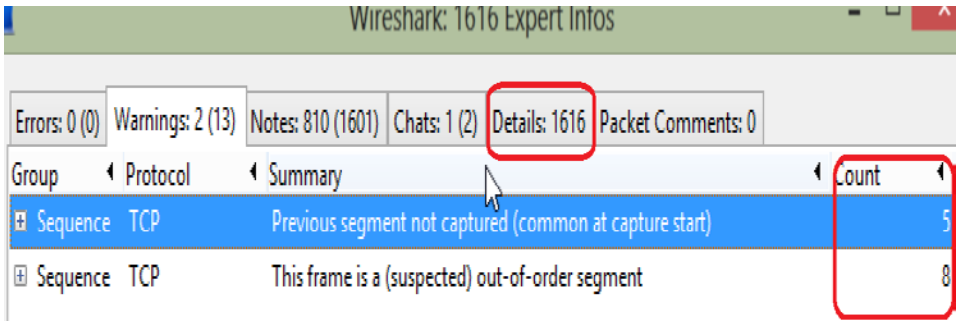
Topic 144: Wireshark Lab 48

In this topic, we find packet loss counts with Expert Infos in Wireshark.

Step 1: Open ***tr-general101d.pcapng***.

Step 2: Click the **Expert Infos** button on the Status Bar.





Step 3: There are 1,616 Expert Infos items in the title bar. There are no entries under the Errors tab as Wireshark could not detect any serious problem in the trace file. When you click the **Warnings** tab, Wireshark has observed 5 packet losses. This is because of the sudden jump in the sequence numbers. Wireshark does not take into

account the size of the increase. From the **Warnings** tab, we can see that there are 8 instances of Out-of-Order segments. If you want to analyze a problem, expand the Expert Infos sections and click on that packet listed. Wireshark will jump to that problem in the trace file. In the end, close the Expert Infos window.

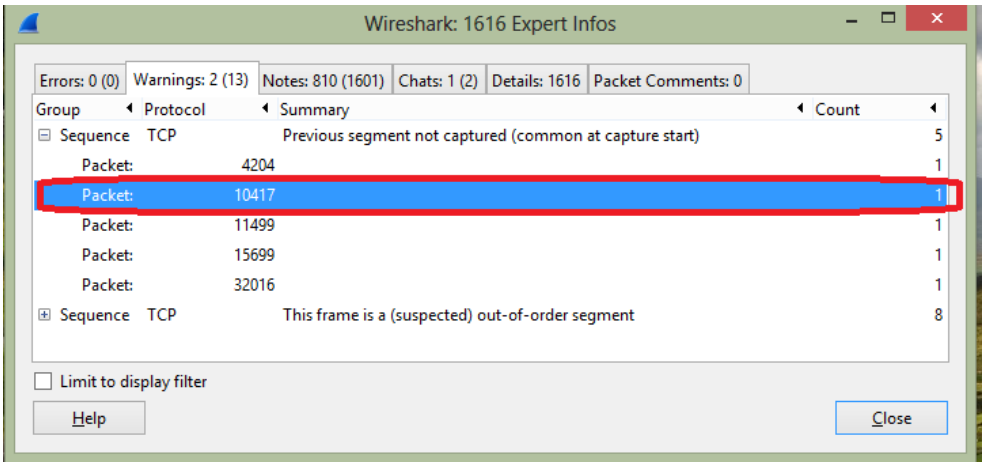
Topic 145: Wireshark Lab 49

In this topic, we find out where packets are being dropped using Wireshark.

Step 1: Open ***tr-general101d.pcapng***.

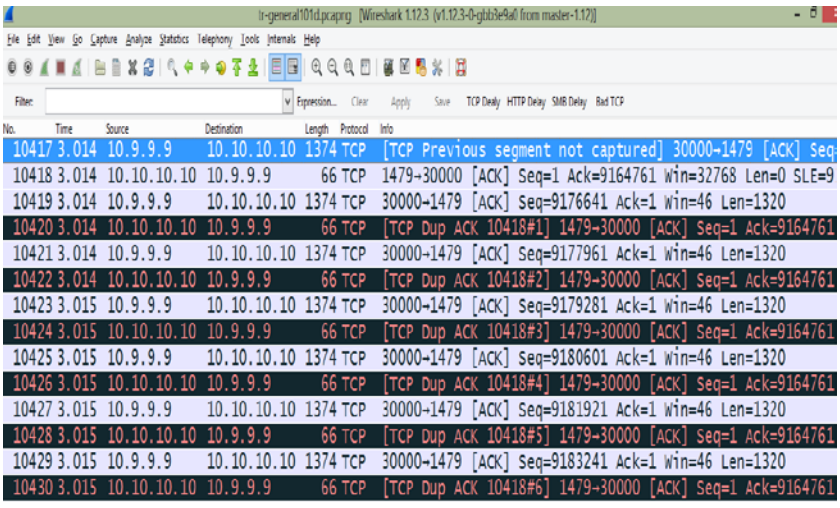
Step 2: To view the Expert Infos window, click **Expert Infos** button on the Status Bar.

Step 3: Click the **Warnings** tab and expand the ***Previous segment not captured (common at capture start)*** section.

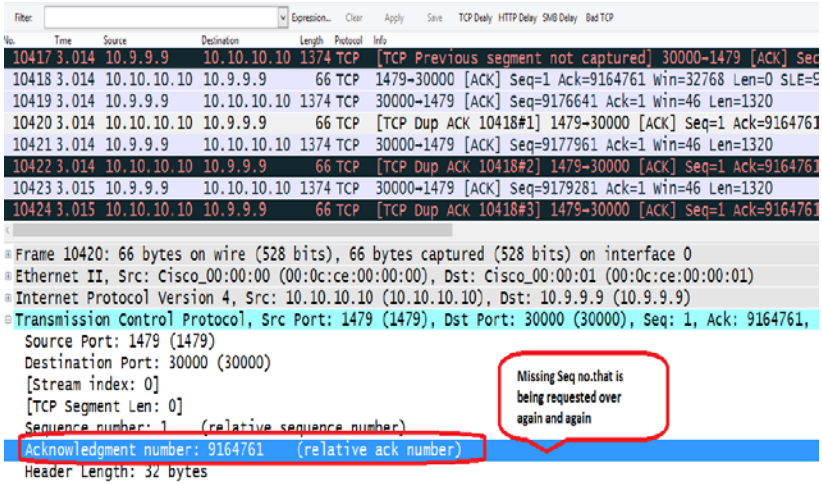


In the listing, let's examine **Packet 10,417.** Click on it and Wireshark will take you to that packet in Main window.

Step 4: After the point of packet loss, we can see numerous Duplicate ACKs after the missing packet indication.



10.10.10.10 (the receiver) supports Fast Recovery as it is using Duplicate ACKs. Each Duplicate ACK is a request for sequence number 9,164,761. See Acknowledgment Number field in the Duplicate ACKs. Close the Expert Infos window.



Step 5: Packets were captured upstream from the point of packet loss (closer to the data sender than the point of packet loss) or downstream from the point of packet loss (closer to the receiver than the point of packet loss)?

Step 6: We can use the sequence number of the packet that is missing to determine if we see the original and the Retransmission or just Retransmission. Enter **tcp.seq==9164761** in display filter area.

We can see that traffic has been captured downstream from point of packet loss. Packet loss always affects network performance. Locate it and then figure out why it is happening.

Topic 146: Duplicate ACKs and their Causes

This topic describes duplicate ACKs and their causes.

Duplicate ACKs are used to inform the sender about packet loss. They can also be an indication of out-of-order packets. A host generates Duplicate ACKs if it supports Fast Recovery and notices that a packet has arrived with a sequence number beyond the calculated next sequence number. Details of Fast Recovery can be found in RFC 5681, "TCP Congestion Control." To determine whether an ACK is a duplicate ACK,

Wireshark uses Data bytes, Window Size, Sequence Number, and ACK Number fields. When two or more packets with same Data bytes, Window Size, Sequence Number, and ACK Number fields arrive at a host from a source, we mark the second and onwards as duplicates of the first ACK. In Duplicate ACKs, the ACK Number field value indicates the requested sequence. A TCP host keeps on sending Duplicate ACKs until it receives missing packet. When a receiver receives a packet with the incoming sequence number value jumping higher than the expected, it does not know if the packet is lost or it is just out of order and will be arriving soon. Wireshark marks a packet as Out-of-Order if the missing sequence number packet arrives within 3 ms. In case, it arrives later than 3 ms, Wireshark marks it a Retransmission or Fast Retransmission. In Wireshark, we can use **tcp.analysis.duplicate_ack** to determine the number of duplicate ACKs, while **tcp.analysis.out_of_order** is used to keep a record of Out-of-Order packets.

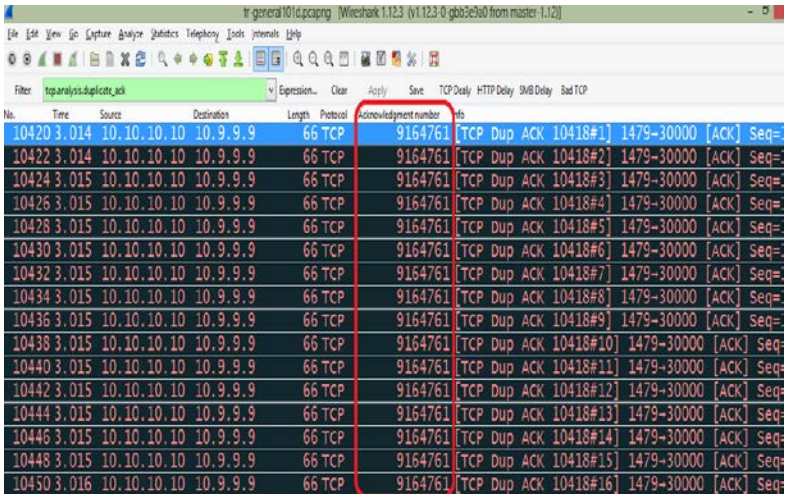
Topic 147: Wireshark Lab 50

In this topic, we use a Filter to count Duplicate ACKs in Wireshark.

Step 1: Open ***tr-general101d.pcapng*.**

Step 2: Enter the filter **tcp.analysis.duplicate_ack** in the display filter area and then Click **Apply**. From the Status Bar, we see that Wireshark has detected 1,019 Duplicate ACKs.

Step 3: Expand **TCP header** of a Packet. Click on the **Acknowledgment Number** field and select **Apply as Column**. Name it **ACK#** by right-clicking on this column and selecting **Edit Column Details**. On scrolling through the trace file, you will observe that these Duplicate ACKs are requests for a single missing packet whose sequence number is 9,164,761.



You can observe that there a many Duplicate ACKs that are requests for a single missing packet whose sequence number is 9,164,761. The host continues sending Duplicate ACKs until missing sequence number is resolved.

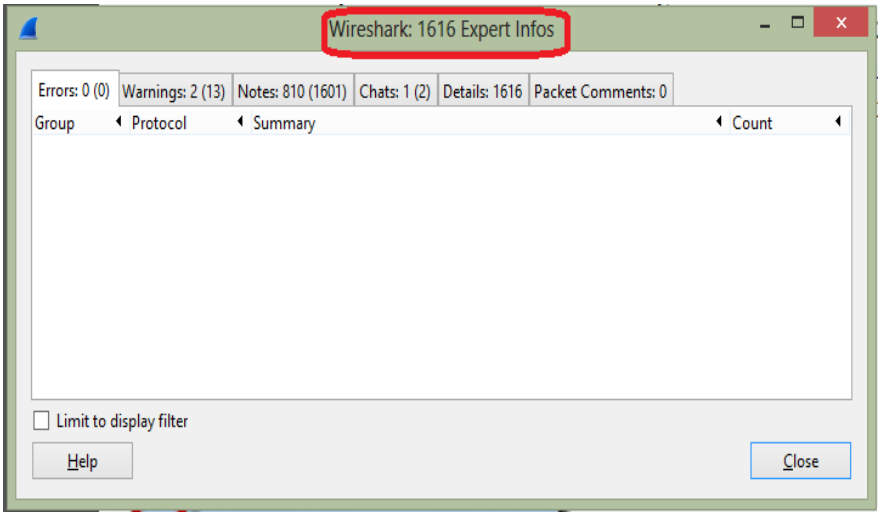
Step 4: To hide the **ACK#** column from view, right-click the **ACK#** column and select **Hide Column**. Click **Clear** to remove the display filter.

Topic 148: Wireshark Lab 51

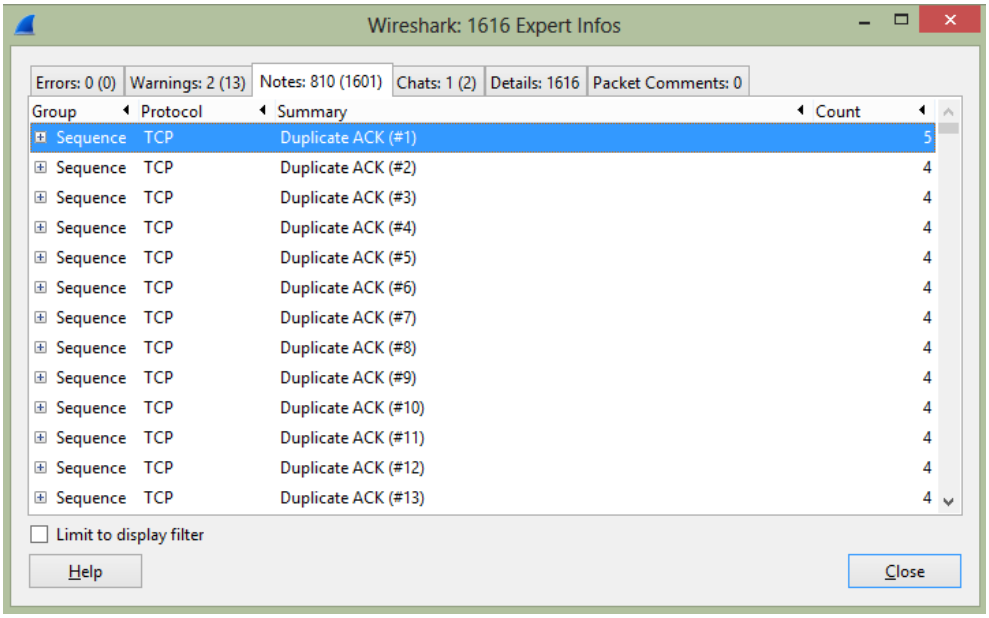
This topic finds Duplicate ACKs using Expert Infos in Wireshark.

Step 1: Open ***tr-general101d.pcapng***.

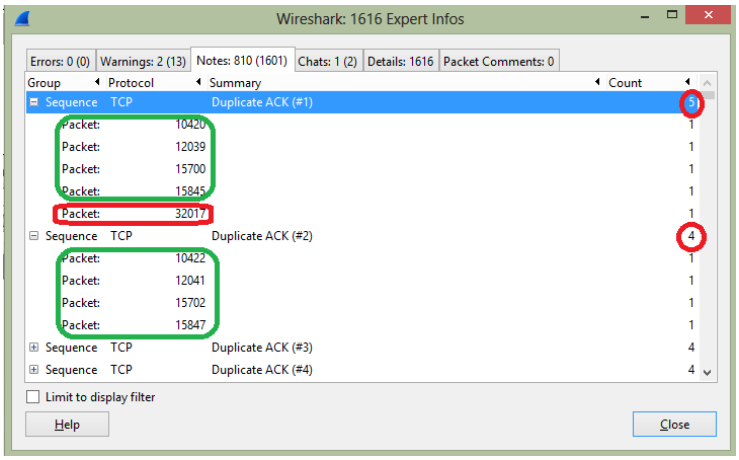
Step 2: Click the **Expert Infos** button on the Status Bar.



Step 3: Let's examine problems in this trace file by clicking the **Notes** tab. Count the Duplicate ACKs. Wireshark does not count all Duplicate ACKs together, it groups Duplicate ACKs based on their number. In a trace file, assume packet loss occurs twice. Both times the original ACK, Duplicate ACK#1, Duplicate ACK#2, and Duplicate ACK#3 were sent. Wireshark will list 3 Duplicate ACKs with an indication that each occurred twice.

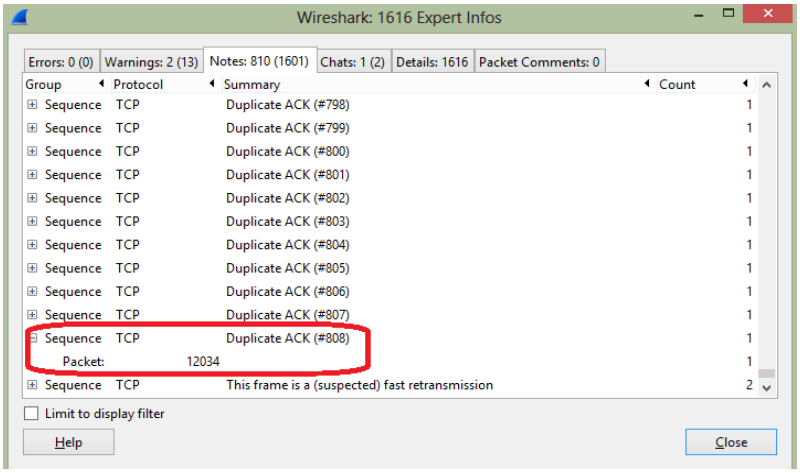


Duplicate ACK (#1) occurs 5 times i.e., the Fast Recovery process was launched 5 times. The 4 Duplicate ACK (#2) indications in one case receiver only had to send the first Duplicate ACK and then it recovered.



Probably, the one out-of-order packet situation in the trace file occurs near Packet 3,217.

Step 4: Scroll to the end of the **Notes** section.



The TCP receiver kept on requesting for a missing packet 809 times. This means a packet got lost and the recovery took a significant amount of time. This can be due to path latency or a network disconnect. Finally, close the Expert Infos window.

Topic 149: Wireshark Lab 52

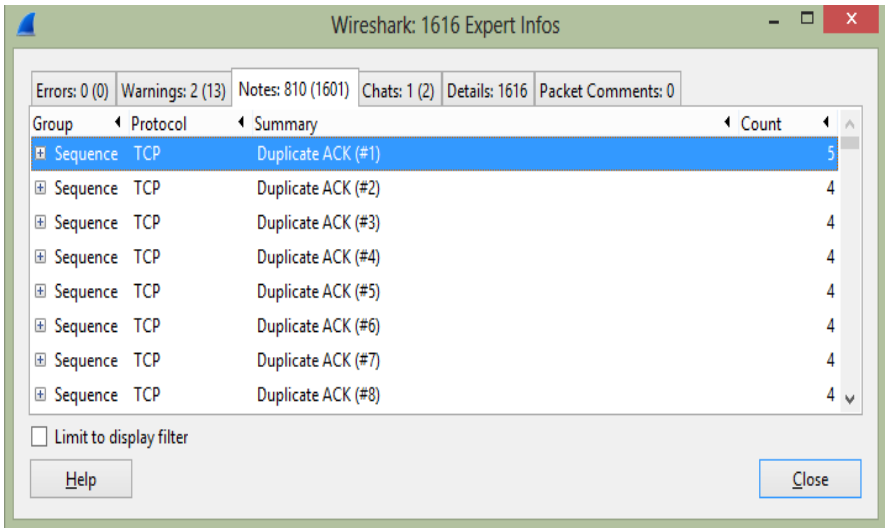
In this topic, we determine if Selective ACK (SACK) is in use by examining Duplicate ACKs in Wireshark.

When two TCP hosts are communicating and are using SACK, only the missing packets are retransmitted. If SACK is not in use many unnecessary retransmissions will be generated. The sender retransmits every data packet starting from the missing sequence number. If the TCP handshake packets are not captured, we can examine duplicate ACKs to determine if SACK is enabled on the connection.

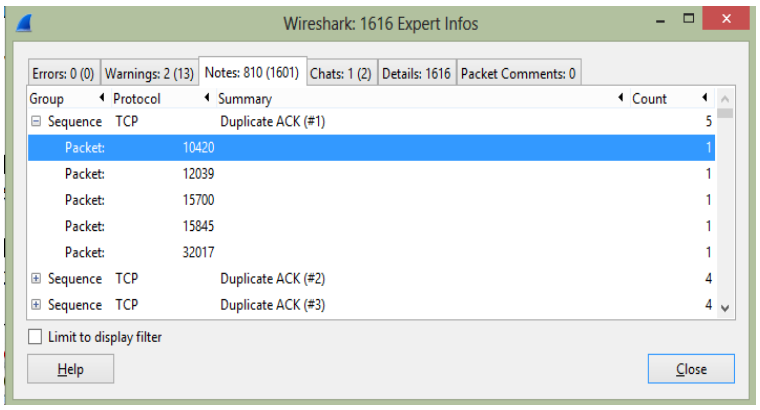
Step 1: Open ***tr-general101d.pcapng***.

Step 2: Click the **Expert Infos** button on the Status Bar.

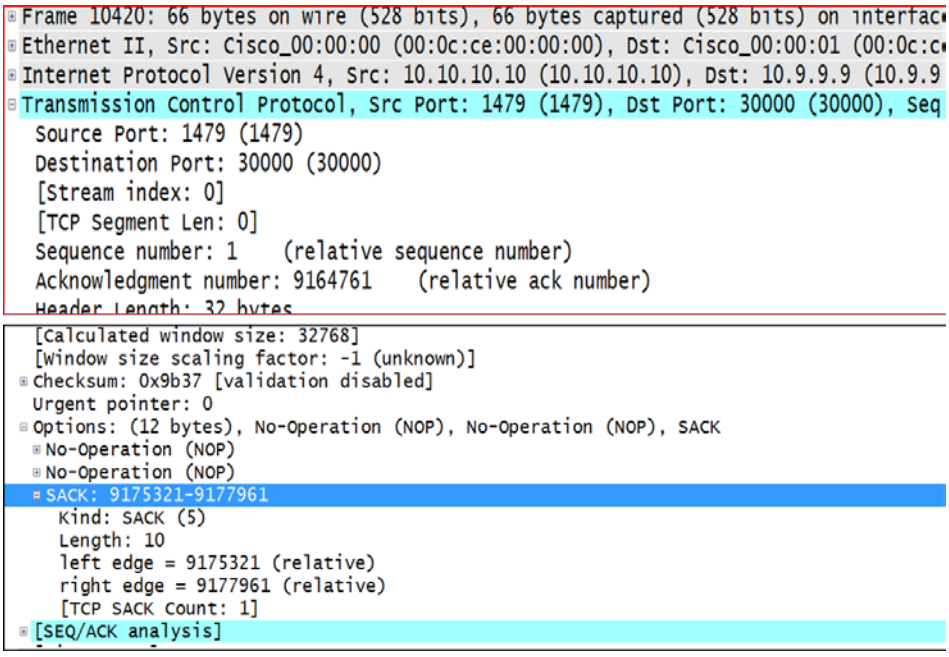
Step 3: Duplicate ACKs can be located by clicking on the **Notes** tab.



Step 4: Expand the **Duplicate ACK (#1)** line and click on the first packet listed, whose number is 10,420. Go to Wireshark to examine that packet.



Step 5: SACK Left Edge (SLE) and SACK Right Edge (SRE) information is listed in the **Info** column. You can also expand packet 10420 and look for the SLE and RLE values in the Options area of the TCP header.



Topic 150: Out-of-Order Packets and their Causes

This topic describes out-of-order Packets and their causes.

On a receiving host, the transmission control protocol (TCP) layer cannot pass the received data up to the application layer until all the bytes are in the correct order.

Let's assume a scenario where two packets arrive at a host in reverse order. The packets both arrive within 1 ms. This situation is unlikely to cause a problem. Therefore, we may expect that performance will not be affected if there is a little time between the expected arrival and the actual arrival of out-of-order packets. Wireshark labels a packet out-of-order if it

(a) Contains data,

(b) Does not advance the sequence number value, and

(c) Arrives within 3 ms of the highest sequence number seen.

Causes of Out-of-Order Packets

- a stream using multiple different speed paths to reach the target,
- a poorly configured queuing along a path or,
- Asymmetric routing.

