

AC 2010-1836: ENHANCING LEARNING IN DATA COMMUNICATION AND NETWORKING WITH HOME NETWORK

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Enhancing Learning in Data Communication and Networking with Home Network

1. Introduction

Data communication and networking is provided as an introductory course to get the students familiar with the concepts and technologies in computer networking. It covers a wide range of technologies and protocols in the network, which makes the hands-on practice necessary for the learning of this course. It is challenging to build a real network with a limited budget because of the cost of equipment, space and network management. It is difficult for the students to have full access to a real network since they have to share it with other students and can not change the configurations easily. Students, especially those taking online courses, prefer to work on a network that they can perform experiments conveniently. So it is important to introduce a network environment that the students have easy and full access to facilitate the learning.

With the prevalence of residential broadband Internet access and the popularity of wireless LAN, a home network is quite common which is composed of cable modem, low-cost wireless router and one or more computers. Over 85% of people in the survey¹¹ with a home network use some form of home router. Most of the students taking the data communication and networking courses have a wireless router at home. For example, more than 90% of the students in the networking class already have the experience of setting up a wireless router at home. But most of the students only use the home network for the sharing of broadband Internet connection. Actually, the home network is a typical Local Area Network (LAN) which illustrates lots of networking concepts. The students can learn more about computer networks if they can perform more experiments at home network. It is desirable to design some labs for the students to work on their home network. The purpose of this paper is to introduce a set of labs that can help the students utilize the available network resources at home and gain some hands-on practice.

Most of the laboratories designed for the computer networking courses are set up on campus networks^{11, 14, 15}. The labs run on real devices which needs a budget. Those networks are maintained by technical staff and shared by all the users, so students only have limited access to the networks. Besides the traditional networking laboratories performed on real devices, there are some other approaches to teach networking labs, such as virtual lab software¹³ and simulation tools. Simulation software^{1,5,8} can be used to simulate the network environment, so real equipment and networks are not necessary. For example, VMWare^{1,12} is used widely in the teaching of computer networks. Compared with the virtual network, the advantage of our approach is that the students can work on the real equipment and network. They can verify the results and understand how a computer network is working in a real environment.

In the design of the labs, besides configuring the home network to share the Internet connection, we extend the home network as a teaching laboratory. The purpose is to enhance the learning in data communication and networking courses with a series of assignments and laboratories performed on the home network. It can help the students enhance the learning of the abstract concepts and theories. At the same time they can gain hands-on experiences of networking

management. This set of assignments can be especially useful for the students that take online computer communication and networking courses.

2. Course Contents

Data Communication and Networking is offered as a junior level undergraduate course in our department. This course is a survey of data communication and networking techniques, protocols, and standards. It covers a wide range of concepts, theories and techniques in data communication and networking. The textbook used in this course is *Data Communication and Networking*, 4th Edition, by Behrouz A. Forouzan³. Major topics covered in the course are:

- Network models: OSI model and TCP/IP models
- Digital signal transmission and analog signal transmission, encoding and modulation
- Transmission medium
- Multiplexing, switching
- Data link layer: Error detection and correction, data link control, and multiple access
- Local area network and wireless networks
- Network layer: IP addressing, network protocol, routing
- Transport layer: port addresses, TCP protocol and UDP protocol
- Internet Application

Since some concepts are difficult to understand, visualization of the concepts will be helpful. The students prefer to see the results to understand the mechanism. For the technology covered in the lectures, students are interested in the examples in a real network. The laboratories will enhance the understanding of the concepts covered in the lectures, such as

- Data communication and networking basics
- Network devices and transmission medium
- Local area network installation
- Basic commands for network management
- TCP/IP layered model and protocols at each layer
- Network addresses: MAC address, IP address, port address
- Configure firewall to provide network security, analysis of network traffic

3. Setup of Labs

Figure 1 is a typical home network with Internet access. It consists of a broadband modem, wireless router, one wireless laptop, and an optional desktop. The broadband modem can be a FiOS, cable or DSL modem depending on the Internet service the user is subscribing to. Here Comcast cable modem is used as the example.

The minimum requirements needed for the lab assignments are: one or two computers with Microsoft Windows, CAT-5 cables, a wireless router, and broadband Internet connection. The design of the modules of the labs follows the 5 layers of TCP/IP protocols. With minor

modifications, most of the labs can be performed without the Internet connection. Some labs can also be running on just one computer if the students do not have an extra computer at home.