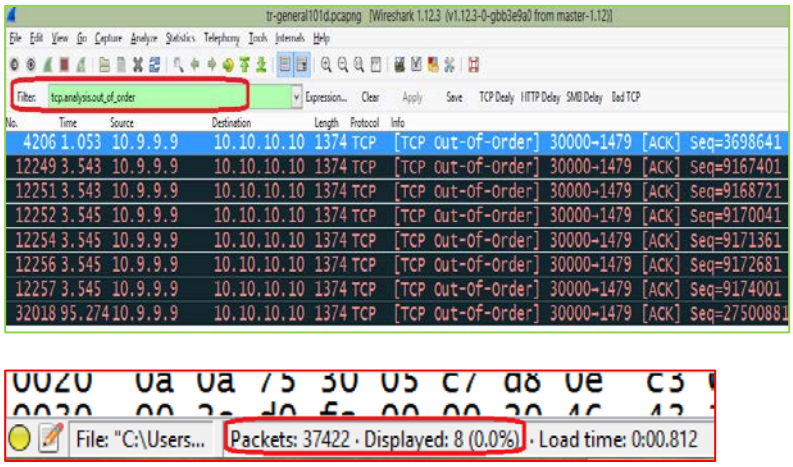
A queuing device that does not forward packets in a first-in/first-out (FIFO) order can cause packets to arrive a host in an out-of-order fashion.

Topic 151: Wireshark Lab 53

This topic uses a filter to count out-of-order packets in Wireshark.

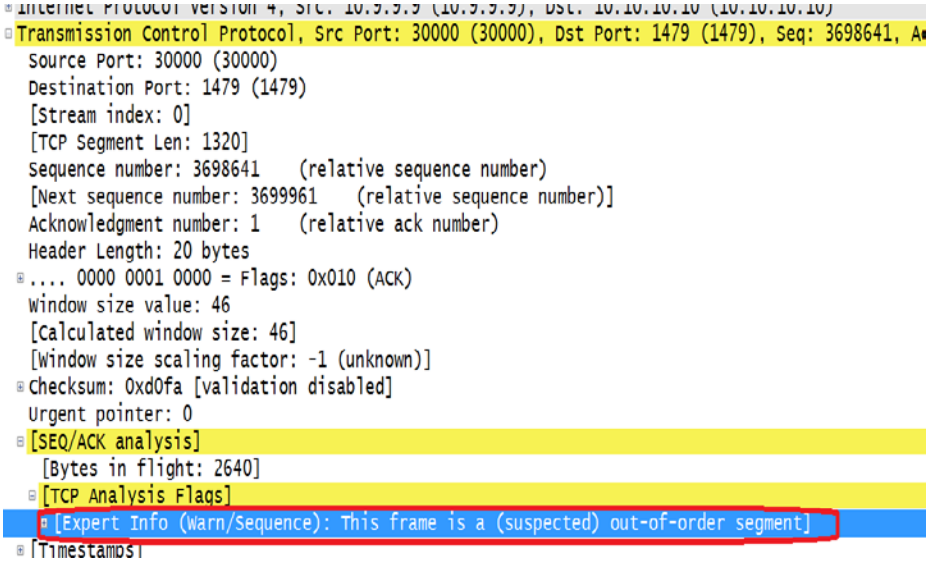
Step 1: Open ***tr-general101d.pcapng***.

Step 2: Enter the expression **tcp.analysis.out_of_order** in the display filter area. Click **Apply**.



We find that Wireshark has detected 8 Out-of-Order packets as indicated by the Status Bar. On examining the packet numbers, we can have an idea that packets

4206 and 32018 are out-of-order packets, while remaining 6 packets belong to a group of out-of-order packets in close proximity.



If you find multiple Out-of-Order packets in close proximity, then it is likely that a set of packets have been lost. These packets are Retransmissions that arrived within 3 ms.

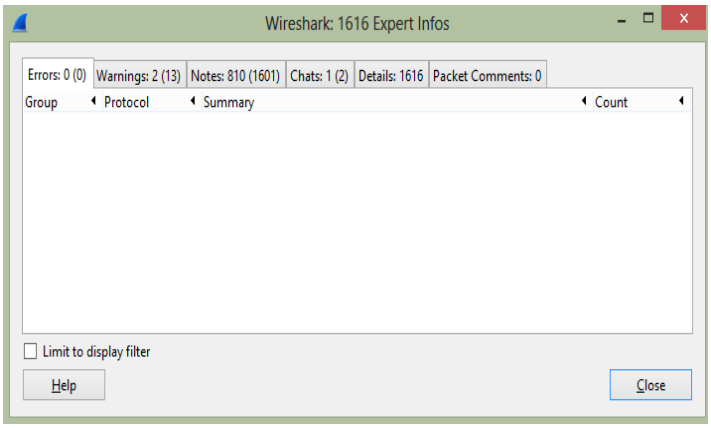
Step 3: When you are done, click the **Clear** button to remove the filter.

Topic 152: Wireshark Lab 54

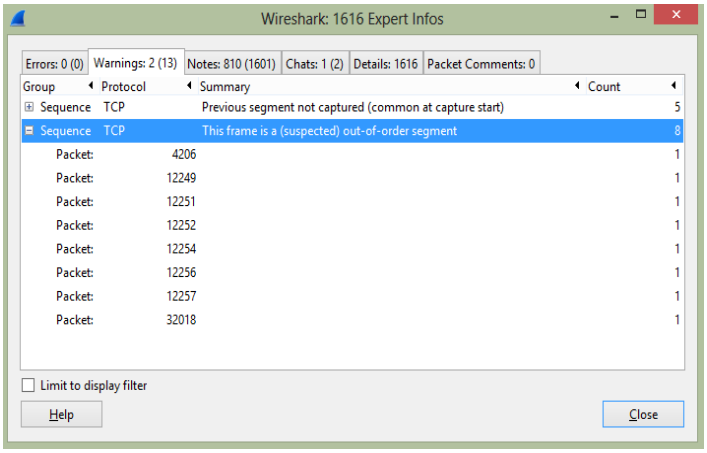
In this topic, we find out-of-order packets with Expert Infos in Wireshark.

Step 1: Open ***tr-general101d.pcapng***.

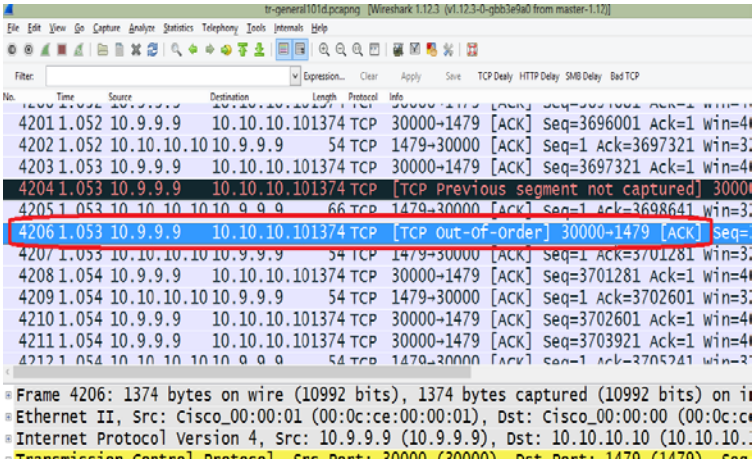
Step 2: On the Status Bar, click the **Expert Infos** button.



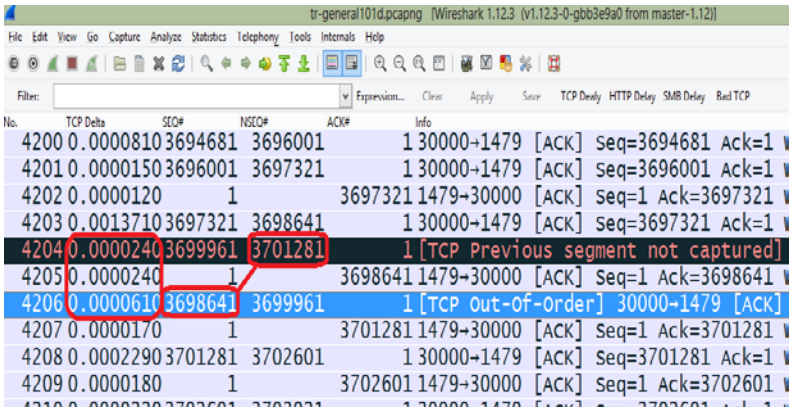
Step 3: Click the **Warnings** tab. Expand the **Out-of-Order segment** section.



Click on the first entry i.e. Packet 4,206 and then click the **Close** button and then go to the main Wireshark window.



Step 4: If you have previously created, **SEQ#**, **NEXTSEQ#** and **ACK#** columns, then right-click on any column heading and display them. Otherwise, create them. Select **Sequence number** field in the TCP header of a packet, and then **Apply as a Column**. Rename the column as **SEQ#** by right-clicking on the column and selecting **Edit Column Details.**



We can see that **SEQ#** of Packet 4,206 is lower than the **NSEQ#** in Packet 4,204. Also, the out-of-order packet arrived 85 microseconds, which is less than 3 ms after the previous packet from 10.9.9.9.

Topic 153: Causes of Fast Retransmissions

In this topic, we describe fast retransmissions and their causes. Fast retransmissions are triggered, when three identical ACKs (the original ACK and two Duplicate ACKs) arrive at a receiving host. Fast Retransmissions are a sign that packet loss has occurred and are part of the Fast Recovery process.

Characteristics of Fast Retransmissions

The segment contains data or has the SYN or FIN bits set to 1. The segment does not advance the sequence number. At least 2 Duplicate ACKs were coming from the reverse direction. The Sequence Number field value matches Acknowledgment Number field value in the preceding Duplicate ACKs. The packet arrived within 20 ms of the last Duplicate ACK.

Causes of Fast Retransmissions

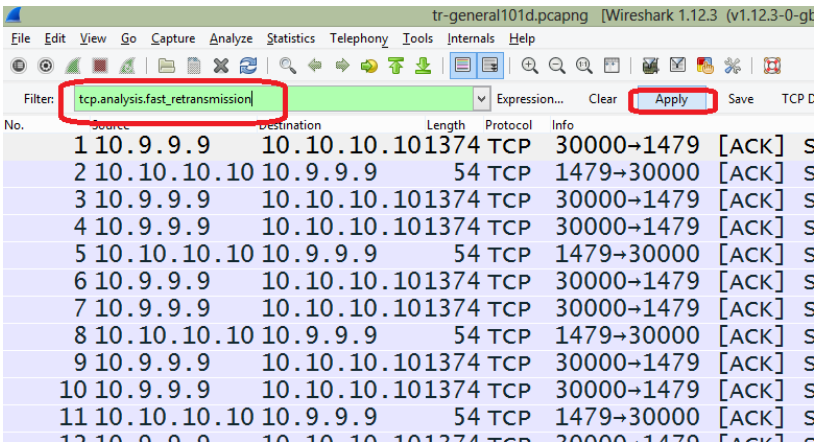
When a host believes there is a packet loss and supports Fast Recovery, then it generates at least four identical ACKs. In addition to the original ACK, at least three Duplicate ACKs are sent towards the sender requesting the missing segment. Packets are typically lost at infrastructure devices.

Topic 154: Wireshark Lab 55

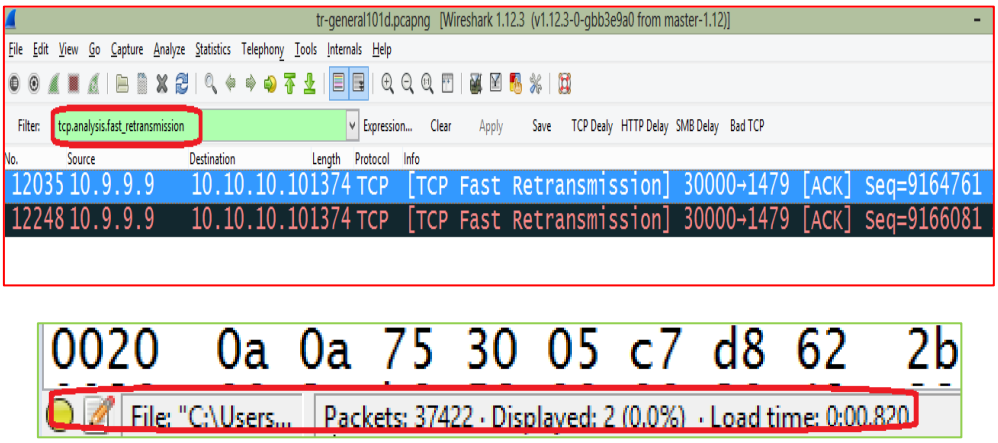
This topic uses a filter to count fast retransmission packets in Wireshark.

Step 1: Open ***tr-general101d.pcapng***.

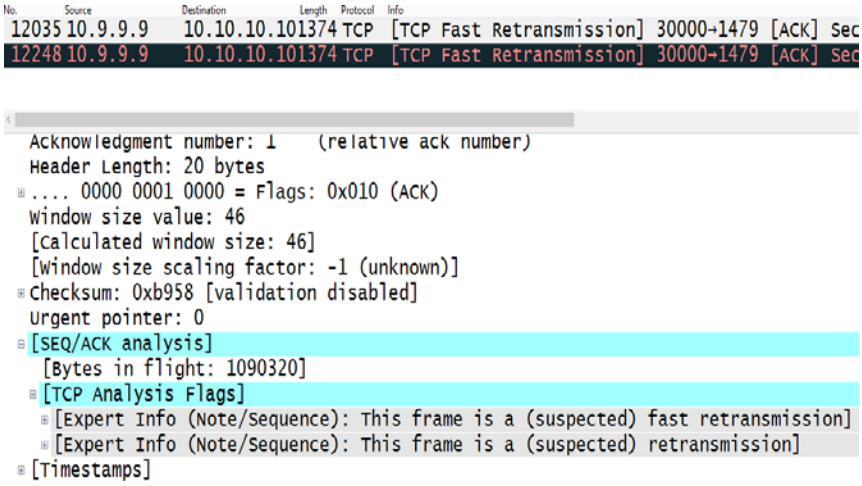
Step 2: Enter the filter **tcp.analysis.fast_retransmission** in the display filter area. Click **Apply**.



In this trace file, Wireshark has detected two Fast Retransmissions as indicated by the Status Bar.



Step 3: Expand the **[SEQ/ACK analysis]** section on one of the Fast Retransmissions. Wireshark colors this area cyan. Color of the Expert Infos Notes is Cyan.



There are two Expert Infos indications marked by Wireshark on this one packet. Frame is marked to be a Fast Retransmission and a Retransmission. Fast Retransmission is a Retransmission.

Step 4: Click the **Clear** button to remove the filter as you finish your analysis.

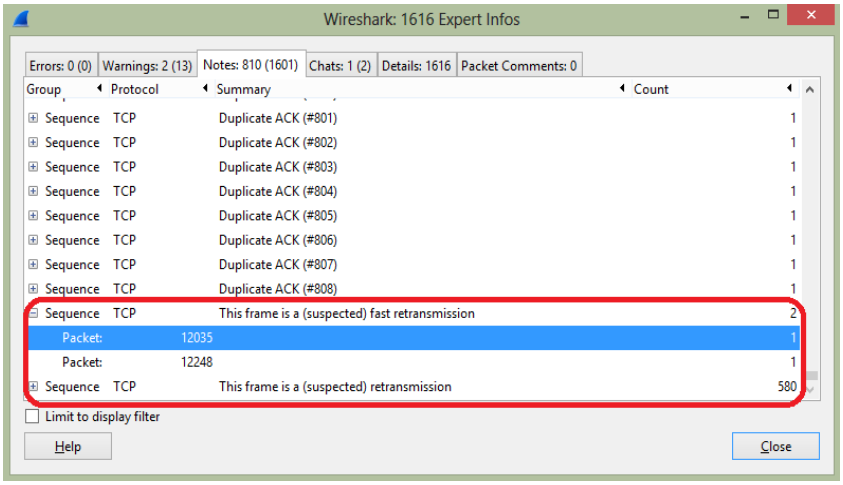
Topic 155: Wireshark Lab 56

In this topic, we find fast retransmission packets with Expert Infos in Wireshark.

Step 1: Open ***tr-general101d.pcapng***.

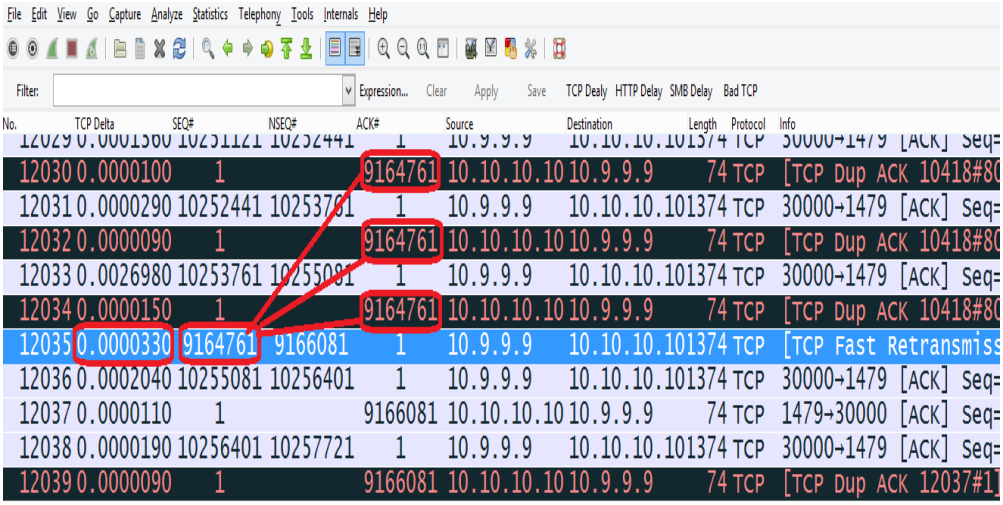
Step 2: Click the **Expert Infos** button on the Status Bar.

Step 3: Click the **Notes** tab. Scroll through the list. As you find the Fast Retransmissions section, expand it and click on the first entry, **Packet 12,035**.



We can observe that there are 808 Duplicate ACKs before the Fast Retransmission packet. Return to the main Wireshark window after clicking the **Close** button.

Step 4: If you have created **SEQ#, NEXTSEQ# and ACK#** columns, then you can display them by right-clicking on a column and selecting them from Displayed Columns.



From the TCP Delta column, we can see that the Fast Retransmission occurred within 20 ms of the last Duplicate ACK. If you consider time, you will find that only about 465 ms have passed between when packet with sequence number 9,164,761 went missing and when Fast Retransmission was initiated. Although there were 808 Duplicate ACKs, but this ½–second delay would be unnoticeable by the user.

Topic 156: Causes of Retransmissions

This topic describes retransmissions and their causes.

Wireshark considers a packet to be a Retransmission if the segment contains data or has the SYN or FIN bits set to 1. Sequence number is not advanced by the segment.

Duplicate ACKs have not triggered Retransmission. The segment arrives > 3 ms later than the previous packet with a higher sequence number. A Retransmission Time Out (RTO) at a sender triggers Standard Retransmissions. The RTO timer is used to ensure data delivery continues even if the TCP peer stops communicating (with ACKs). Each TCP host calculates and maintains a RTO timer. This timer value is based on the round trip time learned through previous data transmissions and related acknowledgments. The RTO value consistently changes through the conversation.

What Causes Retransmissions?

A TCP host begins counting down the RTO, when it sends a data packet. The sender retransmits the unacknowledged data packet, if the RTO timer expires without receiving an ACK for the data packet. The sender has no idea whether the original packet was lost or the acknowledgment was lost. The sender just knows that there some problem as it did not receive an ACK within the RTO.

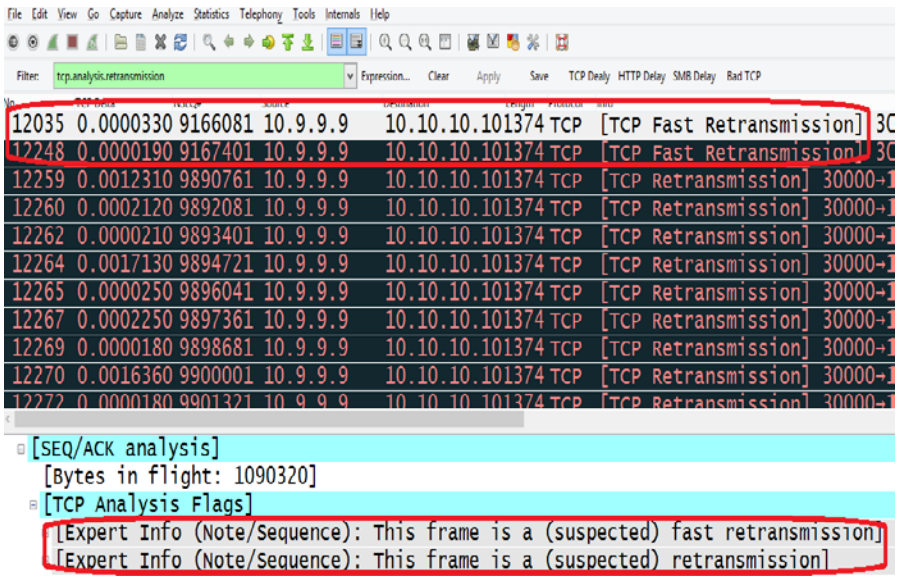
Topic 157: Wireshark Lab 57

This topic uses a filter to count retransmission packets in Wireshark.

Applying **tcp.analysis.retransmission** in Wireshark as a filter for Retransmissions will also display Fast Retransmissions. You need to exclude Fast Retransmissions in the filter, if you are interested in seeing packets that are only labeled as standard Retransmissions.

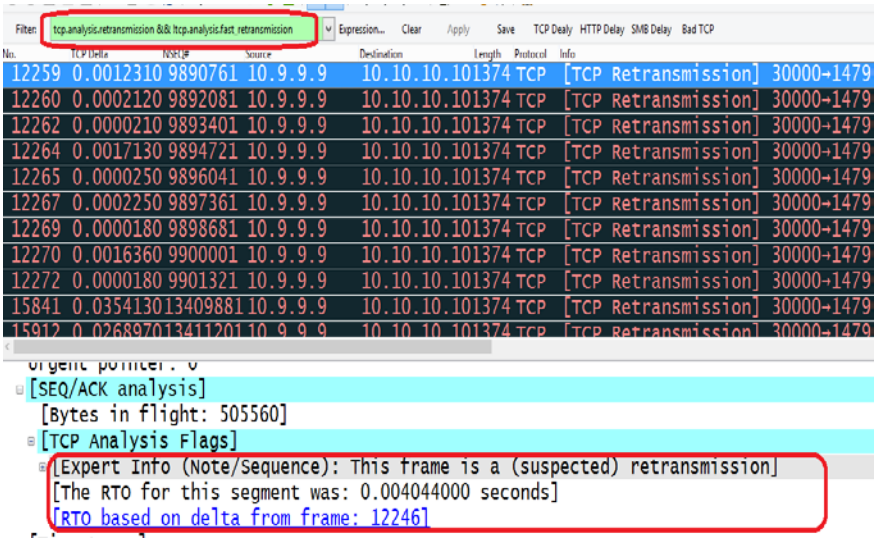
Step 1: Open ***tr-general101d.pcapng***.

Step 2: Enter the filter **tcp.analysis.retransmission** in the display filter area. Click **Apply**.



From the Status Bar, we can see that Wireshark has detected 580 Retransmissions in the trace file. This also includes two Fast Retransmissions.

Step 3: Update the filter to the following: **tcp.analysis.retransmission && !tcp.analysis.fast_retransmission.** Click **Apply**.



There are 578 packets that match this filter. So the two Fast Retransmissions have been removed from view.

Step 4: Click the **Clear button** to remove the filter.

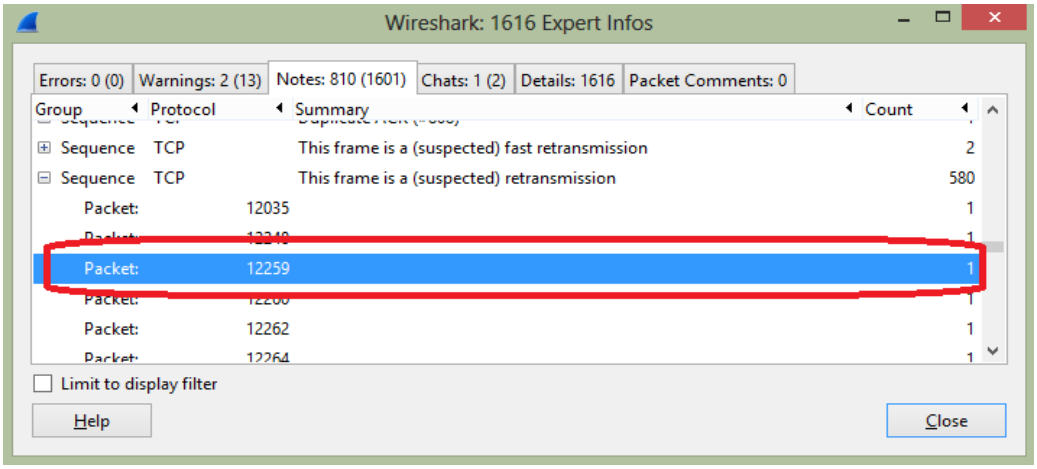
Topic 158: Wireshark Lab 58

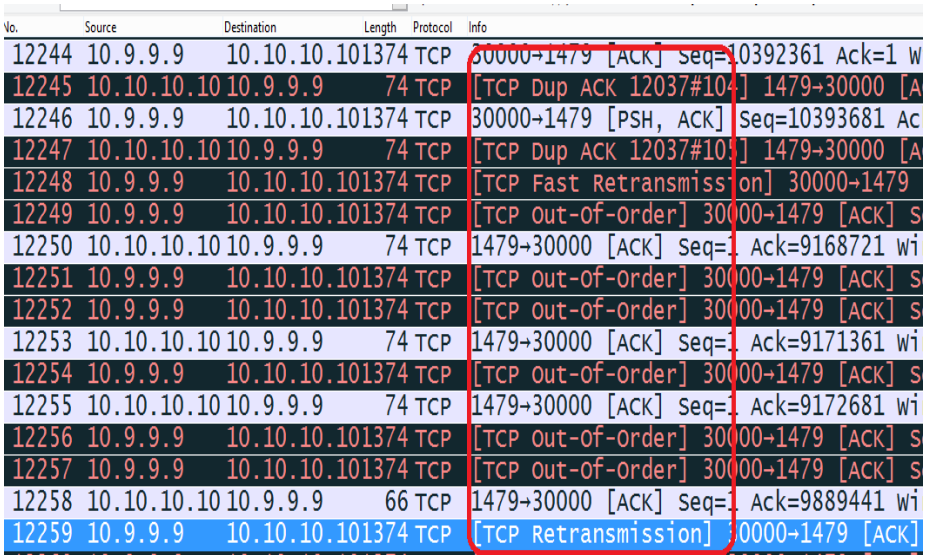
This topic finds retransmission packets with Expert infos in Wireshark.

Step 1: Open ***tr-general101d.pcapng***.

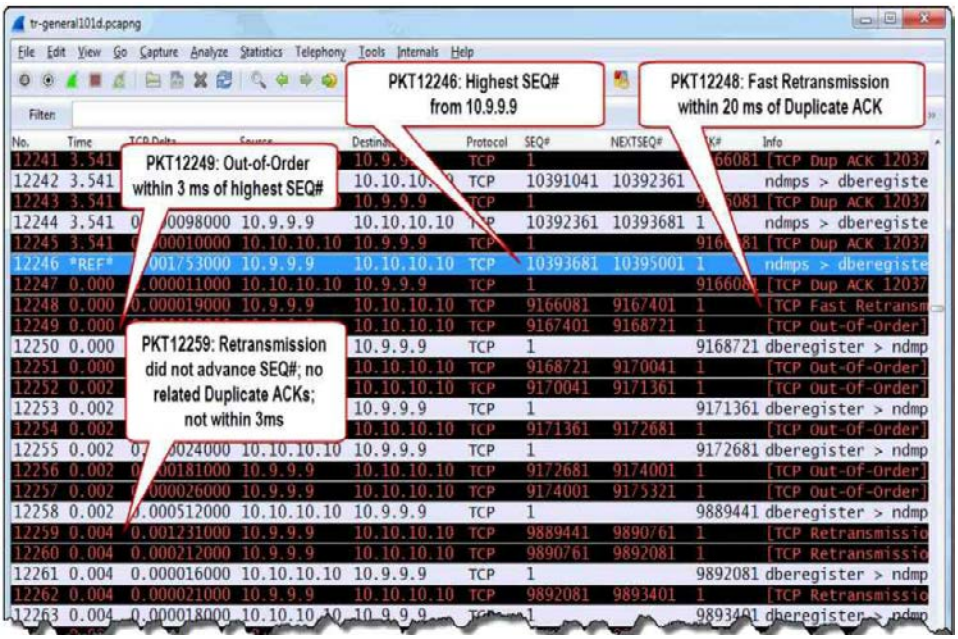
Step 2: On the Status Bar, Click the **Expert Infos** button.

Step 3: Click the **Notes** tab. Scroll through list. Expand the **Retransmissions** section and click on **Packet 12,259**. This will take you to the Wireshark Main window. Click the **Close.**





Step 4: If you have previously created, **SEQ#**, **NEXTSEQ#** and **ACK#** columns, then right-click on any column heading and display them. Otherwise, create them. Select **Sequence number** field in the TCP header of a packet, and then **Apply as a Column**. Rename the column as **SEQ#** by right-clicking on the column and selecting **Edit Column Details.** Scroll up and you will find Packet 12,246 is a data packet from 10.9.9.9, which has the highest Sequence No. field value at this point of the trace file. Right-click on **Packet 12,246** and select **Set Time Reference (toggle)**.



Step 5: Time Reference, can be removed by right-clicking on **Packet 12,246**, and selecting **Set Time Reference (toggle)**.

Topic 159: Causes of ACKed Unseen Segments

In this topic, we explain ACKed Unseen segments and their causes.

What is ACKed Unseen Segment?

When Wireshark sees an ACK, but it did not see the data packet that is being acknowledged, it calls it an ACK Unseen Segment. For each host, Wireshark keeps a track of sequence number, next sequence number, and acknowledgment number values. Wireshark also keeps a track of a "Maximum Sequence Number to be ACKed" (*maxseqtobeacked*) value. This value gets updated as data is received. If Wireshark sees an ACK to acknowledge a data packet that has a higher Sequence Number field value than *maxseqtobeacked*, then it shows that it has missed the data packet that is being ACKed. Let's assume that Wireshark is running on a client which is communicating with a server. An ACK being sent to acknowledge all sequence numbers up to 9,380 has been captured.

Causes of ACKed Unseen Segment:

A) Problems occurring during the capture process can cause ACKed Unseen Segments. If the switch is oversubscribed when you are using switch port spanning, then it is dropping packets that should have been forwarded to Wireshark.

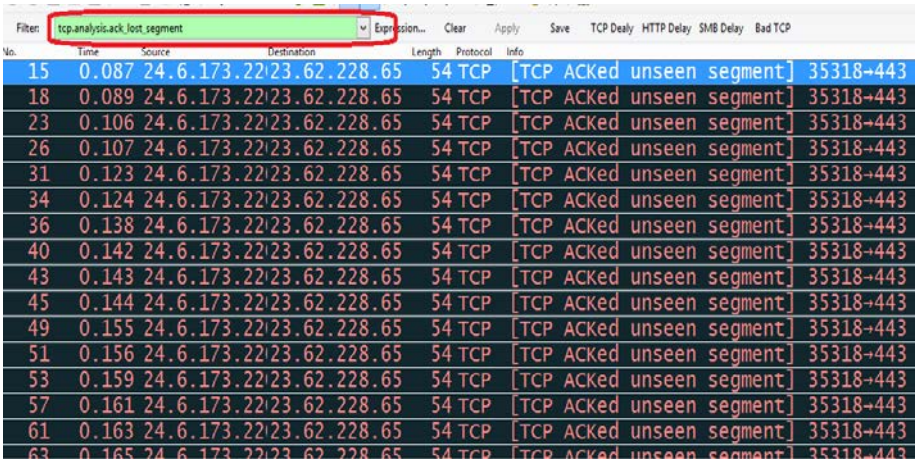
B) Asymmetric routing can cause ACKed Unseen Segments. With asymmetric routing, data may be flowing along one path on the network while ACKs flow along another path. Wireshark was able to capture ACKs but not the data.

Topic 160: Wireshark Lab 59

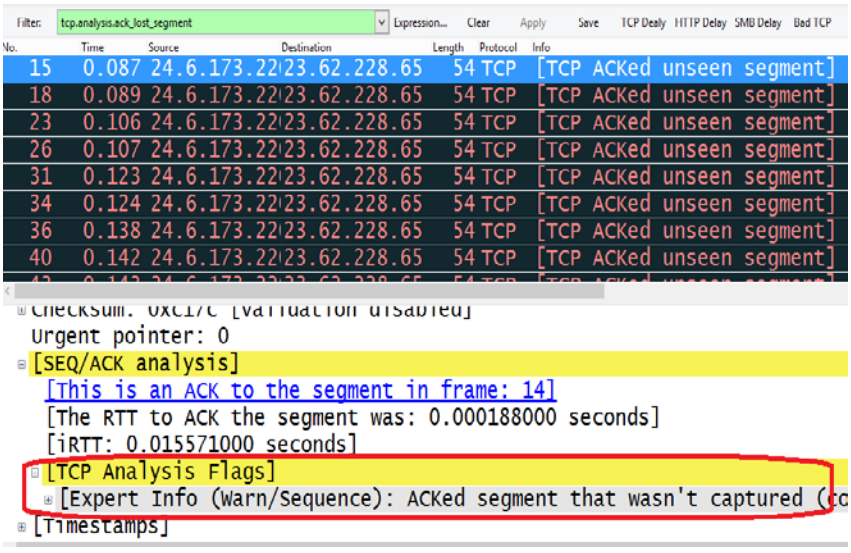
In this topic, we use a filter to count ACKed Unseen Segment warnings in Wireshark.

Step 1: Open ***tr-badcapture.pcapng.***

Step 2: Enter the filter expression: **tcp.analysis.ack_lost_segment** in the display filter area. Click **Apply**.



Look at the Status Bar. You will see that Wireshark has detected 24 ACKed Unseen Segments.



Step 3: Click the **Clear** button so that the filter expression is removed.

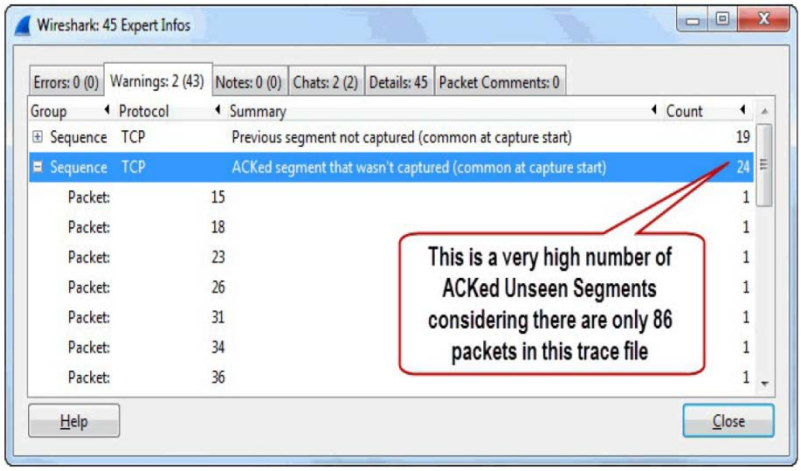
Topic 161: Wireshark Lab 60

In this topic, we find ACKed Unseen Segment indications using Expert Infos in Wireshark.

Step 1: Open ***tr-badcapture.pcapng***.

Step 2: Click the **Expert Infos** button on the Status Bar.

Step 3: Click the **Warnings** tab. Expand the section with title **ACKed segment that wasn't captured (common at capture start)**.



Step 4: Click on the first entry, **Packet 15** and then click the **Close** button. Let's go to the main Wireshark window. Display the **SEQ#**, **NEXTSEQ#** and **ACK#** columns.

No.	Time	SEQ#	NSEQ#	ACK#	Source	Destination	Length	Protocol	Info
12	0.071	3976	5436	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	Ignored Unknown Record
13	0.071	809		5436	24.6.173.220	23.62.228.65	54	TCP	35318→443 [ACK] Seq=809
14	0.087	6896	8356	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	[TCP Previous segment no
15	0.087	809		8356	24.6.173.220	23.62.228.65	54	TCP	[TCP ACKed unseen segmen
16	0.088	8356	9816	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	Ignored Unknown Record
17	0.089	11276	12736	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	[TCP Previous segment no
18	0.089	809		12736	24.6.173.220	23.62.228.65	54	TCP	[TCP ACKed unseen segmen
19	0.104	12736	14196	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	Ignored Unknown Record
20	0.105	14196	15656	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	Ignored Unknown Record
21	0.105	15656	17116	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	Ignored Unknown Record
22	0.105	809		17116	24.6.173.220	23.62.228.65	54	TCP	35318→443 [ACK] Seq=809
23	0.106	809		20036	24.6.173.220	23.62.228.65	54	TCP	[TCP ACKed unseen segmen
24	0.106	20036	21496	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	[TCP Previous segment no
25	0.106	21496	22956	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	Ignored Unknown Record
26	0.107	809		22956	24.6.173.220	23.62.228.65	54	TCP	[TCP ACKed unseen segmen
27	0.121	22956	24416	809	23.62.228.6	24.6.173.220	1514	TLSv1.2	Ignored Unknown Record

As you examine the SEQ# values, there are jumps in values. But no Retransmissions, Duplicate ACKs, or Fast Retransmissions can be observed. As far as the TCP peers are concerned, no packets have been lost. The spanned switch is not sending all the traffic down the port to which Wireshark is connected.

Topic 162: Causes of Keep Alives

In this topic, we explain Keep Alives and their causes.

Keep Alives are used refer to TCP Keep Alive Probe packets. These packets are used to detect dead connections, detect dead TCP peers, and prevent a connection from terminating when idle. Keep Alives are implemented as ACK packets that are either empty or contain 1 byte of data. The sequence number value in a Keep-Alive packet is 1 less than the next expected sequence number. TCP SYN, FIN and RST packets cannot be considered to be Keep Alives.

How Wireshark detects Keep-Alives?

Wireshark can easily detect Keep Alives because it keeps a track of the Sequence Number field values in all TCP streams. The Notes column of Wireshark's Expert Info window provides information about Keep Alives/Keep Alive ACKs.

What Causes Keep Alives?

Applications written to use Keep Alives generate Keep Alives. Three parameters are defined for Keep Alives:

1) Keep Alive Time: The amount of time between the last data packet and the first Keep Alive probe.

2) Keep Alive Interval: Interval between Keep Alive Probes.

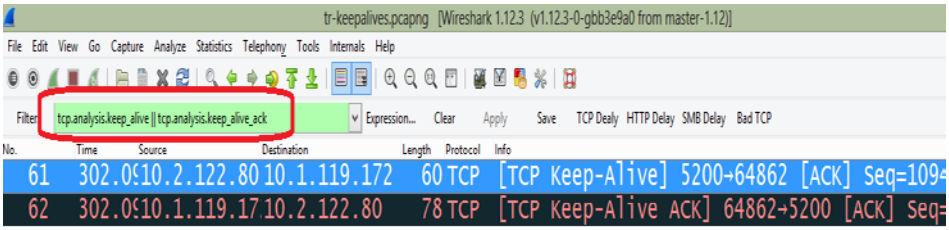
3) Keep Alive Probes: Number of unacknowledged Keep Alive Probes that should be sent before considering the connection to be dead.

Topic 163: Wireshark Lab 61

This topic uses a filter to count Keep Alive/Keep Alive ACK Packets in Wireshark.

Step 1: Open ***tr-keepalives.pcapng***.

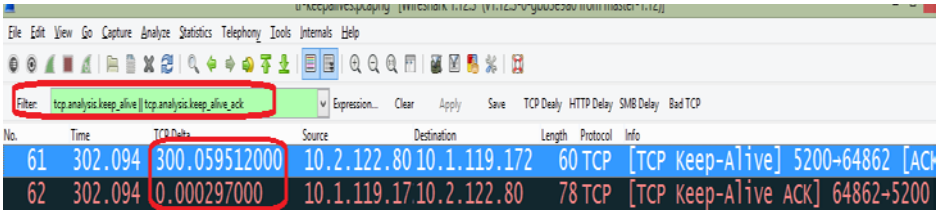
Step 2: Enter the filter **tcp.analysis.keep_alive || tcp.analysis.keep_alive_ack** in the display filter area. Click **Apply**.



We can see that only two packets match the filter.

```
[Calculated window size: 65273]
[Window size scaling factor: 1]
Checksum: 0x139a [validation disabled]
Urgent pointer: 0
[SEQ/ACK analysis]
  [iRTT: 0.097910000 seconds]
  [Bytes in flight: 1]
  [TCP Analysis Flags]
  [Expert Info (Note/Sequence): TCP keep-alive segment]
[Timestamps]
```

Step 3: Display **TCP Delta** column if it is hidden. Otherwise, create it. If you look at the TCP Delta before Packet 61, then you can see that 10.2.122.80 has a 300 second Keep Alive Time value. Packet 62 is the Keep Alive ACK packet.



Step 4: Remove the filter by clicking the **Clear** button.

Topic 164: Wireshark Lab 62

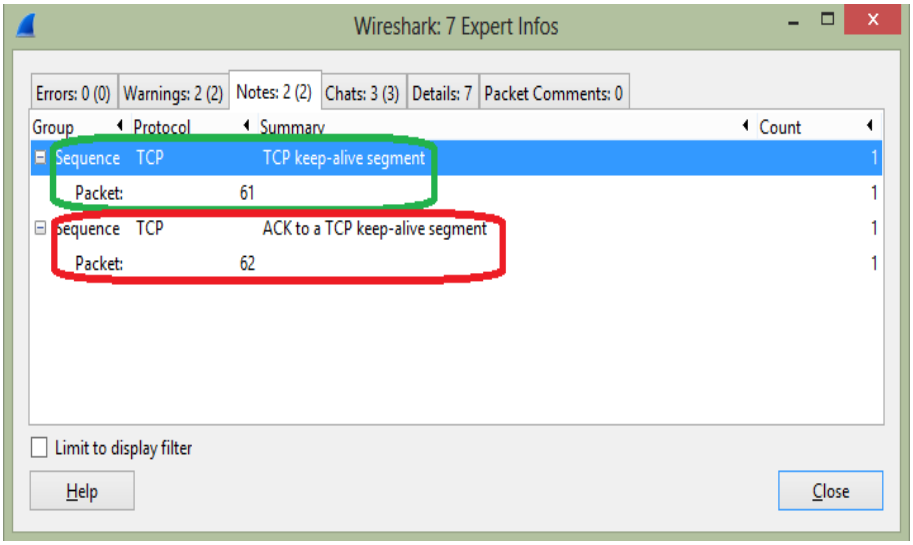
In this topic, we find Keep Alive/Keep Alive ACK Packets with Expert Infos in Wireshark.

Keep Alives and Keep Alive ACKs are typically used to check for dead TCP peers and avoid time out of idle connections. They are not indications of problems.

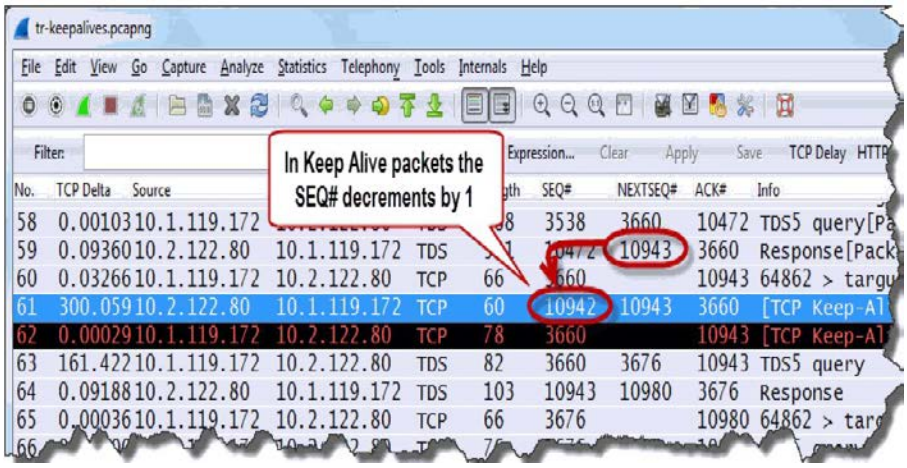
Step 1: Open ***tr-keepalives.pcapng***.

Step 2: Click the **Expert Infos** button on the Status Bar.

Step 3: Click the **Notes** tab. You can see **Keep Alives** and **Keep Alive ACKs**. Expand the **Keep Alive** and **Keep Alive ACK** lines. You can see Packets 61 and 62 listed.



Step 4: Click on the **Keep Alive** entry (Packet 61). This will take you to the main Wireshark window. Click the **Close** button to close the Expert Infos window. Display the **SEQ#**, **NEXTSEQ#** and **ACK#** columns. For Packet 61, you can find that Sequence Number field value has been decremented by 1 from 10,943 to 10,942.

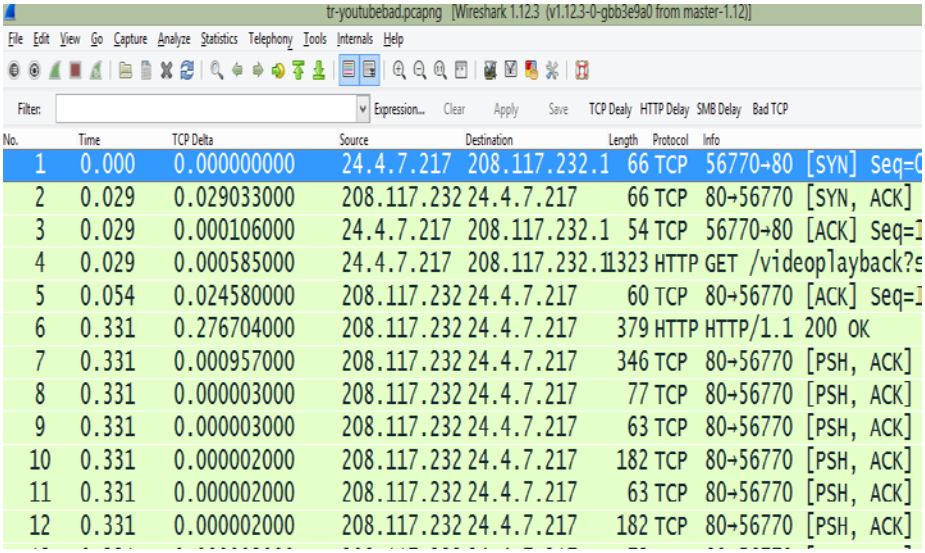


Topic 165: Wireshark Lab 63

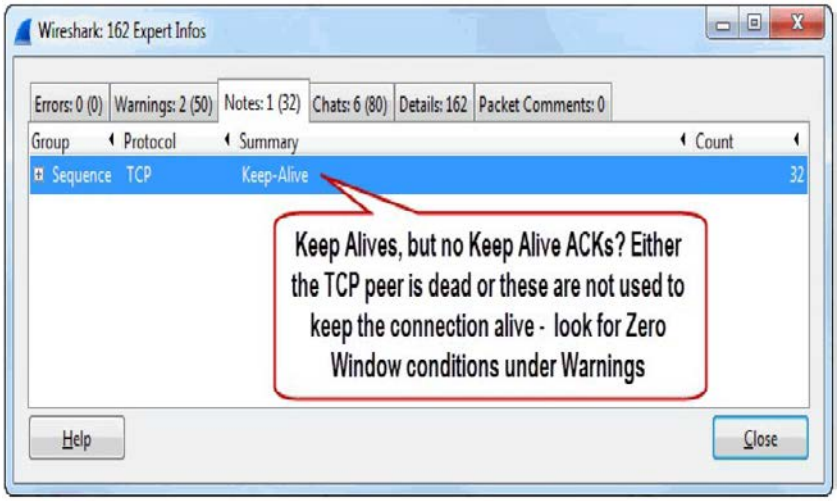
In this topic, we identify Keep Alive Packets used in Zero Window Conditions in Wireshark.