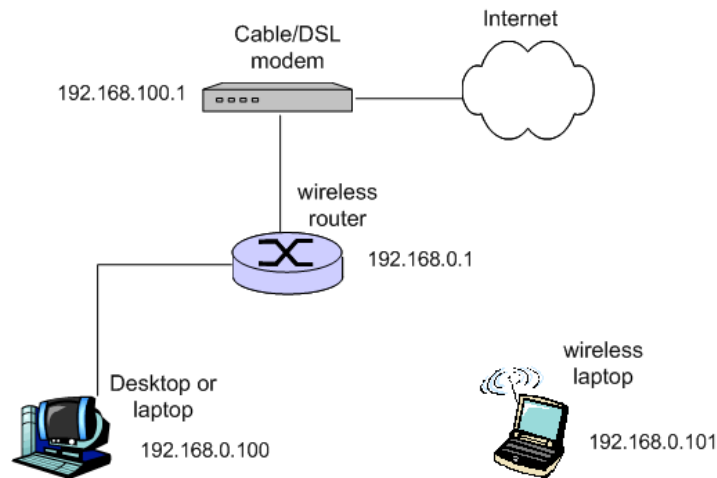


Figure 1. A typical home network with Internet connection

The home network is an infrastructure based wireless LAN (WLAN), where the communication between two computers must go through the wireless router. A typical WLAN router has four built-in Ethernet ports and 802.11 access points. The wireless router can serve multiple purposes, such as IP address allocation, connecting multiple networks, improving network performance, and enhancing network security. The wireless router can work as both an access point and a router. In access point mode, the router can be used to create a wireless network where multiple clients can connect to the network and communicate with each other. In router mode, the router can be used to create a wired/wireless network and share a single broadband Internet connection. The router can also work as a DHCP server to automatically assign IP addresses to each computer. In addition, the router can provide VPN pass-through firewall features to protect the network from malicious attacks.

Most of the wireless routers provide web-based utility for the users to perform the management and configuration of the router. The lab examples in this paper use the D-Link DI-624 router⁷ as the wireless router. The labs can be easily extended to other low-cost wireless routers in the market.

4. Design of Lab Exercises

This set of lab exercises covers the set up of a LAN, configuration of wireless router, packet capture, firewalls, and exercises related to the each layer of TCP/IP model starting from the lower layers.

Table 1. IP addresses of the devices

Device	IP address
Cable modem	192.168.100.1
Wireless router	192.168.0.1
Computer 1	192.168.0.100
Computer 2	192.168.0.101

Lab 1: Set up the home network

The first step is to configure the wireless router and set up the home network. Enable the wireless router work as the DHCP server during the configuration, so the router can allocate IP addresses automatically to computers connected to it. Table 1 gives a summary of the IP addresses of the devices in the network. To test the connectivity, the students can run *ping* command to verify the connection between two devices.

The web page of the configuration of the wireless router D-Link DI-624 is displayed in Fig 2. It covers the basic parameters in configuring a wireless LAN, such as SSID and authentication.