The two sides of a TCP conversation advertise their receive buffer space in the Window Size Value field. It is a 2-byte field whose maximum value can be 65,535 bytes. Over today's high-speed links, if a receiving application is slow in pulling data out of the receive buffer, it's not unusual that the advertised Window Size value can drop to zero – Zero Window Condition. Hosts can send TCP Keep Alives in place of Window Zero Probes. When a TCP host sends a Keep Alive to a peer that is advertising a Zero Window condition. You will not see Keep Alive ACK responses.

Step 1: Open ***tr-youtubebad.pcapng***.

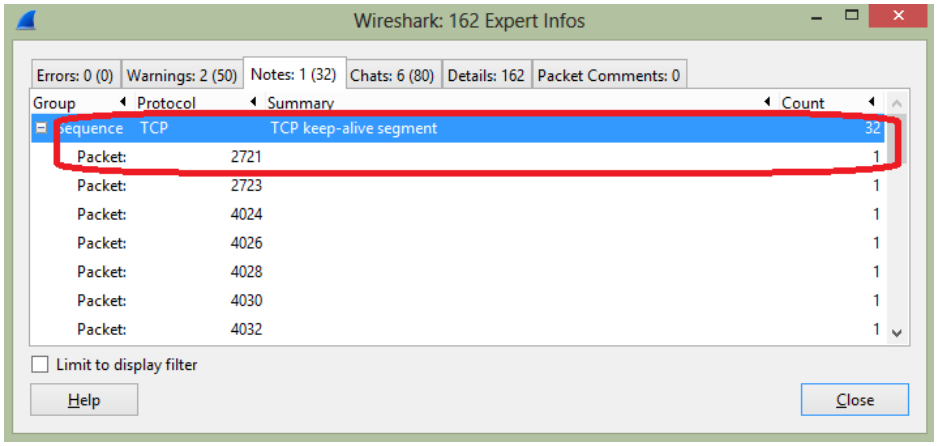


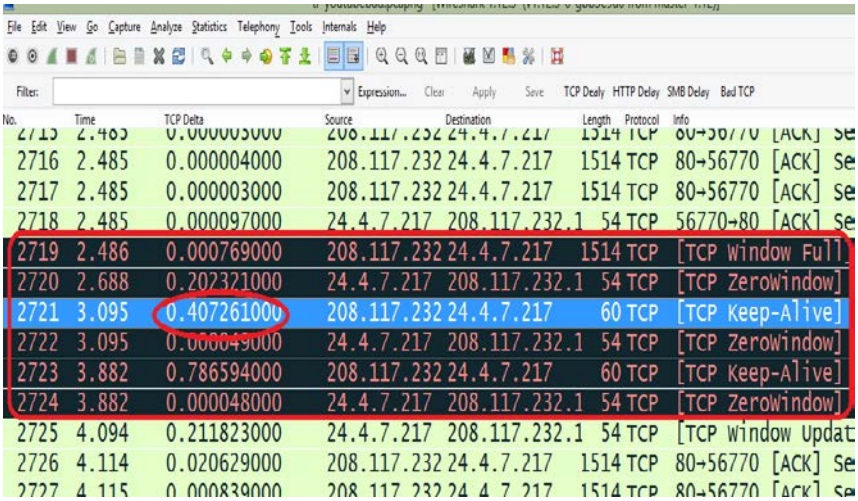
Step 2: Click the **Expert Infos** button on the Status Bar and then click the **Notes** tab.



During a successful keep alive process, hosts exchange Keep Alives and Keep Alive ACKs. In this case, either the peer is dead or this is not a standard keep alive process.

Step 3: If you expand the **Keep-Alive** section, you will find **Packet 2,721** the first Keep Alive listed. Click on it and then click the **Close** button to return to the main Wireshark window.





You can see that the first Keep Alive occurs almost 400 ms after a packet from the peer. It is not used to check for a dead peer. It is used to determine if Window Update (Window Size value has increased) has taken place.

Topic 166: Causes of Reused Ports

In this topic, we explain reused ports and their causes.

Sometimes Reused Ports are not a problem. Other times Reused Ports can cause significant delays in communications. Mostly, we can reuse port numbers without any problem as long as the previous TCP connection is terminated. Let's assume a client establishes a TCP connection with a server using source port number 1026 and destination port number 80. After a while, without terminating the previous connection, it tries to establish another new connection with same port number. In this case, if the first connection had been terminated, then reused ports would have not been a problem. Reused Ports become issue, when previous connection has not terminated (through TCP FINs/RSTs).

When Wireshark detects a previous SYN packet using the same IP address/port number combination in a trace file, then it marks SYN packets with the Reused Ports Expert Analysis definition.

What Causes Reused Ports?

Reused ports can be seen if

A) An application defines a static source port number, or

B) An application uses a very small range of source port numbers.

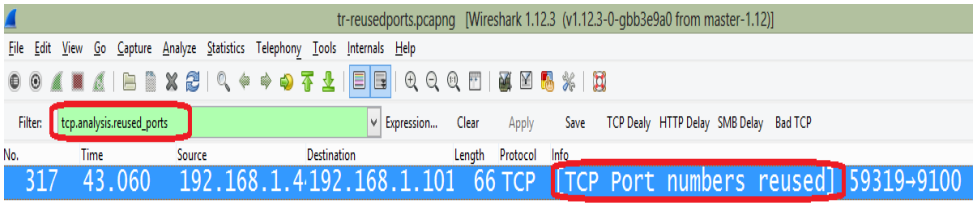
C) A host is going through a lot of source port numbers very quickly.

Topic 167: Wireshark Lab 74

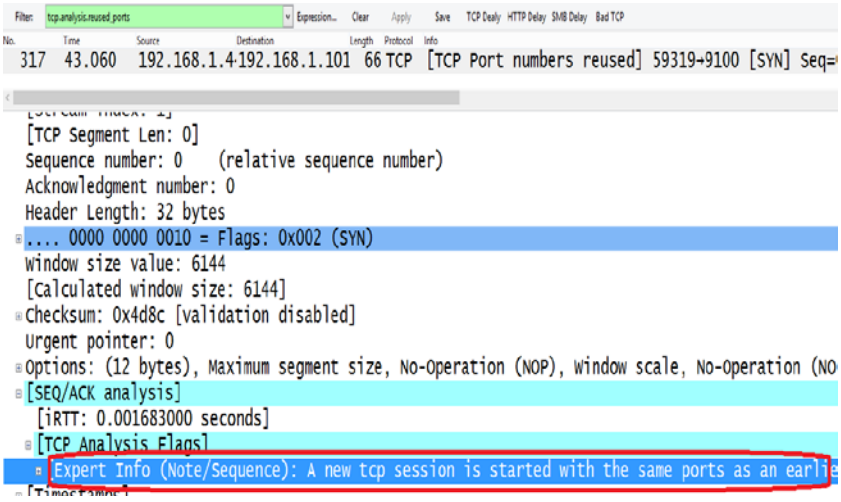
This topic uses a filter to count reused port Packets in Wireshark.

Step 1: Open ***tr-reusedports.pcapng***.

Step 2: Type the filter **tcp.analysis.reused_ports** in the display filter area. Click **Apply**. In this trace file, Wireshark has detected one Reused Port as indicated by Status Bar.



Step 3: Expand the **[SEQ/ACK analysis]** section of the resued port packet whose number is 317. This area is colored cyan. Wireshark associates cyan with Expert Infos **Notes**.



Step 4: Let's remove filter by clicking the **Clear** button.

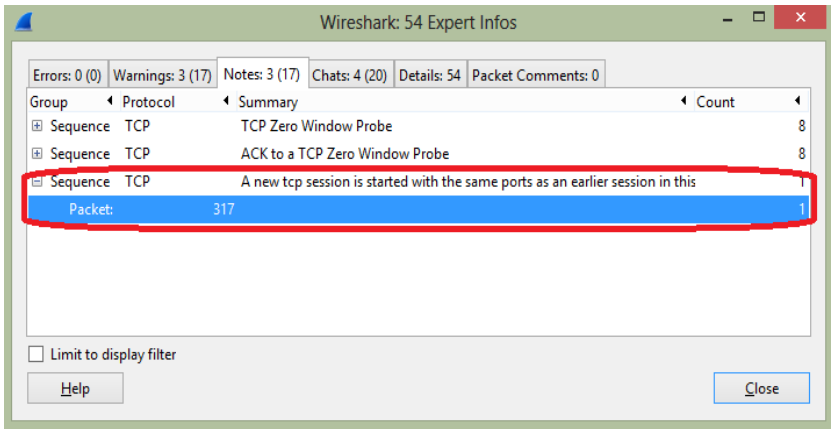
Topic 168: Wireshark Lab 75

This topic finds Reused Ports with Expert Infos in Wireshark.

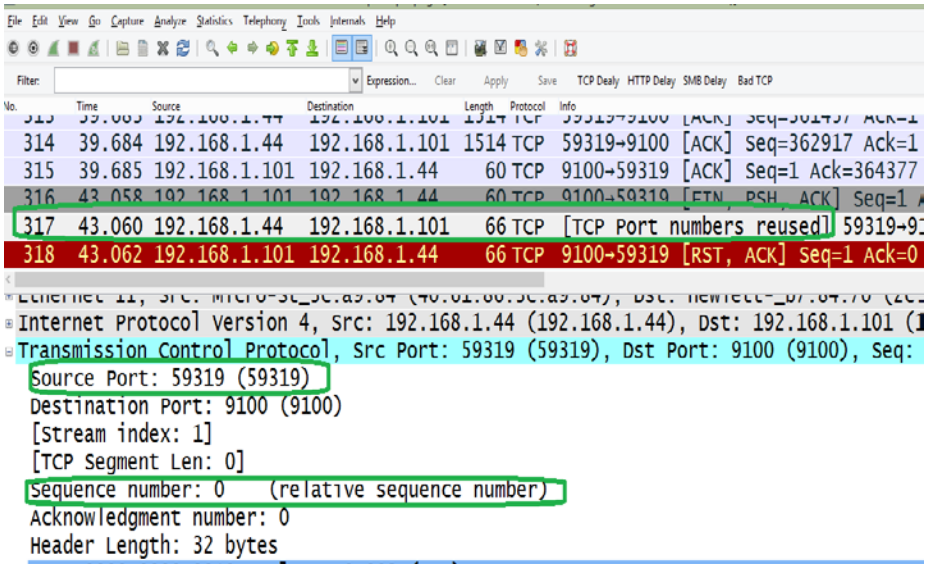
Step 1: Open ***tr-reusedports.pcapng***.

Step 2: Click the **Expert Infos** button on the Status Bar.

Step 3: Click the **Notes** tab. Expand the **A new tcp session is started with the same ports as an earlier session in this trace** section. Click on Packet **317**. Close the Expert Infos window by clicking **Close.** Wireshark will take you to main Wireshark window.



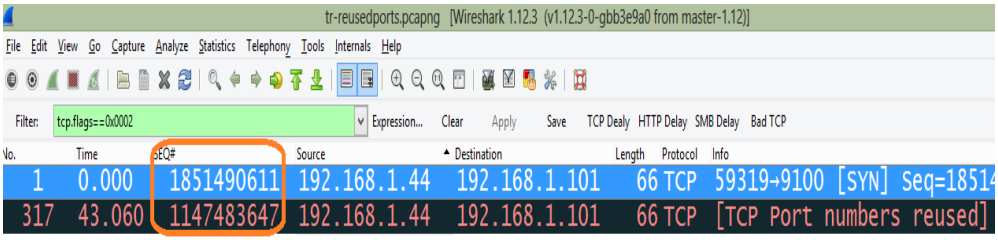
Step 4: As expected, the Reused Ports packet shown is a SYN packet. This packet uses IP address 192.168.1.44 and port 59319.



Step 5: The sequence number field can be used to determine whether the SYN belongs to a unique connection request, a retransmission or a reused port. Wireshark applies a relative sequence number to TCP. In the Packet Details pane of any packet, right-click on the **TCP header.** Select **Protocol Preferences** and toggle ***Relative sequence numbers*** off.

Step 6: To view the sequence number value of SYN packets. Enter **tcp.flags==0x0002** in the display filter area and click **Apply**. You will find only 2 packets.

Step 7: Display your **SEQ#** column to view the sequence numbers quickly. The sequence numbers are different. Packet 317 would be a retransmission if they were the same.



Step 8: To turn the ***Relative sequence numbers*** preference setting on, click on a **TCP header** in the Packet Details pane, select **Protocol Preferences**.

Topic 169: Causes of Checksum Errors

This topic explains checksum errors and their causes.

A checksum is used to detect errors (e.g., flipped bits) in a transmitted segment. In TCP/IP model, UDP, TCP, IPv4 and link-layer protocols check against errors using a checksum. By default, Wireshark does not perform TCP, UDP or IPv4 checksum validation. Wireshark's Checksum validation processes can be enabled/disabled easily using the Preference settings. To enable checksum validation for IPv4, TCP and UDP, select the **Preferences** button on the Main Toolbar. Expand the Protocols section and select **IPv4**. Check the ***Validate the IPv4 checksum if possible*** preference setting.

Causes of Checksum Errors

A faulty Network Interface Card (NIC) or any device that alters the content of the packets along the path. On a capturing device, task Offloading. By task offload, we mean that numerous processes are offloaded to a network interface card to free up a host's CPU for other tasks. Assume you are capturing your own traffic to and from your machine on which Wireshark is running. You would see Checksum Errors on all outbound traffic if

(a) Task offloading is enabled on that host, and

(b) Wireshark checksum validation processes are enabled.

Topic 170: Wireshark Lab 76

This topic detects checksum errors with Expert infos in Wireshark.

Step 1: Open ***tr-checksums.pcapng***.

Step 2: To enable checksum validation for IPv4, TCP and UDP, select the **Preferences** button on the Main Toolbar.

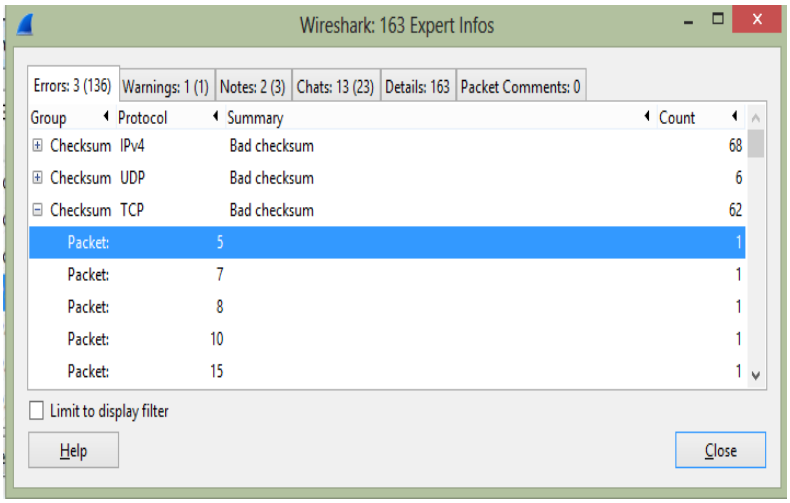
Step 3: Expand the Protocols section and select **IPv4**. Check the ***Validate the IPv4 checksum if possible*** preference setting.

Step 4: Repeat step 3 for **TCP**.

Step 5: Repeat step 3 for **UDP**. Click **OK** to save these preference settings. You will see that the coloring in the Packet List pane changes. Packets from 192.168.1.72 have a black background and red foreground.

Step 6: Click the **Expert Infos** button on the Status Bar.

Step 7: Go to **Errors** tab. You can see 68 bad IPv4 checksums, 6 bad UDP checksums and 62 bad TCP checksums. Expand the **TCP Bad Checksum** section.



Step 8: Packet 5 is the first TCP Bad Checksum entry. Click on it. This will take you to the main Wireshark window. You can see that the packets from 192.168.1.72 when arrived at the target do not contain error. The target acknowledged receipt of the packets, processed them, and replied to the requests. Host with 192.168.1.72 is configured to use task offloading.

Step 9: Disable, IPv4, UDP and TCP checksum validation settings.

Topic 171: Wireshark Lab 77

This topic uses DNS errors Filter in Wireshark.

Two most common DNS errors are 1) a server failure (Reply Code 2), and 2) a name error, listed as Non-Existent Domain, (Reply Code 3).

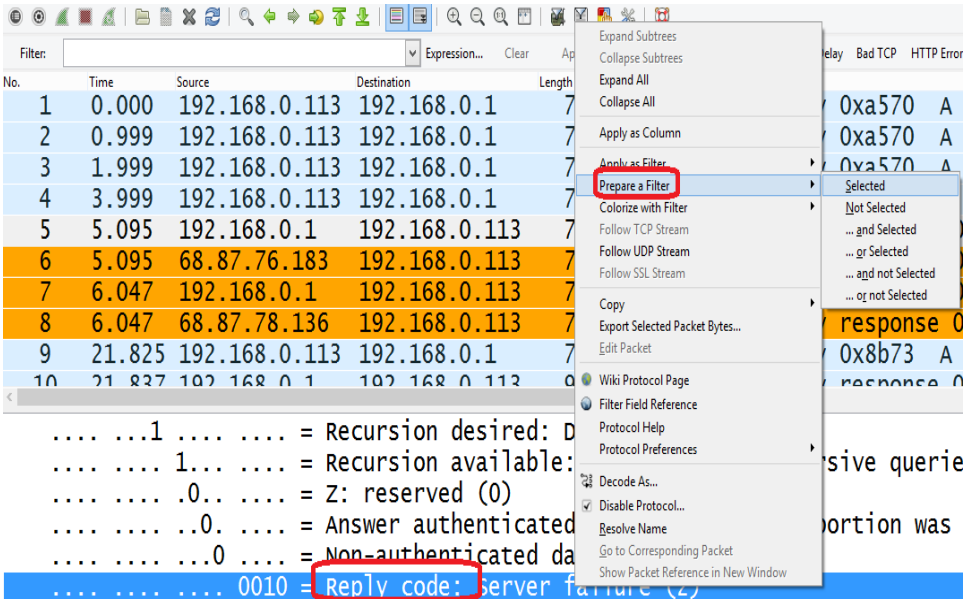
To quickly identify DNS errors in a trace file, let's create a button.

Step 1: Open ***tr-dnserrors.pcapng***.

Step 2: Packet 5 is the first DNS response. Click on it. From the Info column, we can see that it is a Server Failure reply.

Step 3: In **Packet 5**, right-click on the **Domain Name System (response)** line and select **Expand Subtrees**. You will find the DNS Reply Code field inside the Flags section.

Step 4: Right-click on the **Reply code** field and select **Prepare a Filter | Selected**.

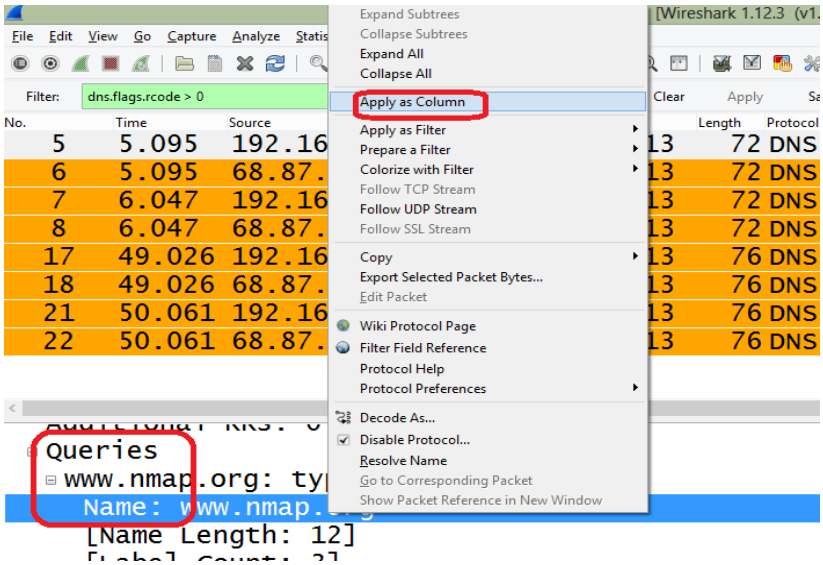


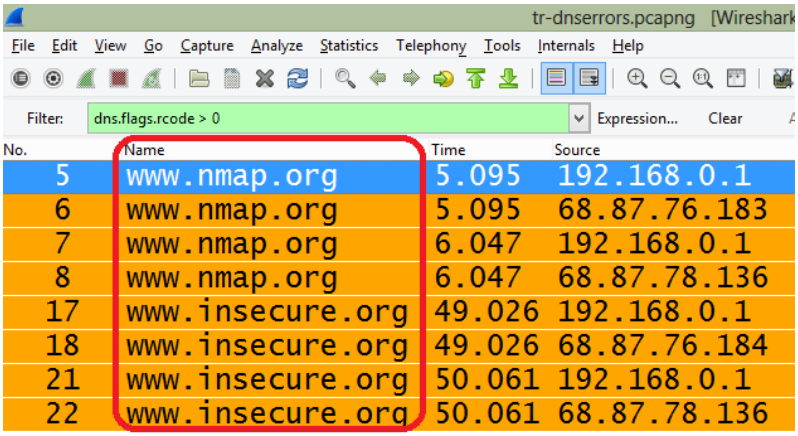
Using this filter will locate Server Failures. As we want to create a button to display DNS errors. All such packets will have values larger than 0 in the **dns.flags.rcode** field.

Step 5: Type **dns.flags.rcode > 0** and click the **Save** button. Rename the button's name to **DNS Errors** and click **OK**.

Step 6: Click the new **DNS Errors** button. You will find that there are eight DNS error responses in this trace file.

Step 7: Expand the **Queries** section in Packet Details pane of a response. Right click on the **Name** field and **Apply as Column**. This will determine what name(s) generated these responses





The errors can be because of a server upstream from our local server is not responding to recursive DNS queries.

Step 8: Click the **Clear** button to remove filter.

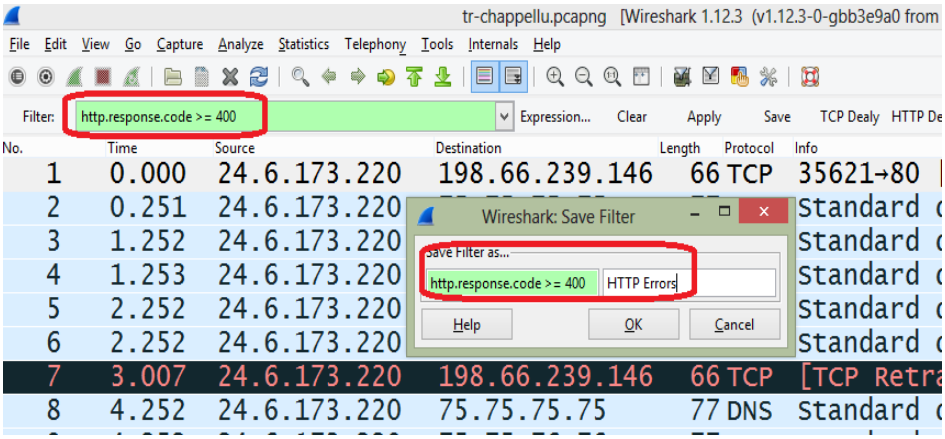
Topic 172: Wireshark Lab 78

This topic uses an HTTP errors filter in Wireshark.

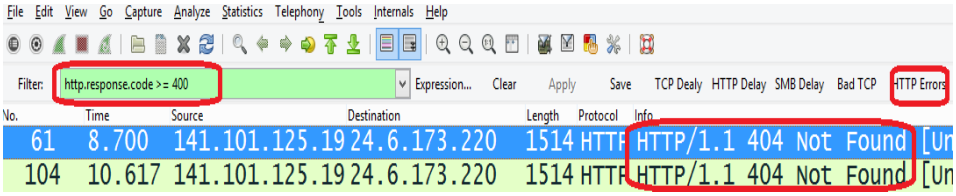
We will create a button, which when clicked will quickly identify HTTP errors in your trace files.

Step 1: Open ***tr-chappellu.pcapng***.

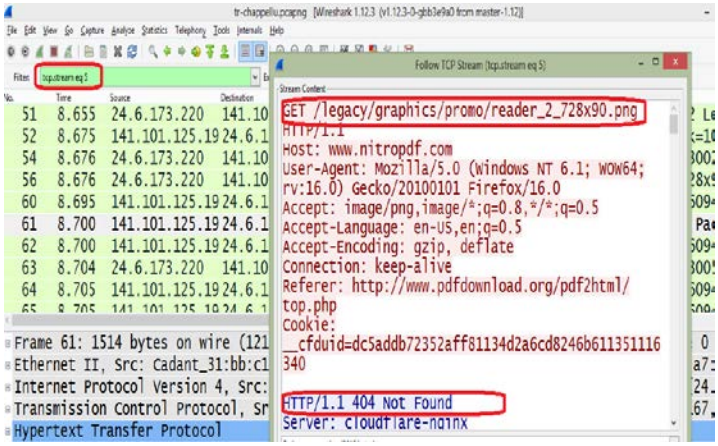
Step 2: Type **http.response.code >= 400** in the display filter area and click the **Save** button. Let's name the button **HTTP Errors** and click **OK**.



Step 3: Click the newly created **HTTP Errors** button. This will identify the two HTTP error responses in this trace file. The codes are 404 "Not Found" errors.



Step 4: Right-click on **Packet 61** and select **Follow TCP Stream**. This will allow us to figure out what item was not found on the server. **Follow TCP Stream** applies **a** filter based on the Stream Index number. Also, a window is opened that depicts the conversation without headers.



Step 5: Click **Clear** to remove the filter.

Figures and Material used for Part3 (from Topics 173 to 192) have been adapted from A. Jesin's "Packet Tracer Network Simulator", 2014.

Topic 173: Introduction to Packet Tracer

This topic provides an introduction to Packet Tracer.

Packet Tracer is a network simulator from Cisco. It allows you to get a taste of everything in Cisco without needing to purchase real hardware. With Packet Tracer, complex topologies with tens of Cisco devices can be designed and troubleshot. You can also watch the packets moving between them. A wide range of Cisco switches and routers, several end devices such as PCs and servers and wireless devices from Linksys, are available in Packet Tracer.

Layer	Cisco Packet Tracer Supported Protocols
Application	• FTP , SMTP, POP3, HTTP, TFTP, Telnet, SSH, DNS, DHCP, NTP, SNMP, AAA, ISR VOIP, SCCP config and calls ISR command support, Call Manager Express
Transport	• TCP and UDP, TCP Nagle Algorithm & IP Fragmentation, RTP
Network	• BGP, IPv4, ICMP, ARP, IPv6, ICMPv6, IPSec, RIPv1/ v2/ng, Multi-Area OSPF, EIGRP, Static Routing, Route Redistribution, Multilayer Switching, L3 QoS, NAT, CBAL , Zone-based policy firewall and Intrusion Protection System on the ISR, GRE VPN, IPSec VPN
Network Access/ Interface	• Ethernet (802.3), 802.11, HDLC, Frame Relay, PPP, PPPoE, STP, RSTP, VTP, DTP, CDP, 802.1q, PAgP, L2 QoS, SLARP, Simple WEP, WPA, EAP

Packet Tracer Workspaces

Two workspaces are supported; logical and physical. In the logical workspace, we can build logical network topologies by placing, connecting, and clustering virtual network devices. The physical workspace provides a sense of scale and placement in how network devices such as routers, switches, and hosts would look in a real environment

Packet Tracer Modes

It supports two operating modes—real-time mode and simulation mode. In real-time mode, all network activities take place with immediate real-time response. The simulation mode allows a user to control time intervals, and the propagation of data across a network.

Installation of Packet Tracer

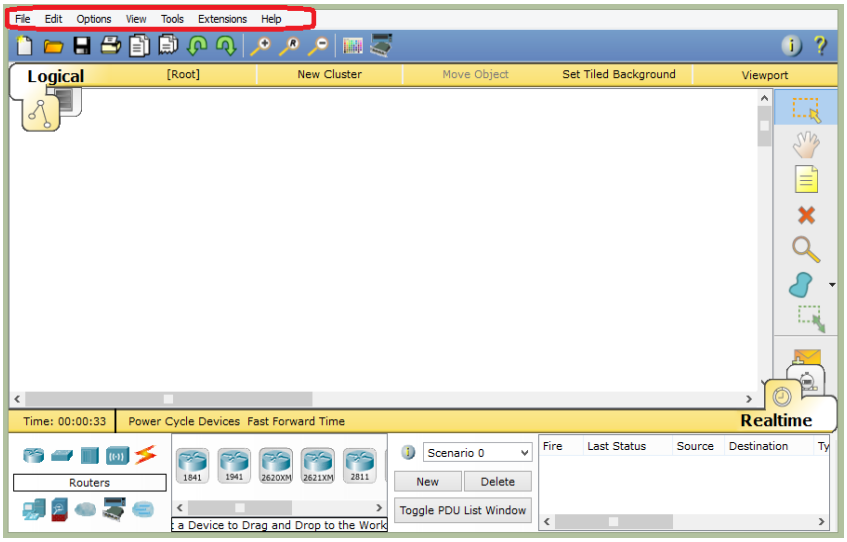
You can download the latest version of Packet Tracer for free from www.netacad.com/about-networking-academy/packet-tracer.

Topic 174: Packet Tracer's Interface Overview

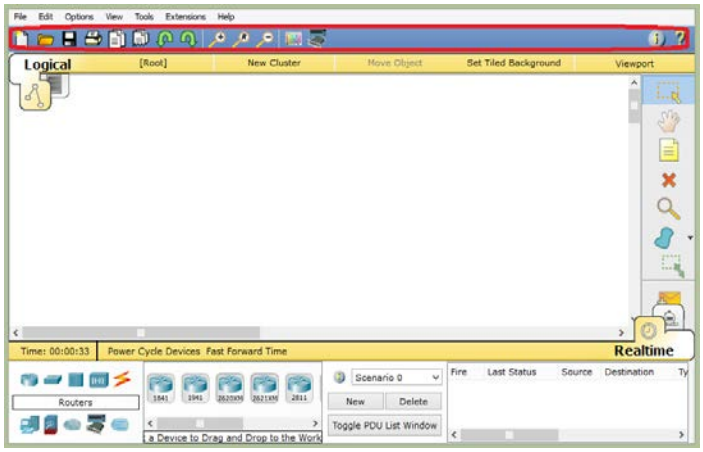
This topic has a look at the Interface of Packet tracer.

The layout of Packet Tracer can be divided into several components.

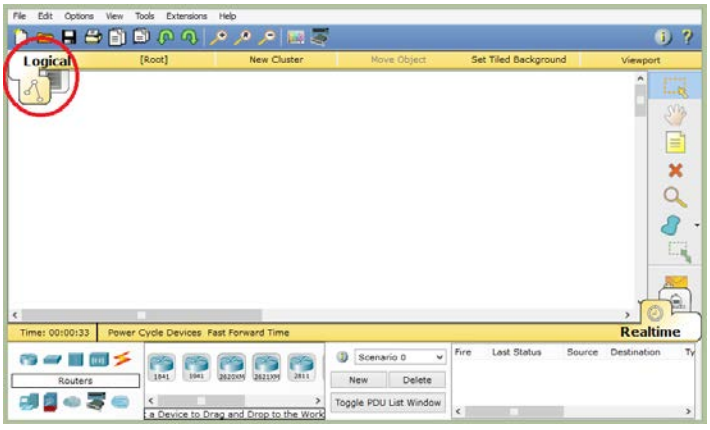
Menu bar: This is a commonly found menu. It is used to open, close, print, save, change preferences, and so on.



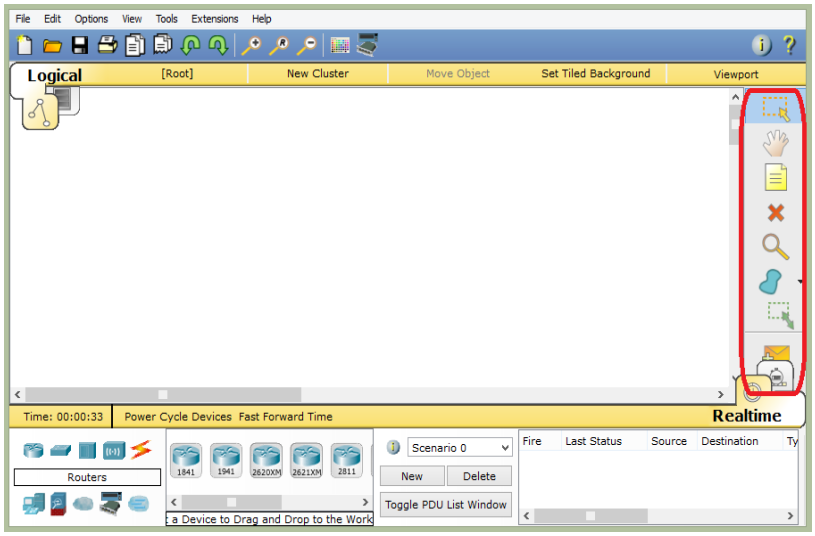
Main toolbar: This bar contains shortcut icons to menu options that are frequently accessed. For example, open, save, zoom, undo, and redo.



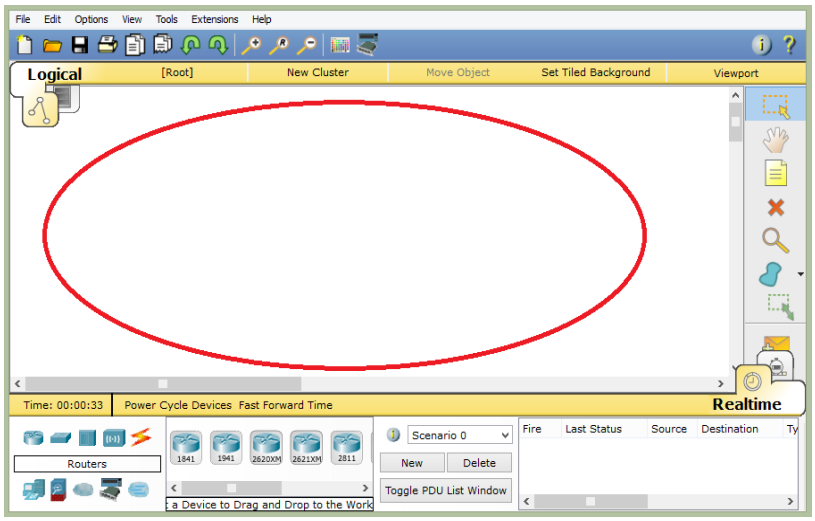
Physical/Logical workspace tabs: These tabs allow you to choose between the **Logical** and **Physical** work areas.



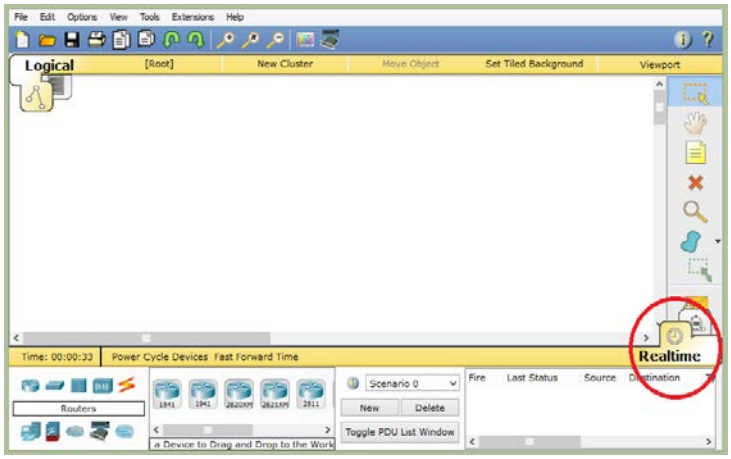
Common tools bar: With help of this toolbar, we can manipulate topologies. For example, select, move layout, place note, delete, resize shape, add simple/complex Protocol data unit (PDU).



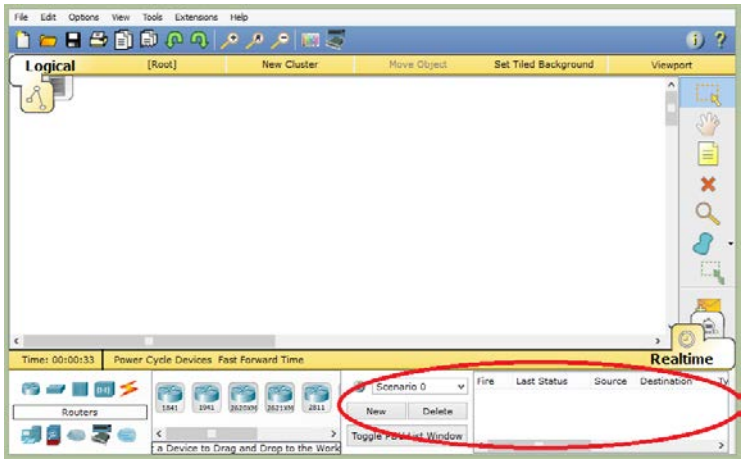
Workspace: Here, we create topologies and display simulations.



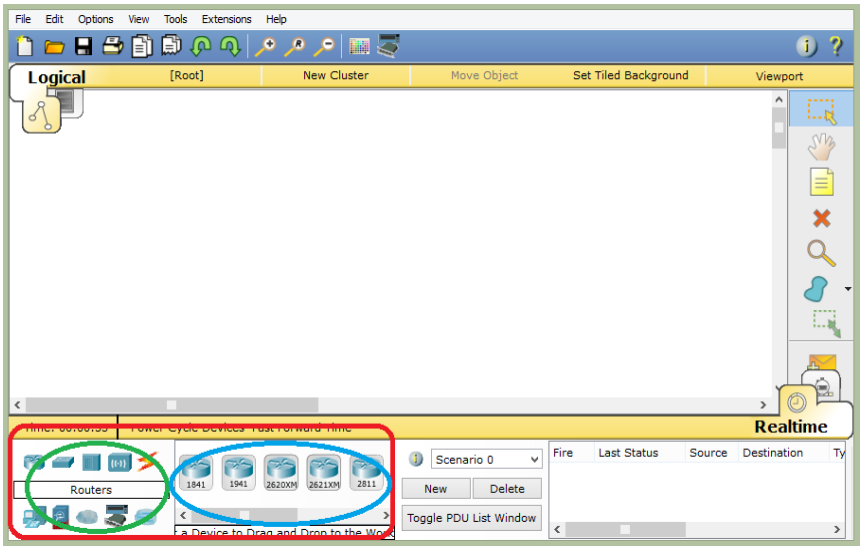
Real-time/Simulation tabs: With these tabs, the operating mode can be switched between the real and simulation modes. Buttons are also provided to control the time.



User-created packet box: From this area, you can create highly-customized packets in order to test your topology.



Network component box: All of the network and end devices available in Packet Tracer are listed in this component. It can be sub-divided into two areas:



Device-type selection box: Device categories are given here.

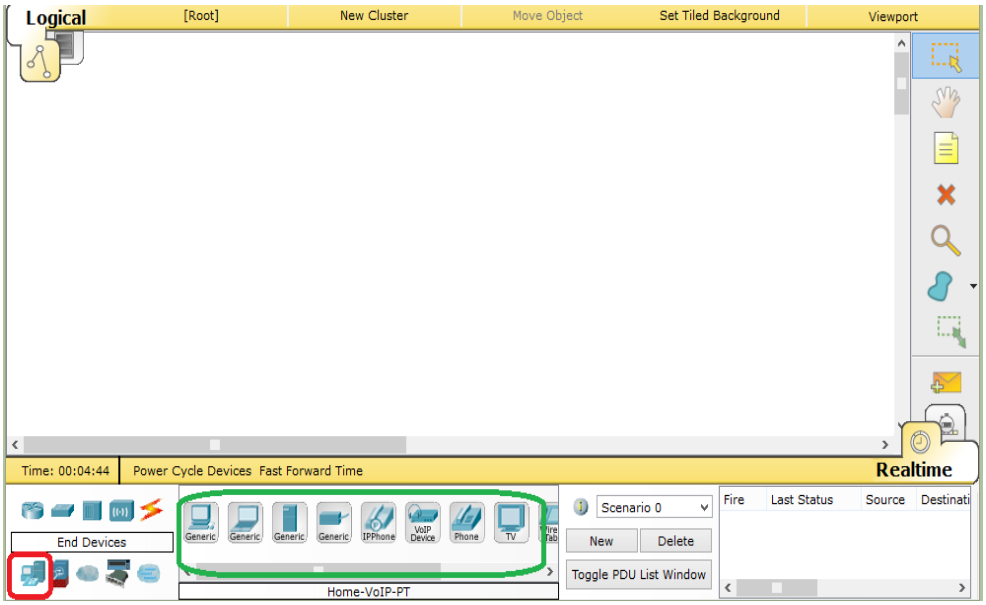
Device-specific selection box: Given a device category, this box displays different device models within that category.

Topic 175: Creating a Simple topology

In this topic, we create our first simple topology in Packet Tracer.

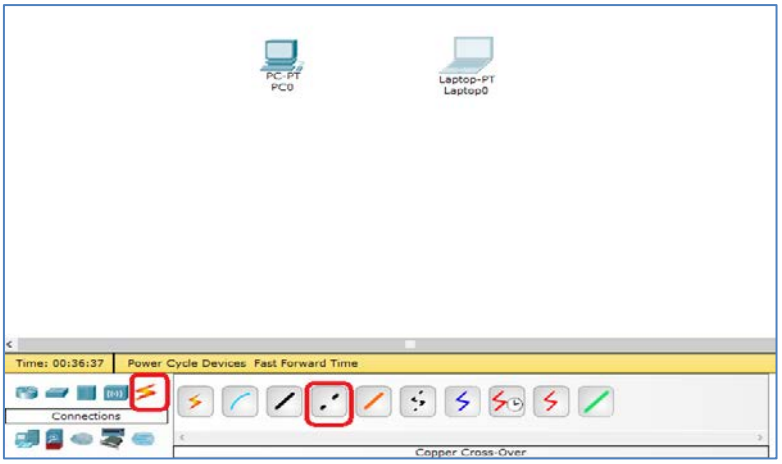
Step 1: Run Packet Tracer.

Step 2: Click **End Devices** in **Device-type selection box**. This will select the end devices category in **Device-specific selection box**.



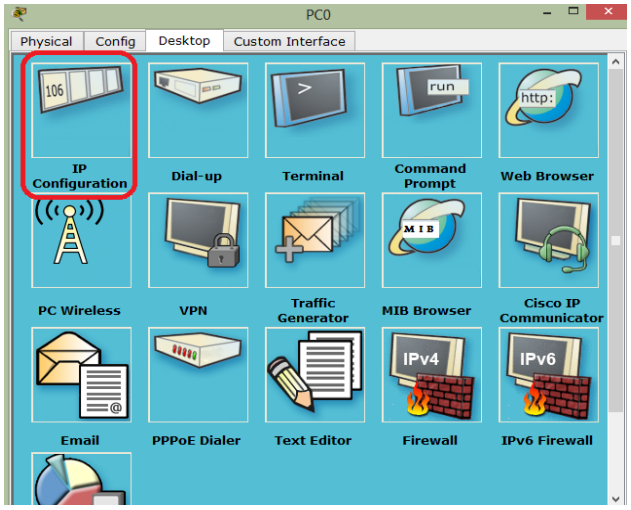
Drag-and-drop a **Generic** PC icon into the Workspace. Do the same for a **Generic** laptop icon.

Step 3: Click on **Connections** in **Device-type selection box**. Then, click on **Copper Cross-Over** in **Device-specific selection box**.

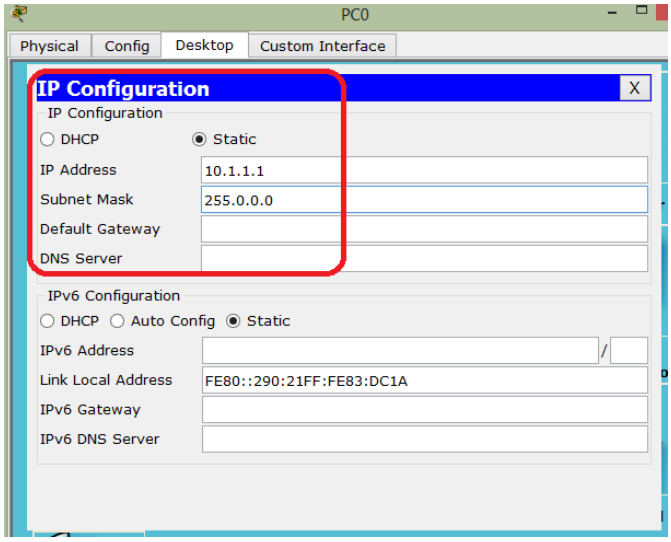


Now, click on **PC0**, and select **FastEthernet**. Click on **Laptop0** and select **FastEthernet**. When the link is up, the color of link status LED becomes green.

Step 4: Click on the PC, and go to the **Desktop** tab.

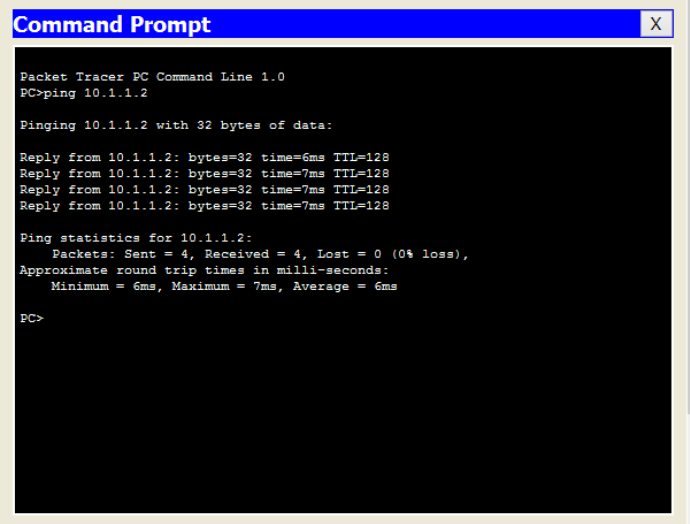


Click on **IP Configuration**, and enter an IP address and subnet mask. No information required for a default gateway and DNS server. Close the window



Step 5: Repeat step 4 for the laptop. Make sure that both of the IP addresses are in the same subnet.

Step 6: Click on the laptop, open the **command prompt**, and ping the IP address of the device at the other (PC) end to check connectivity.



Step 7: This topology can be saved by going to **File** | **Save As**. The topology with the devices in the same state will be saved with a **.pkt**.

Topic 176: Introduction to Cisco and PT devices

This topic describes Cisco and PT devices available in Packet Tracer.

Network devices form the core of networking. Routers, switches are used to Interconnect end devices such as PCs, laptops, servers.

Routers in Packet Tracer: To examine the Cisco and **Generic** routers. Select **Routers** in the **device-type selection box**, then, go to the **device-specific selection box**.

Cisco 1841: An **Integrated Service Router** (**ISR**). Contains two Fast Ethernet ports, two slots for **High Speed WAN Interface Cards** (**HWICs**), and one slot for **Advanced Integration Module** (**AIM**).

Cisco 1941: Similar to **Cisco 1841.** But runs on Cisco IOS Version 15. There are two ports that operate at Gigabit Ethernet speeds.

Cisco 2620XM: A multiservice router. It contains one Fast Ethernet port, two slots for WAN interface cards, and one slot for AIM.

Cisco 2621XM: Similar to Cisco 2620XM, except that this router has two Fast Ethernet ports.

Cisco 2811: An ISR router with two Fast Ethernet ports, four WIC slots, and a dual slot for AIM.

Cisco 2901: Two Gigabit Ethernet ports, four WIC slots, and two **Digital Signal Processor** (**DSP**) slots. Cisco IOS Version 15 runs on it.

Cisco 2911: Three Gigabit Ethernet ports and all the other features of **Cisco 2901**.

Generic Router: contains 10 slots, and is a custom router running on Cisco IOS.

Switches in Packet Tracer: To examine the Cisco and **Generic** switches. Select **Switch** in the **device-type selection box**, then, go to the **device-specific selection box**.

Cisco 2950-24: a managed switch. There are 24 Fast Ethernet ports.

Cisco 2950T-24: It has two Gigabit Ethernet ports in addition to the 24 Fast Ethernet ports.

Cisco 2960-24TT: It contains 24 ports and has **Small Form-factor Pluggable** (**SFP**) modules.

Cisco 3560-24PS: It is a layer 3 switch and performs routing and switching. The suffix **PS** means it supports **Power over Ethernet** (**PoE**). It can power up IP phones without using power adapters.

Bridge PT: It is a device used to segment a network with only two ports.

Generic Switch PT: It is a customizable Packet-Tracer switch with 10 slots and several modules and runs on Cisco IOS.

Hub PT: It is a Packet Tracer device with 10 slots, and is an oldest way to connect end devices.

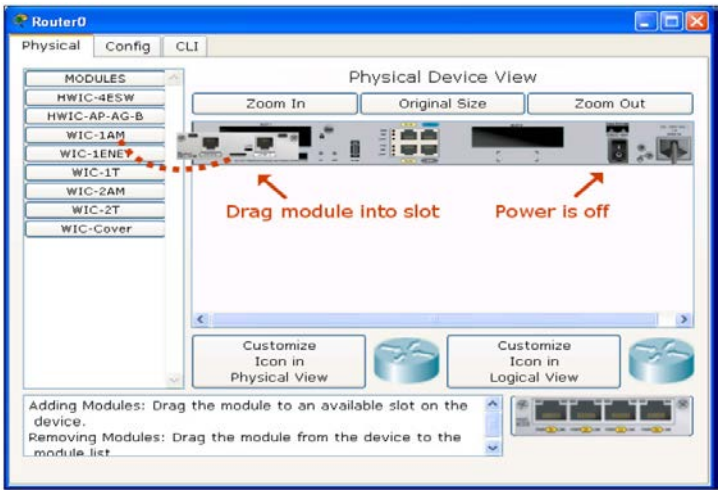
Repeater PT: It is used to boost the signal on a wire when the distance between two points is high.

Coaxial Splitter PT: It is used to split a single coaxial connector into two. It contains three coaxial ports.

Topic 177: Customizing Devices with Modules

In this topic, we customize devices with modules and learn naming conventions in PT.

A piece of hardware that contains several device interfaces e.g. **HWIC-4ESW** (High-Speed WAN Interface Card) is a module having four Ethernet (10 MBps) ports. There is a power switch located on the right-hand side of each device. If you see a green LED on the power switch, then it indicates that device is powered up. If you want to add a module, you need to click on this switch to turn the device off. This is similar to a real router/switch. Drag a module from the modules list and drop it onto an empty slot. The module will automatically return to the module list, in case it does not fit into that slot.



A module can be removed by first, powering off the device and then, dragging it from the slot back to the module list.

Naming convention for Interfaces:

Router Interfaces can be identified by their names. The interfaces can be broadly grouped as:

Copper Ethernet Interface: is a normal LAN interface, employs RJ-45 connector with a copper cable. **Ethernet** (10 MBps), **FastEthernet** (100 MBps), and **GigabitEthernet** (1000 MBps). A number followed by **E**, **FE**, **CE**, **CFE,** or **CGE** is used to identify modules with **Ethernet** interfaces. **SW** is used for those modules, which provide switching features when used on routers. **Examples:**

- **HWIC-4ESW** (four Ethernet switching ports)
- **WIC-1ENET** (single Ethernet port)
- **NM-1E** (single Ethernet port)
- **NM-1FE-TX** (single Fast Ethernet port)

Fiber Ethernet Interface: similar to **Copper Ethernet Interface** but employs fiber cables. **Examples:**

- **NM-1FE-FX** (single Fast Ethernet fiber media).

Serial Interface: synchronous modules are identified by **T** while asynchronous – **A/S.**

Examples:

- **WIC-1T** (a single synchronous serial port)

Modem Interface: these interfaces consist of RJ11 ports with analog telephone cables and are identified by **AM.**

Examples:

- **WIC-8AM** (eight RJ11 ports)

If you have created a device that you have customized with a set of modules, you can save it for future use. 1- Drag-and-drop a network device into the work area. 2- Turn the device off. 3-Add modules to it. 4- Click **Tools** | **Custom Devices Dialog.** 5- Click **Select**, and then click on the device that was just customized. 6- Provide a name, and then click on **Add** and **Save.** The device is saved with a .ptd extension.

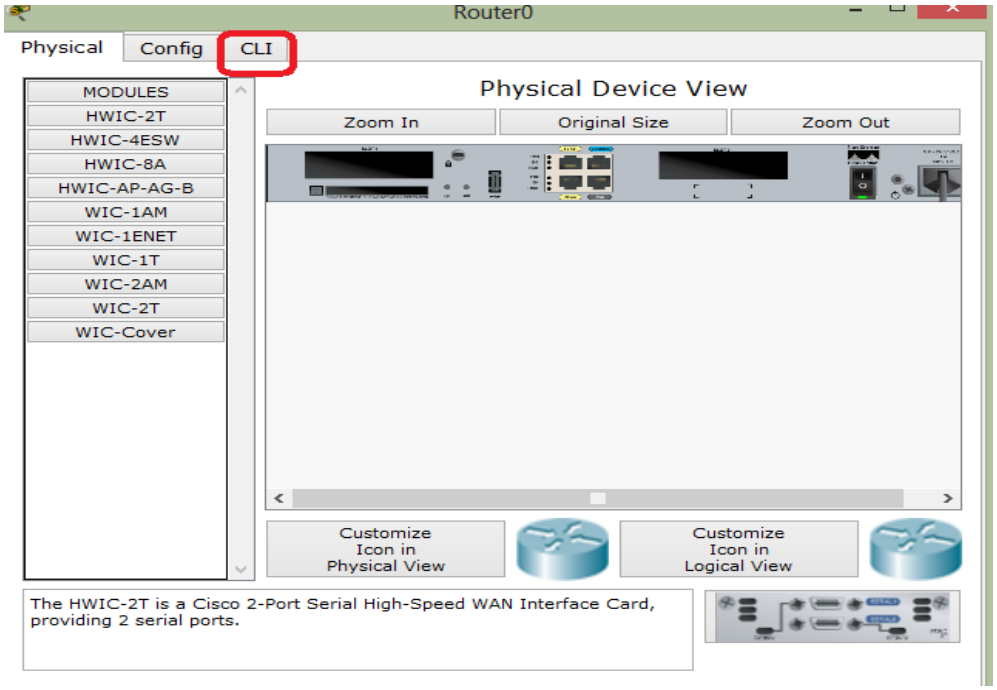
Topic 178: Accessing CLI of a Device

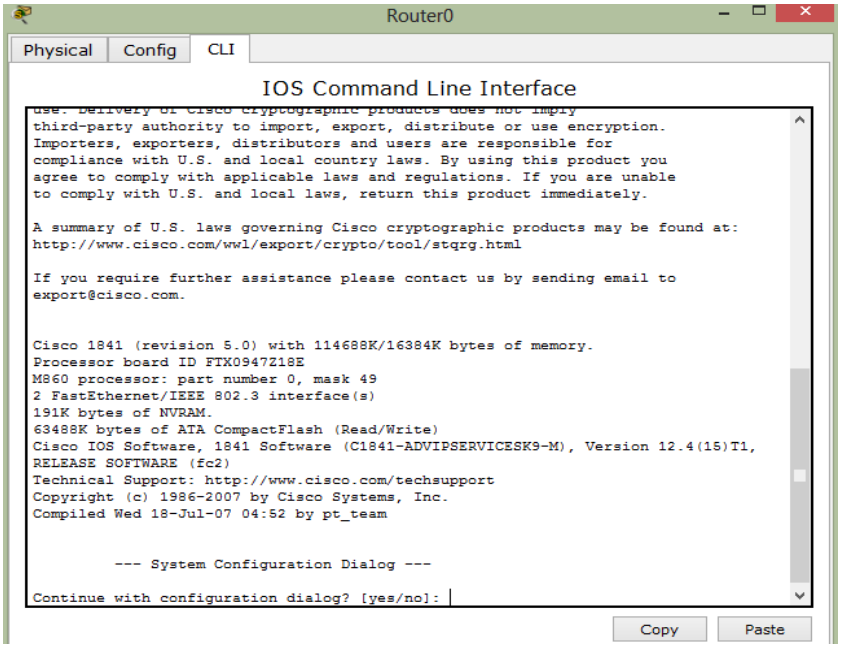
In this topic, we describe how to access Command Line Interface (CLI) of a device in Packet Tracer.

There are two ways to access the Command-line Interface of a device in Packet Tracer:

The CLI Tab: It can be used to configure devices e.g. you can assign IP addresses to router interfaces. You can use Paste and Copy buttons to copy text to and from the

command line. Click on a network device, go to the **CLI** tab to access the Cisco IOS command line interface, and you can enter commands as on a real device (router).





You should refer to the HELP files which lists the IOS commands supported by Packet Tracer.

The Console port: No difference with respect to CLI tab method. The use of console port makes the topology look similar to the real world. Let's illustrate with an example.

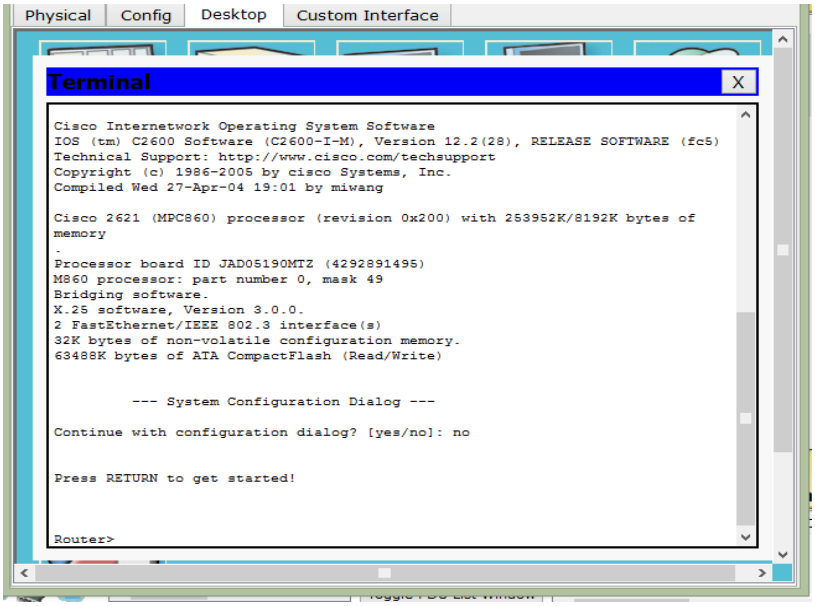
Step 1: Click **End Devices** in **Device-type selection box** and then drag and drop a PC or laptop from **Device-specific selection box** to the workspace.

Step 2: In a similar fashion, add a router, let's say **2621 XM**.

Step 3: Click **Connections** in **Device-type selection box** and then select console port from **Device-specific selection box** to the workspace.

Step 4: Connect the console cable of the network device to the RS-232 port of the PC/laptop.

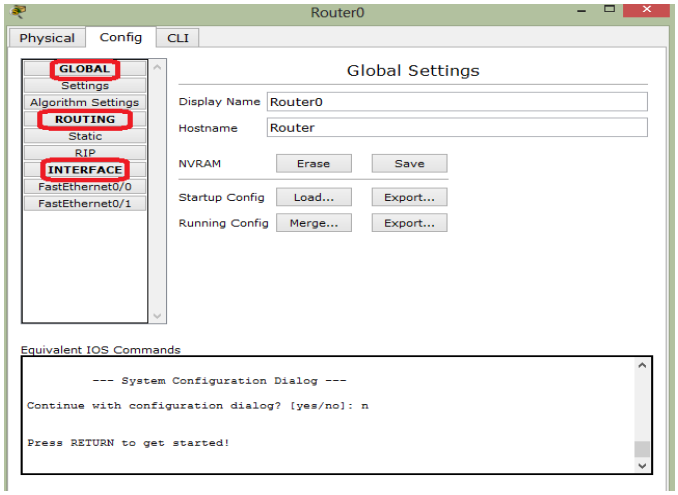
Step 5: Click the PC/laptop, go to the **Desktop** tab, and open **Terminal.** Click **OK** with the default settings to view the console. The router's console through its terminal is displayed:



Topic 179: Configuring Devices with Config Tab

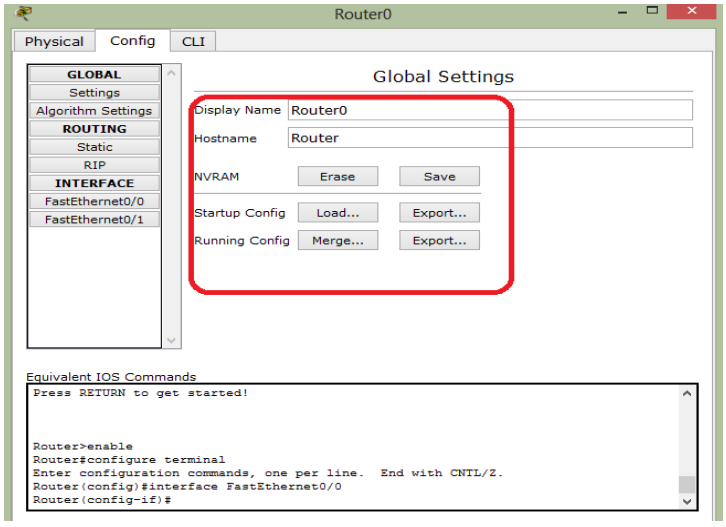
In this topic, we configure routers/switches using the config tab in Packet Tracer.

You can configure Cisco routers and switches without using a single command. This becomes possible by using a **Config** tab. The **Config** tab contains a Graphical User Interface (GUI) options for the most common configurations. As you fiddle with a GUI, the equivalent Cisco IOS commands are also displayed.



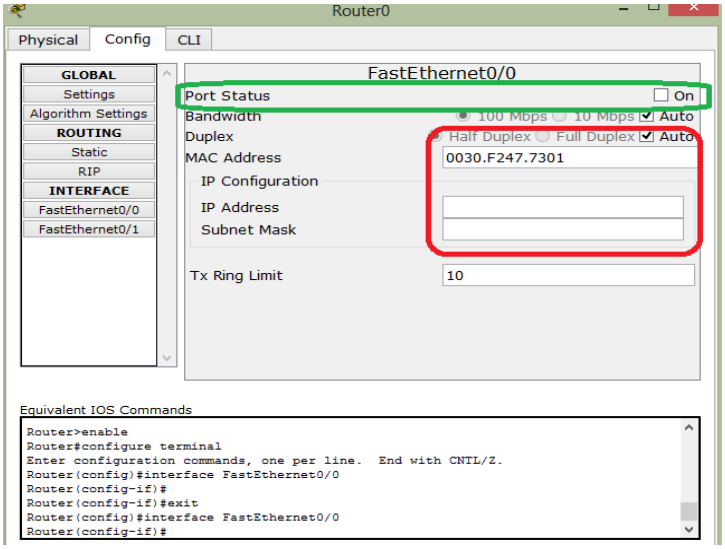
There are 3 general levels of configurations: Global, Routing, and Interface.

Global Settings: You can change the router's name. This can also be done directly in the workspace. The configuration file of a device can also be saved, erased, or exported.

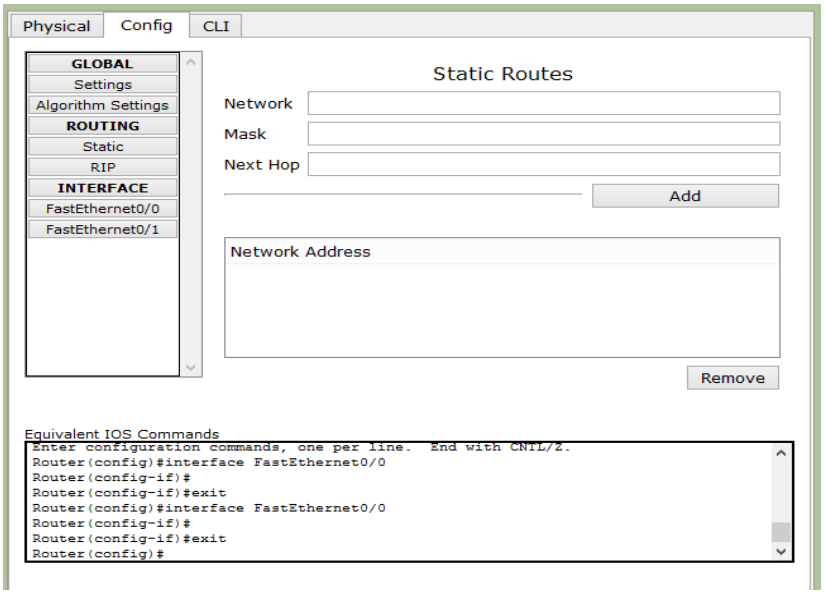


The **Global's Algorithm Settings** are meant for advanced users. You can minutely tweak your device to see how it responds to certain situations.

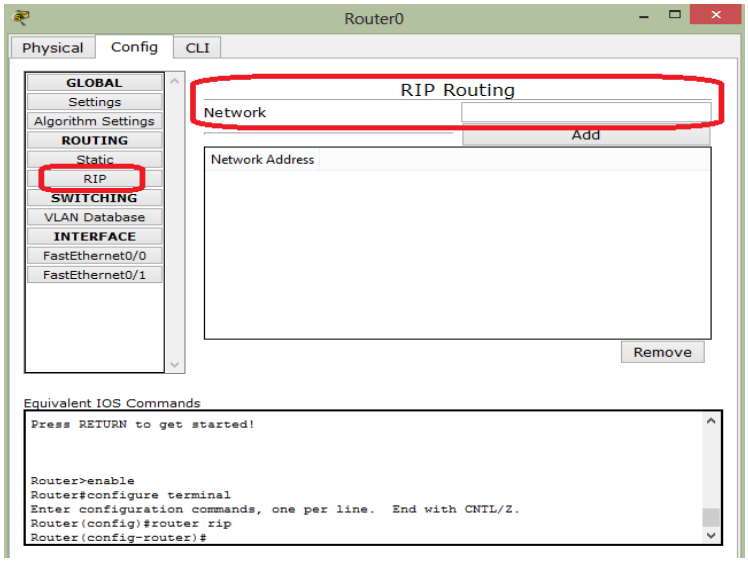
Interface Settings: The IP, MAC addresses and subnet mask can be entered here. To view the port status, you need to check the "On" of "Port status".



Routing Settings: Here, there are two options for configuring **static** and **dynamic** routing. For static routing configuration, you can enter network address, net mask, and its next hop address, and then click on **Add**.



Dynamic routing such as Routing Information Protocol (RIP) can be configured by adding only the network IP.



VLAN database: Available on a switch. It allows you to create and remove VLANs.

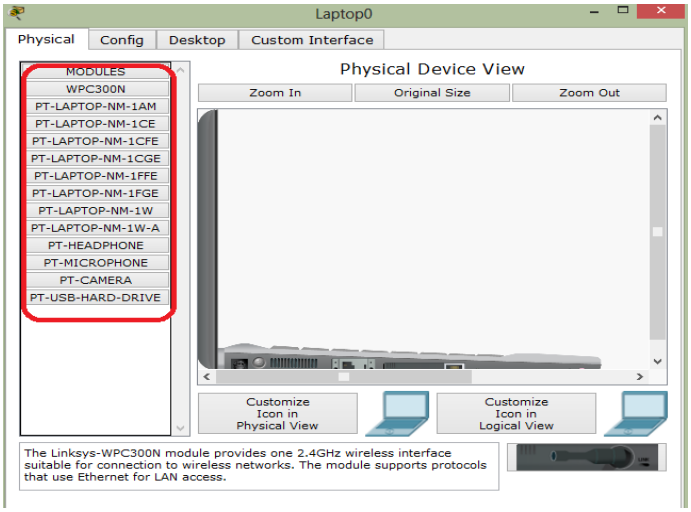
Topic 180: Generic IP End Devices in PT

This topic describes Generic IP End Devices in Packet Tracer.

Network devices such as switches, routers are the core of a network. End devices (PCs, servers) are the ones that use this core. PCs, laptops, tablets, personal digital assistant (PDAs), and a TV a wide range of end devices are available in PT. We can group them

- A) clients
- B) server
- C) Other devices

A) Clients: Desktops and laptops: As far as usability is concerned, there is no difference between them. Most usable and highly configurable client devices. Next, we describe those modules which are available for desktops and laptops. Addition and removal of a module require a device to be switched off.



Linksys-WMP300N: Through this wireless interface, you can configure a WLAN.

PC-HOST-NM-1AM: It can be used as a modem as it provides RJ11 interface.

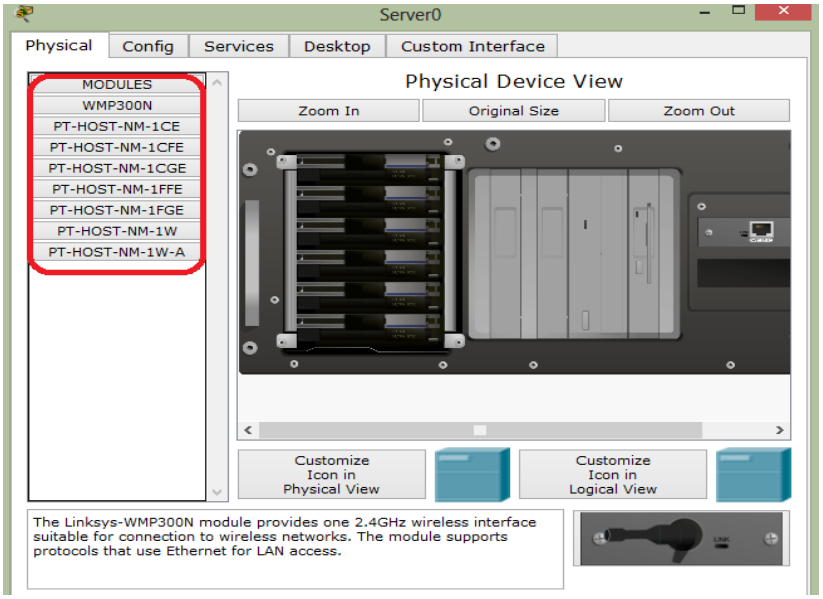
PC-HOST-NM-1CE, **PC-HOST-NM-1CFE**, **PC-HOST-NM-1CGE**: Through these modules, **Ethernet**, **FastEthernet**, and **GigabitEthernet** connections are provided respectively.

PC-HOST-NM-1FFE, **PC-HOST-NM-1FGE**: Fiber version of the previous module.

PC-HOST-NM-1W, **PC-HOST-NM-1W-A**: Wireless interface for WLAN. The first has a frequency of 2.4 GHz and the second has 5GHz.

PC-HEADPHONE, **PC-MICROPHONE**, **PC-CAMERA**, **PC-USB-HARD-DRIVE**: No functionality associated with them.

B) Servers: Space for two network interfaces. Modules available are the same as PC modules, except **PC-HOST-NM-1AM** module.

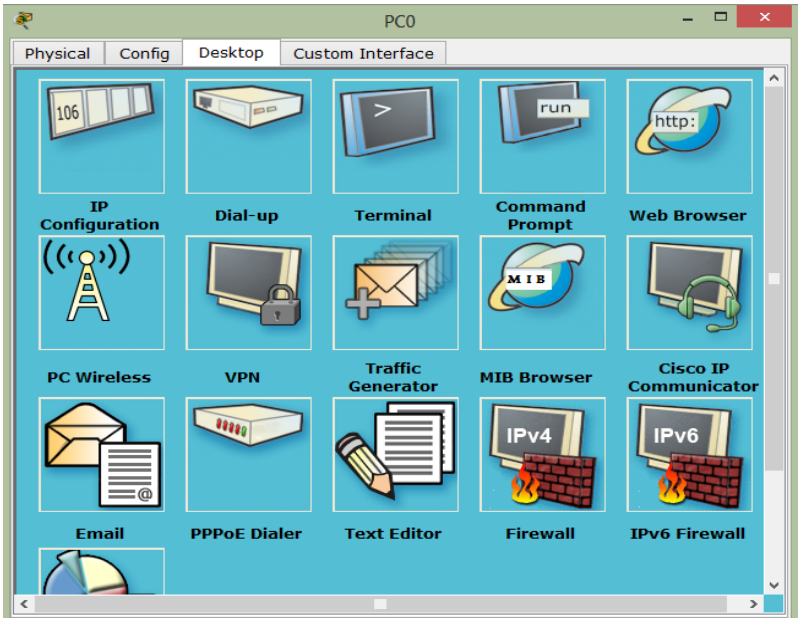


Let's look at services that are available for servers. **HTTP service:** Both HTTP and HTTPS (HTTP employing Secure Sockets Layer (SSL) protocol) protocols can be supported by a web server. You can also create and edit static HTML pages. **DHCP service:** can assign IP addresses to routers. You can create and edit DHCP pools of IP addresses. The default pool is called **serverPool**, which cannot be removed or edited. **DNS service:** resolves domain names to IP addresses. **AAA service:** Authentication, Authorization, and Accounting and supports RADIUS and TACACS authentication protocols. **NTP:** Network Time Protocol ensures that the clocks of all devices are synchronized properly. **EMAIL services: SMTP** and **POP3** services are supported. **FTP Services:** Users can be created and permissions can be granted to them. **Firewall:** You can configure rules based on source/destination IP addresses and source/destination port numbers. Connections can be allowed or denied.

Topic 181: Configuring End Devices in PT

This topic configures End devices in Packet Tracer.

Click on an end device in the workspace, then go to the **Desktop** tab. A lot of utilities are available here. These can be used for testing and debugging the network.

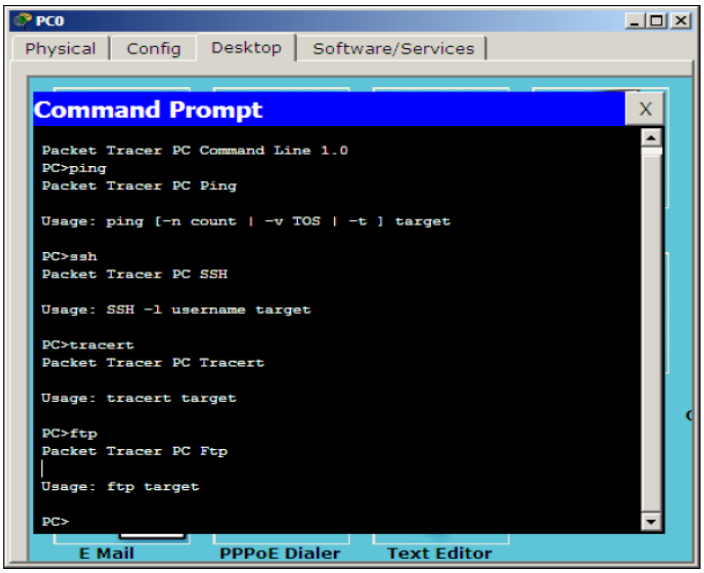


IP Configuration: With this utility, you can assign a dynamic or static IP address to an end device. If you choose to enter a static IP address, **Subnet Mask** field gets filled according to the class of the IP address. In case you want your devices to obtain IP dynamically, then choose **DHCP** here. Configure **DHCP** on **Server-PT**.

Dial-up: End devices such as **PC-PT** and **Laptop-PT** have the **PC-HOST-NM-1AM.** This utility allows to simulate a modem dialer.

Terminal: This utility can be used for accessing the CLI through the console port. **Server-PT** device does not enjoy this utility as it does not have an RS-232 interface.

Command Prompt: It simulates the command line offered by Windows OS. Commands such as **arp, delete, dir, ftp, help, ipconfig, netstat, nslookup, ping, ssh, telnet tracert**.



Web Browser: It can be used with a **Server-PT** configured with HTTP. It provides only **back**, **forward**, **go**, and **stop** buttons. Cache or history are not available.

PC Wireless: Using this utility, you can display information such as signal strength of a **Linksys-WMP300N** module.

VPN: Virtual private network (VPN) is used to create connection for secure communication. This works when a router has been configured as a VPN server.

Traffic Generator: With this utility, you can create customized packets and send them at periodic intervals. Similar to the **Add Simple Protocol Data Unit (PDU)** and **Add Complex PDU** tools**.**

MIB Browser: The Management Information Base (**MIB**) Browser utility allows you to generate Simple Network Management Protocol (**SNMP**) requests.

Cisco IP Communicator: A computer can be turned into an IP phone with the help of this utility. It is not available on the **Server-PT.**

Email: You can send and receive emails with the help of this utility.

Text Editor: You can use this utility to create, edit, and save text files.

Topic 182: Packet Tracer's Simulation Mode

This topic discusses simulation mode of Packet Tracer.

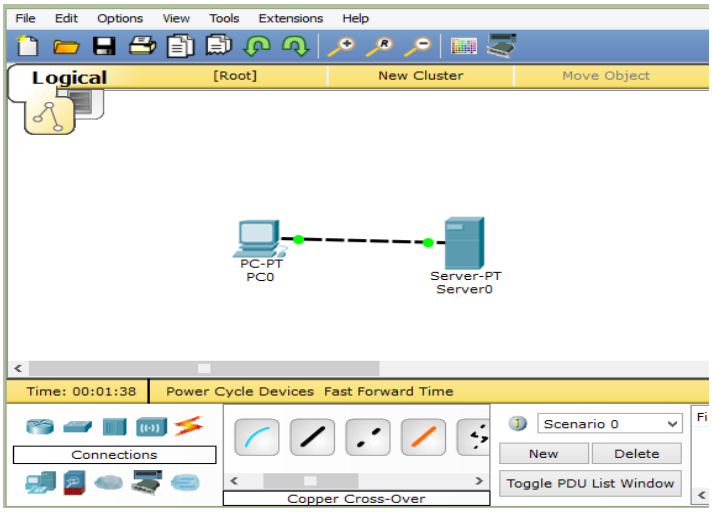
In Packet Tracer's simulation mode, you can observe packets flowing from one device to another. Also, when you can click on a packet, you can see detailed information about the TCP/IP layers.

Step 1: Open Packet Tracer

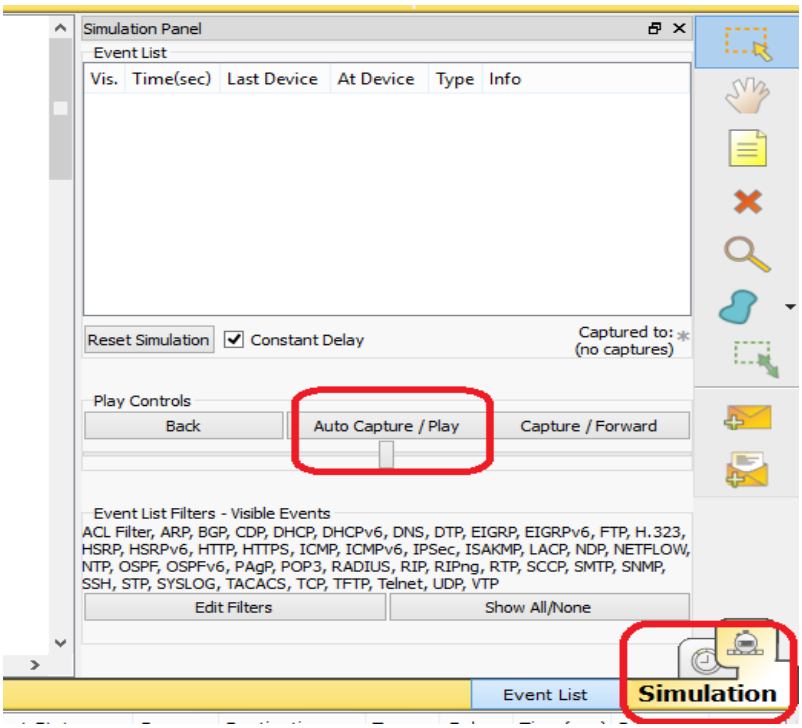
Step 2: Add a PC and a server to the workspace.

Step 3: Connect two devices with a copper crossover cable.

Step 4: Assign IP addresses. **PC:** 192.168.0.1/255.255.255.0 and **Server:** 192.168.0.2/255.255.255.0. Both of them are in the same subnet.

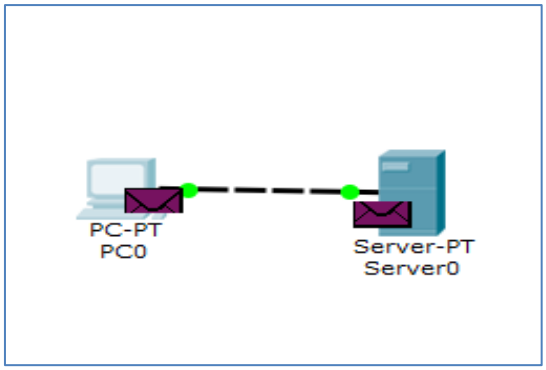


Step 5: Click on the **real time/simulation** tab and switch to the simulation mode.

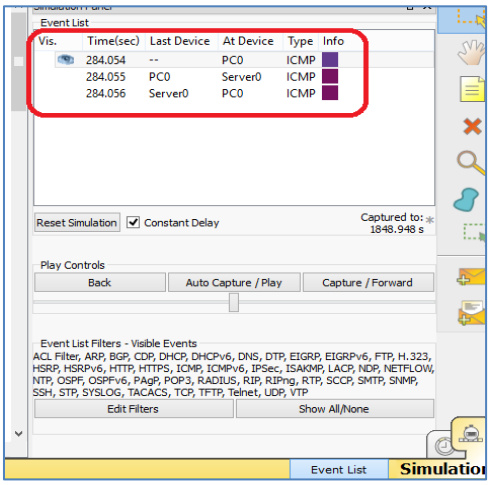


Step 6: Click on the **Auto Capture / Play** button. Packet capture begins.

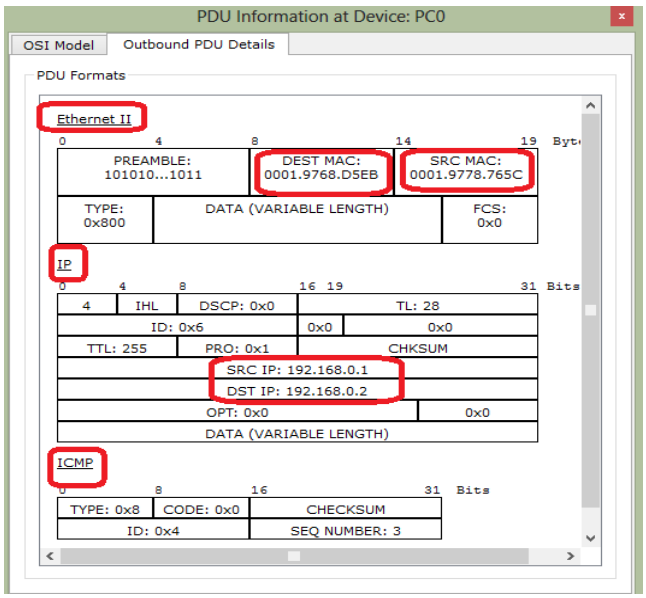
Step 7: From the **common tools** bar, click on the closed envelope icon. Click on the PC first and then on the server.



In the event list, you will observe three entries: creation of an ICMP packet, ICMP echo sent, and ICMP reply received.



To view a packet's TCP/IP layers information, click on a packet (the envelope icon). The **Outbound PDU Details** tab lists each layer's information.



The simulation mode has control buttons:

Back: Each time you click on it, the simulation moves one step back.

Auto Capture / Play: The network traffic will be continuously captured when it is pressed.

Capture/Forward: Each time, you want to move the packet from one place to another you have to press this button.

Topic 183: Connecting Devices and Link Status

This topic discusses how to connect devices and to check the link status in Packet Tracer.

In Packet Tracer, there are a number of cables available to connect devices. Click **Connections** icon from the **device-type selection box**. Now, you can view the various cables in **device-specific selection box.**

Automatically choose connection type: If you have no idea which cable to use, this option automatically allows two devices to get connected with the best cable.

Console: The console port of a network device can be connected to the RS-232 port on a PC/laptop. This allows you to view the network device's console from a PC/laptop.

Copper straight-through: It is a standard Ethernet cable that connects devices operating in different layers of the OSI model. For example, hub to router, switch to PC.

Copper cross-over: This Ethernet cable connects devices such as hub to hub, PC to PC, PC to router, and PC to printer i.e. devices operating in the same OSI layer.

Fiber: Connects Fast Ethernet and Gigabit Ethernet ports of a fiber port.

Phone: RJ11 cable. It connects the analog phone to a VoIP phone. Also, modem interface of routers can be connected.

Serial DCE and DTE: Serial cables connect routers together. There is a clock symbol on the **Data Circuit-terminating Equipment** (**DCE**) end. If you have selected Serial **Data Terminal Equipment (DTE)**, the DTE end will be the first device connected with this cable and the DCE end will be the next. In case of the Serial DCE cable, just the opposite happens.

Link status: Once you have connected devices together, you will find a light, at each end of the cable. The light indicates the state of the connection.

- **Bright green**: When the physical link is up, it is indicated by bright green. Status of the line protocol is not indicated by it.
- **Blinking green**: Link activity is represented by it.
- **Red**: In case a physical link is down, it is indicated by red. This can be due to incorrect cables or by a port being administratively shut down.
- **Amber**: When the port of a switch is running the **Spanning Tree Protocol** (**STP**) algorithm to detect layer 2 loops, the light becomes amber.

Topic 184: Testing Connectivity with PDUs

In this topic, we test connectivity with Protocol Data Units (PDUs) in Packet Tracer.

When you have created a topology in Packet Tracer, then you would like to test connectivity between devices. Connectivity can be tested by: using either simple or complex Protocol Data Units (PDUs), or pinging devices from their command-line interface. For large topologies, the PDU option is quicker.

Simple PDU

The **Add Simple PDU** tool relies on **Internet Control Message Protocol (ICMP**). Let's create a simple topology to demonstrate the working of simple PDU.

Step 1: Add a PC and a server to the workspace and connect them using a copper crossover cable.

Step 2: Click on PC and use IP configuration. Type: 192.168.0.1/255.255.255.0. Do the same for the server and type: 192.168.0.2/255.255.255.0.

Step 3: Go to the common tools bar, click on the closed **envelope icon** or simply press key ***P***. Click the envelope symbol on PC first and then on the server. Then, look at the **User Created Packet** box.

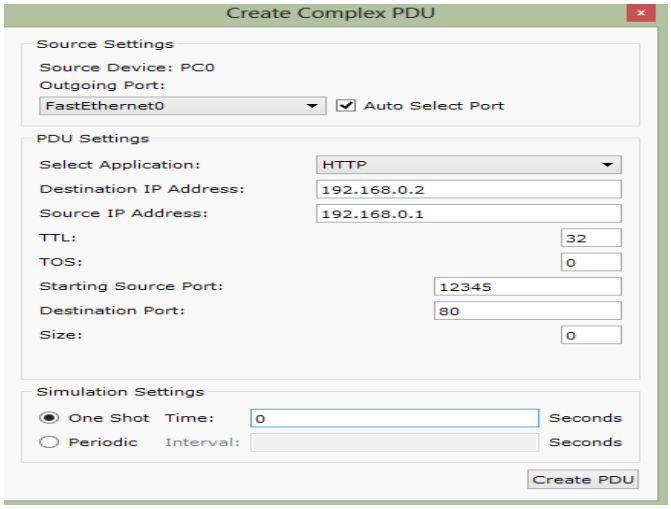
Fire	Last Status	Source	Destination	Type	Color	Time (sec)	Periodic	Num	Edit
	Successful	PC0	Server0	ICMP		0.000	N	0	(edit)

Complex PDU

We use the previous example to understand working of Complex PDU.

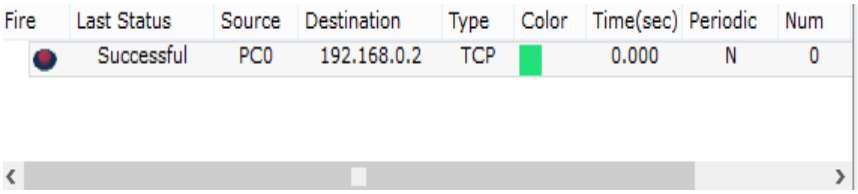
Step 1: Click on the open envelope icon or press *C*.

Step 2: Click on the PC. This opens the **Create Complex PDU** dialog box.



Select application as HTTP, fill the **Destination IP address =** 192.168.0.2, **Starting Source Port**, (let's say 12345), and **Time = 0,** and then click on the **Create PDU** button.

Step 3: Now, click on the server. Examine the **user-created packet box**.



Fire	Last Status	Source	Destination	Type	Color	Time(sec)	Periodic	Num
	Successful	PC0	192.168.0.2	TCP		0.000	N	0

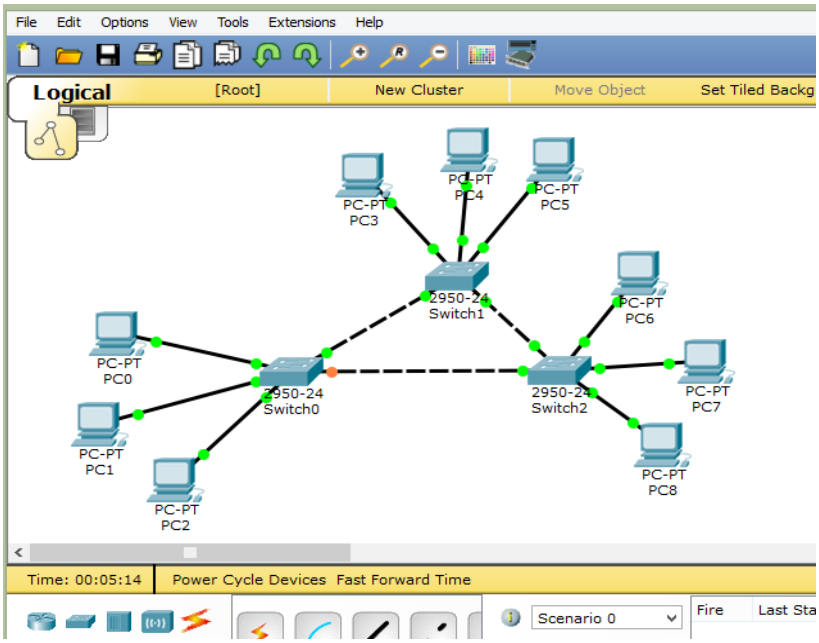
The entry indicates a successful TCP three-way handshake.

Topic 185: Clustering a Topology

This topic discusses how to cluster a topology in Packet Tracer.

When large topologies are created, understanding them becomes difficult. Clustering combines several devices that you choose into a single cloud icon. Upon double-clicking the cluster, it will get expanded and will display the devices normally.

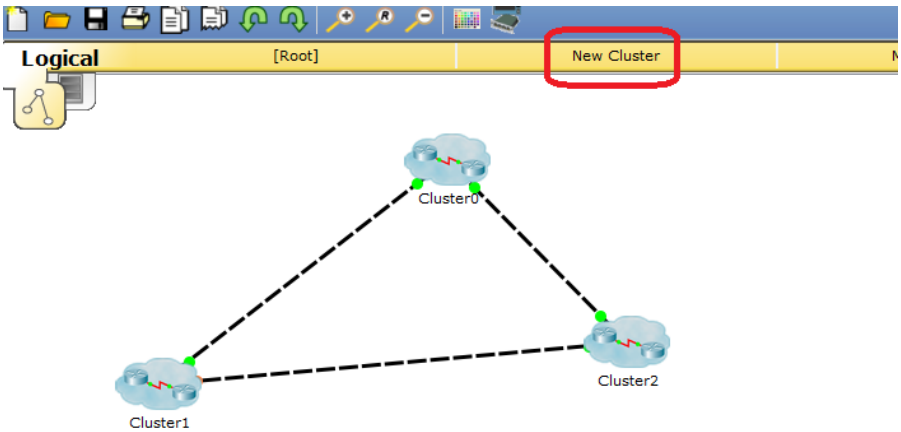
Step 1: Let's create a topology that consists of three switches and nine PCs. Select **End Devices** in **device-type selection box.** From the **Device-specific selection box**, drag-and-drop 9 PCs in the workspace. Select **switches** in **device-type selection box**. From the **Device-specific selection box**, drag-and-drop three 2950-24 switches in workspace. Select **Connections** in **device-type selection box**. From the **Device-specific selection box**, drag-and-drop Copper Straight-through cable in workspace. Connect a PC with a switch. Use copper cross-over cables to connect the switches.



Step 2: Combine PC0, PC1, PC2 and Switch0. Select PC0, PC1, PC2, and Switch0 by clicking on whitespace. Click on the **New Cluster** button on the top-right corner.

Step 3: Form a group of PC3, PC4, PC5 and Switch1. Click on whitespace next to PC3. Drag your mouse to select PC3, PC4, PC5, and Switch1. Click on the **New Cluster** button on the top-right corner.

Step 4: Repeat the same procedure done in **Steps 2 and 3** for combining PC6, PC7, PC8 and Switch2.



Double-clicking on a cluster expands it and displays only the devices within it.

Topic 186: Creating Cities, Offices & Wiring Closets

This topic discusses how to create cities, offices, and wire closets in Packet Tracer.

Packet Tracer can simulate the required environment logically and physically. In the physical workspace, it gives logical topology a physical dimension. Thus, making logical topologies more realistic. There are 4 environments available in the physical workspace:

- Intercity,
- City,
- Building, and
- Wiring closet.

1-Intercity: Being the largest environment, it consists of cities. You can create cities, buildings, and wiring closets in this layer.

2-Cities: Buildings and wiring closets are part of it. The default city name is **Home City**. You can drag and place cities anywhere on the intercity map.

3-Buildings: It contains only wiring closets. **Corporate Office** is default name.

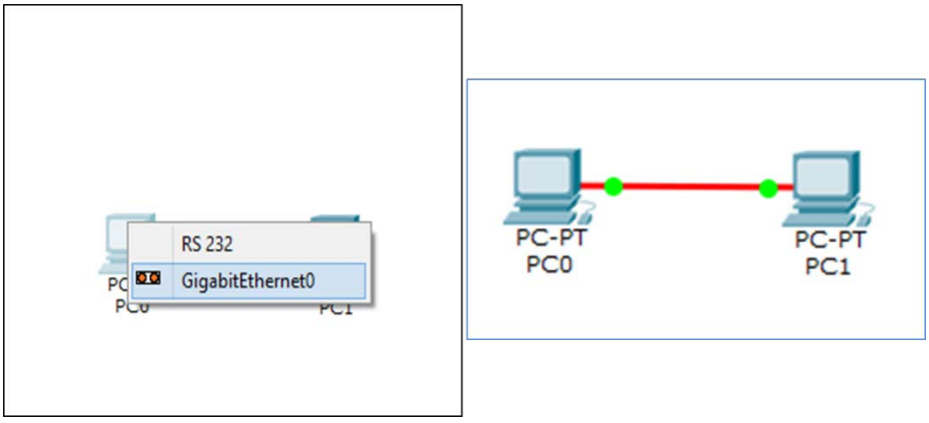
4-Wiring closet: This layer contains only devices. Default name is **Main Wiring Closet.**

Moving devices physically: Packet Tracer places all devices that are used in the logical workspace in Main Wiring Closet. Now we learn how to move them.

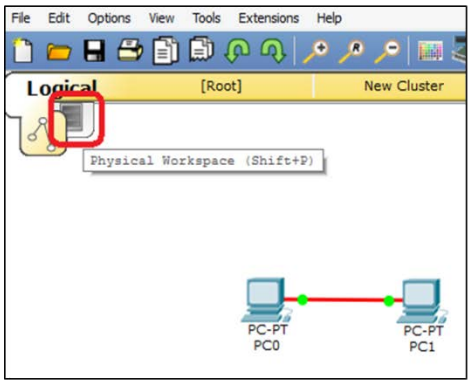
Step 1: Create a topology consisting of two PCs in the logical workspace.

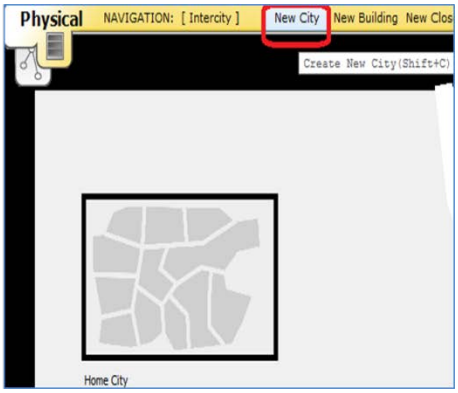
Step 2: As Ethernet has distance restrictions, switch off both the PCs and replace their default modules with **PT-HOST-NM-1FGE.**

Step 3: Connect both of the PCs with a fiber cable and assign IP addresses.

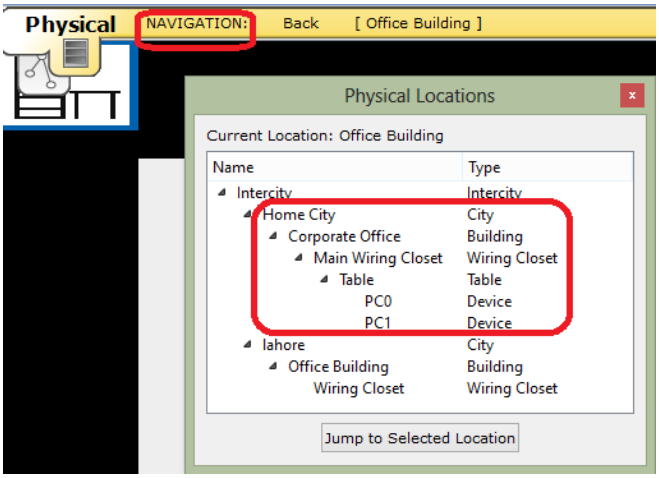


Step 4: Switch to the physical view, and click on the **New City** button. Rename it Lahore. Click on this city and create a new building, and then create a new wiring closet within this building.

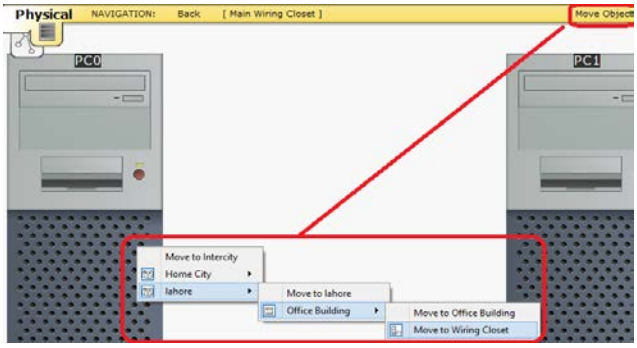


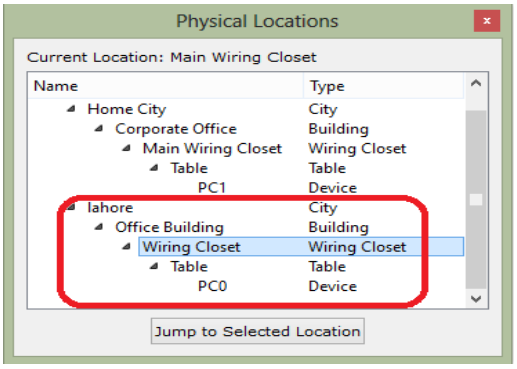


Step 5: Use the **NAVIGATION** button and go to **Home City** | **Corporate Office** | **Main Wiring Closet**. Both the PCs we inserted in the logical workspace are located here. Jump to their location.



Step 6: Use the **Move Object** button and move one of the PCs to **Lahore**| **Office Building** | **Wiring Closet.**

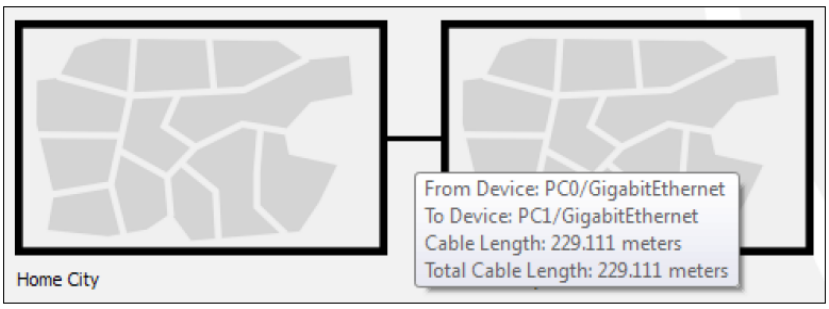




Topic 187: Managing Cables and Distances

In this topic, we discuss how to manage cables and distances in physical space of Packet Tracer.

Assume that we have created two cities in Packet Tracer. Each consists of a PC. Both PCs are connected via fiber. In physical view, we can measure a cable's distance by placing the pointer on the cable.



The length of Standard copper Ethernet cables can extend up to 100 meters. Let's test that the connection comes down due to the distance.

Step 1: Create a topology consisting of two PCs in the logical workspace.

Step 2: Connect both of the PCs with a copper cable and assign IP addresses.

Step 3: Switch to the physical view, and click on the **New City** button. Rename it Lahore. Click on this city and create a new building, and then create a new wiring closet within this building.

Step 4: Use the **NAVIGATION** button and go to **Home City** | **Corporate Office** | **Main Wiring Closet**. Both the PCs we inserted in the logical workspace are located here. Jump to their location.

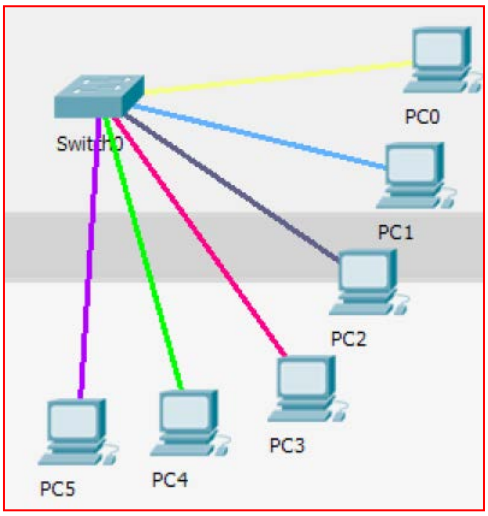
Step 5: Use the **Move Object** button and move one of the PCs to **Lahore**| **Office Building** | **Wiring Closet.**

Step 6: Check the distance between them. In case the distance is less than 100 meters, move them further apart, so that the distance becomes greater than 100 meters.

Step 7: When you go to the logical view, you will find that the connection comes down due to the distance as indicated by red color of the link status.

Cable manipulation

As number of devices increase, it becomes confusing to see which cable connects to what. This can be reduced by adding colors to cables. In the physical view, click on a wire and then, choose **Color Cable.** Pick a color from the Select Color dialog box.



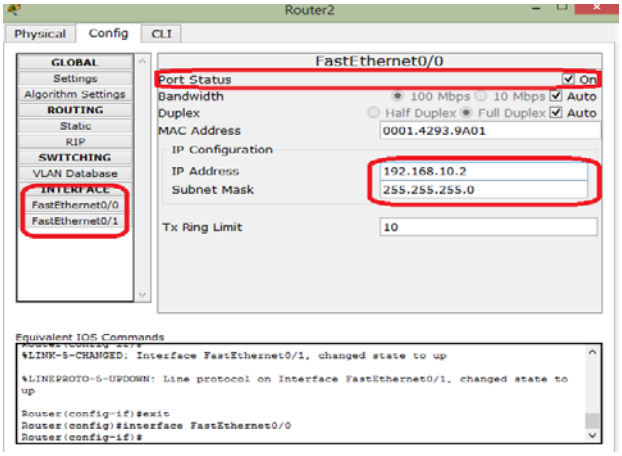
Topic 188: Static Routing with GUI

This topic configures static routing with GUI in Packet Tracer.

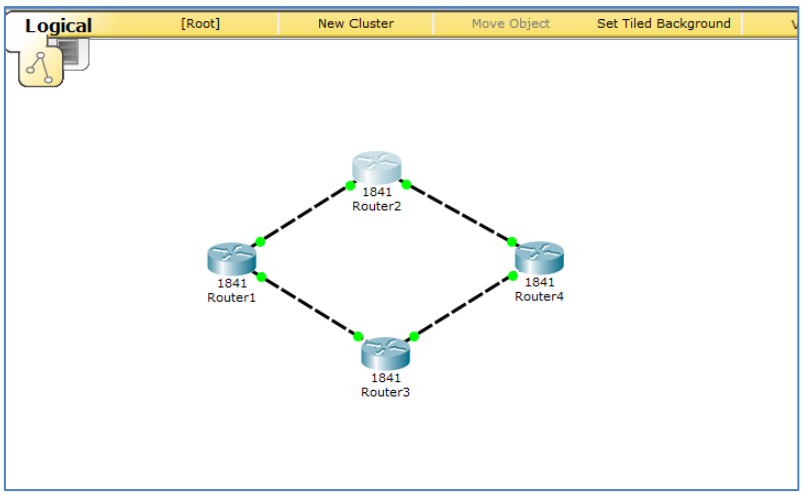
In **static routing algorithms**, routes change very slowly over time, often as a result of human intervention. A human manually edits a router's forwarding table. Let's learn the usage of the GUI feature with the help of a network consisting of four routers in a ring topology, with no PCs or loopback interfaces.

Step 1: Drag and drop 4 routers in the workspace.

Step 2: Click on a router icon, go to the **Config** tab, select an interface, and configure the IP address. Check the **On** checkbox. This will bring the port status up.



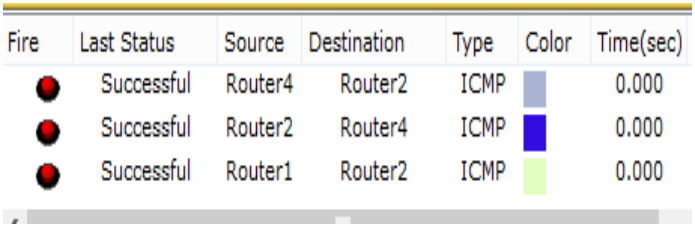
Router	Interface	IP Address
R1	FastEthernet0/0	192.168.10.1
	FastEthernet0/1	192.168.20.1
R2	FastEthernet0/0	192.168.10.2
	FastEthernet0/1	192.168.30.1
R3	FastEthernet0/0	192.168.20.2
	FastEthernet0/1	192.168.40.1
R4	FastEthernet0/0	192.168.30.2
	FastEthernet0/1	192.168.40.2



Step 3: Now go to the **ROUTING** section, and click on **Static**. The settings that we use for configuring static routing using the GUI are shown next:

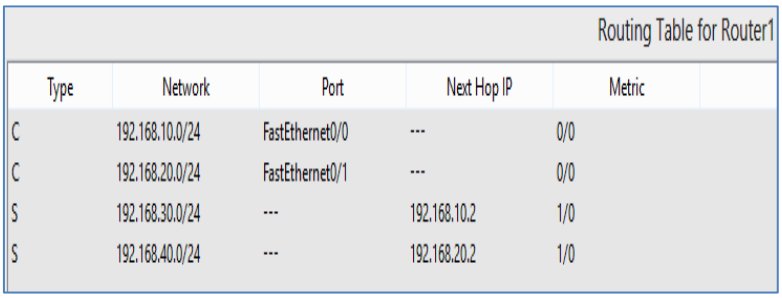
Device	Network/Mask	Next Hop
R1	192.168.30.0 / 255.255.255.0	192.168.10.2
	192.168.40.0 / 255.255.255.0	192.168.20.2
R2	192.168.20.0 / 255.255.255.0	192.168.10.1
	192.168.40.0 / 255.255.255.0	192.168.30.2
R3	192.168.10.0 / 255.255.255.0	192.168.20.1
	192.168.30.0 / 255.255.255.0	192.168.40.2
R4	192.168.10.0 / 255.255.255.0	192.168.30.1
	192.168.20.0 / 255.255.255.0	192.168.40.1

Step 4: Test the connectivity between all of the routers with the help of **simple PDU**. Click on a router first and then click on another router. Look at the **User Created Packet** box.



Fire	Last Status	Source	Destination	Type	Color	Time(sec)
	Successful	Router4	Router2	ICMP		0.000
	Successful	Router2	Router4	ICMP		0.000
	Successful	Router1	Router2	ICMP		0.000

Step 5: Let's view the routing table of a router. Go to the **Common tools bar,** click on the inspect icon. Select a router and click on it. Then select **Routing Table**.



Routing Table for Router1

Type	Network	Port	Next Hop IP	Metric
C	192.168.10.0/24	FastEthernet0/0	---	0/0
C	192.168.20.0/24	FastEthernet0/1	---	0/0
S	192.168.30.0/24	---	192.168.10.2	1/0
S	192.168.40.0/24	---	192.168.20.2	1/0

Topic 189: Static Routing with CLI

This topic configures static routing with CLI in Packet Tracer.

To learn the usage of the CLI feature, assume a network consisting of four routers in a ring topology, with no PCs or loopback interfaces.

Step 1: Drag and drop 4 routers in the workspace.

Step 2: Click on a router icon, go to the **CLI** tab. As the device boots up, then you will see the prompt.

Step 3: Assign IP addresses to R1's interfaces:

- **R1(config)#interface FastEthernet0/0**
- **R1(config-if)#ip address 192.168.10.1 255.255.255.0**
- **R1(config-if)#no shutdown**
- **R1(config-if)#exit**
- **R1(config)#interface FastEthernet0/1**
- **R1(config-if)#ip address 192.168.20.1 255.255.255.0**
- **R1(config-if)#no shutdown**
- **R1(config-if)#exit**

Repeat Step 3 for the remaining routers with the following configurations for their interfaces:

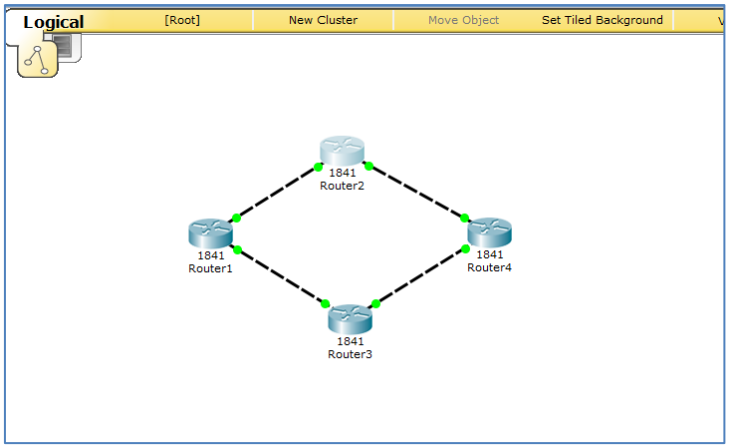
Router	Interface	IP Address
R1	FastEthernet0/0	192.168.10.1
	FastEthernet0/1	192.168.20.1
R2	FastEthernet0/0	192.168.10.2
	FastEthernet0/1	192.168.30.1
R3	FastEthernet0/0	192.168.20.2
	FastEthernet0/1	192.168.40.1
R4	FastEthernet0/0	192.168.30.2
	FastEthernet0/1	192.168.40.2

Step 4: Configure static routing:

- **R1(config)#ip route 192.168.30.0 255.255.255.0 192.168.10.2**
- **R1(config)#ip route 192.168.40.0 255.255.255.0 192.168.20.2**

Repeat **Step 4** for the remaining routers using the configuration shown next:

Device	Network/Mask	Next Hop
R1	192.168.30.0 / 255.255.255.0	192.168.10.2
	192.168.40.0 / 255.255.255.0	192.168.20.2
R2	192.168.20.0 / 255.255.255.0	192.168.10.1
	192.168.40.0 / 255.255.255.0	192.168.30.2
R3	192.168.10.0 / 255.255.255.0	192.168.20.1
	192.168.30.0 / 255.255.255.0	192.168.40.2
R4	192.168.10.0 / 255.255.255.0	192.168.30.1
	192.168.20.0 / 255.255.255.0	192.168.40.1



Step 5: Test the connectivity between all of the routers with the help of **simple PDU**. Click on a router first and then click on another router. Look at the **User Created Packet** box.

Fire	Last Status	Source	Destination	Type	Color	Time(sec)
	Successful	Router4	Router2	ICMP		0.000
	Successful	Router2	Router4	ICMP		0.000
	Successful	Router1	Router2	ICMP		0.000

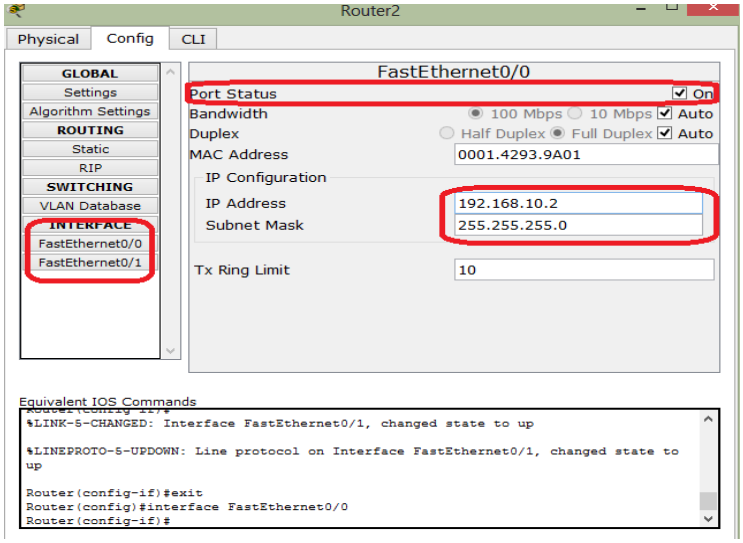
Topic 190: Configuring RIP with GUI

This topic configures RIP with GUI in Packet Tracer.

Dynamic Routing Protocols: A) Form "neighbor ship" with other routers. B) Send them the directly-connected routes and other received routes. Updates are also sent out by routers, when a topology change occurs. A GUI to configure a dynamic routing protocol called **Routing Information Protocol** (**RIP**) is available in Packet Tracer. Let's learn the usage of the GUI feature with the help of a network consisting of four routers in a ring topology, with no PCs or loopback interfaces.

Step 1: Drag and drop 4 routers in the workspace.

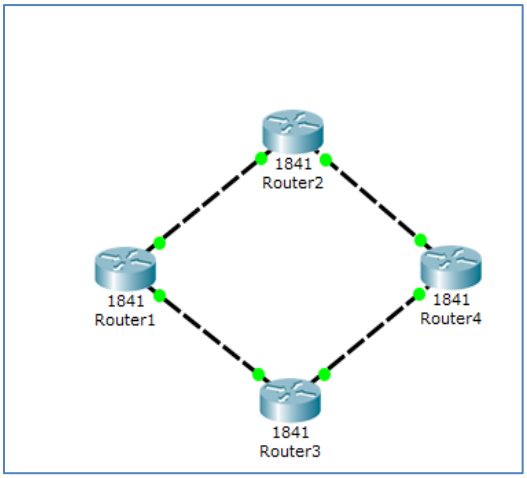
Step 2: Click on a router icon, go to the **Config** tab, select an interface, and configure the IP address.



Router	Interface	IP Address
R1	FastEthernet0/0	192.168.10.1
	FastEthernet0/1	192.168.20.1
R2	FastEthernet0/0	192.168.10.2
	FastEthernet0/1	192.168.30.1
R3	FastEthernet0/0	192.168.20.2
	FastEthernet0/1	192.168.40.1
R4	FastEthernet0/0	192.168.30.2
	FastEthernet0/1	192.168.40.2

Step 3: Click on **RIP.** Enter **Network** IP of its own interfaces.

Device	RIP Network
R1	192.168.10.0
	192.168.20.0
R2	192.168.10.0
	192.168.30.0
R3	192.168.20.0
	192.168.40.0
R4	192.168.30.0
	192.168.40.0



Step 4: Once the topology is configured, use the simple PDU to check for connectivity.

Fire	Last Status	Source	Destination	Type	Color	Time(sec)
	Successful	Router1	Router4	ICMP		0.000
	Successful	Router2	Router3	ICMP		0.000

Step 5: Use the delete tool and remove one link. Let's say we remove link between **R1** and **R2**. Use the simulation mode and test connectivity with the simple PDU. The packet takes the alternate, longer route and succeeds in reaching the destination.

Topic 191: Configuring RIP with CLI

In this topic, we configure RIP with CLI in Packet Tracer.

Let's assume a network consisting of four routers in a ring topology, with no PCs or loopback interfaces.

Step 1: Drag and drop 4 routers in the workspace.

Step 2: Click on a router icon, go to the **CLI** tab. As the device boots up, then you will see the prompt.

Step 3: Assign IP addresses to R1's interfaces:

- **R1(config)#interface FastEthernet0/0**
- **R1(config-if)#ip address 192.168.10.1 255.255.255.0**

- **R1(config-if)#no shutdown**
- **R1(config-if)#exit**
- **R1(config)#interface FastEthernet0/1**
- **R1(config-if)#ip address 192.168.20.1 255.255.255.0**
- **R1(config-if)#no shutdown**
- **R1(config-if)#exit**

Repeat Step 3 for the remaining routers with the following configurations for their interfaces:

Router	Interface	IP Address
R1	FastEthernet0/0	192.168.10.1
	FastEthernet0/1	192.168.20.1
R2	FastEthernet0/0	192.168.10.2
	FastEthernet0/1	192.168.30.1
R3	FastEthernet0/0	192.168.20.2
	FastEthernet0/1	192.168.40.1
R4	FastEthernet0/0	192.168.30.2
	FastEthernet0/1	192.168.40.2

Step 4: Enter into the config mode of RIP:

- **R1(config)#router rip**

Step 5: Enter the network IP addresses:

- **R1(config-router)#network 192.168.10.0**
- **R1(config-router)#network 192.168.20.0**

Step 6: Test the connectivity between all of the routers with the help of **simple PDU**. Click on a router first and then click on another router. Look at the **User Created Packet** box.

Fire	Last Status	Source	Destination	Type	Color	Time(sec)
	Successful	Router1	Router4	ICMP		0.000
	Successful	Router2	Router3	ICMP		0.000

Topic 192: Load Sharing

In this topic, we look at how load sharing works in Packet Tracer.

When a source router has multiple paths to a target path, then it can load balance traffic across them. If multiple paths exist from a source to a network destination with the same metric, then RIP automatically balances the traffic between them. Assume a network that consists of four routers in a ring topology with no PCs.

Step 1: Drag and drop 4 routers in the workspace.

Step 2: Configure the IP address.

Router	Interface	IP Address
R1	FastEthernet0/0	192.168.10.1
	FastEthernet0/1	192.168.20.1
R2	FastEthernet0/0	192.168.10.2
	FastEthernet0/1	192.168.30.1
R3	FastEthernet0/0	192.168.20.2
	FastEthernet0/1	192.168.40.1
R4	FastEthernet0/0	192.168.30.2
	FastEthernet0/1	192.168.40.2

Step 3: Configure **Network** IP of its own interfaces.

Device	RIP Network
R1	192.168.10.0
	192.168.20.0
R2	192.168.10.0
	192.168.30.0
R3	192.168.20.0
	192.168.40.0
R4	192.168.30.0
	192.168.40.0

Step 4: On **Router 4**, let's add a loopback interface (a virtual interface that works like a real interface and needs IP address). Go to the **CLI** tab of **R4** and enter:

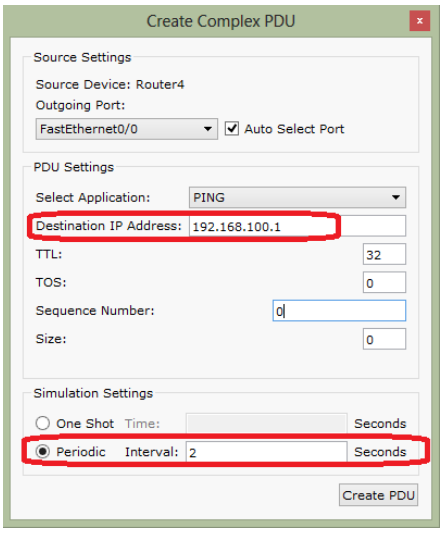
- **R4(config)#interface loopback 0**

- **R4(config-if)#ip address 192.168.100.0 255.255.255.0**

Step 5: Go to the RIP config mode and enter the network IP for this loopback interface.

- **R4(config)#router rip**
- **R4(router-if)#network 192.168.100.0 .**

Step 6: Create a complex PDU that is sent every two seconds.



Step 7: Turn on the simulation mode. You will find that the first packet takes the **R1**-**R2**-**R4** route while the second takes the **R1**-**R3**-**R4** route.