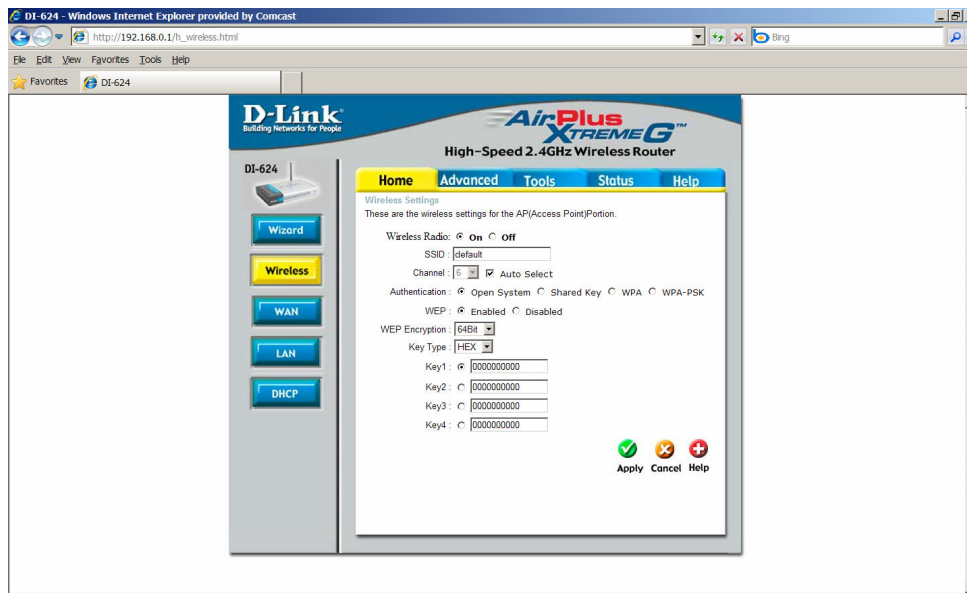


Figure 2. Configuration of wireless router

Lab 2: Network basics

For technologies covered in the lecture, such as modulation, analog signal transmission, digital signal transmission, the students can find the real examples in this network. The IP address of the Comcast cable modem is 192.168.100.1. A web interface is provided to view the performance of the cable modem as in Fig 3. The students can use web browser to view the information of the cable modem to know some of the parameters used in the broadband Internet connection.

The students are asked to study the local area network and answer the following questions about the concepts illustrated in the network.

1. Topology of the network
 - Star topology
2. Analog signal transmission in the network.
 - Between cable modem and ISP
 - Between wireless laptop and wireless router
3. Digital signal transmission in the network
 - Wired connection between desktop and router
 - Between router and cable modem
4. Modulation methods in digital signal transmission
5. Modulation methods in analog signal transmission
6. Transmission medium
 - wireless medium, UTP cable, coaxial cable or fiber cable, connectors of the cables
7. Underlying networks:
 - IEEE 802.3 Ethernet and IEEE 802.11 WiFi

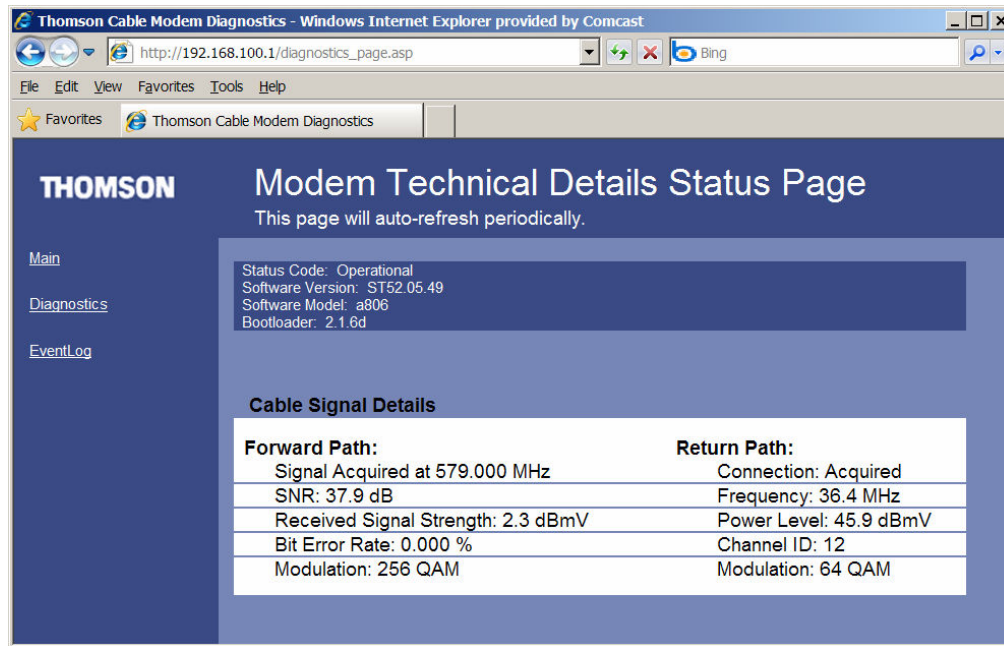


Figure 3. Web interface of cable modem.

Lab 3: Data link layer

This lab helps the students get familiar with the MAC address and network interface card (NIC) used at the data link layer. The students learn to use commands to check the MAC address and IP address of a computer.

To view the IP configuration of a computer, open a command window and run the command `C:\> ipconfig /all`

To view the IP configuration of the wireless router, use Status/Device Info utility provided by the router as in Figure 4. Since a router is used to connect multiple networks, each interface of the router has a pair of MAC/IP address, which can be seen from the Figure 4.

The students also use *arp* command to study how the mapping between IP address and MAC address is stored in the ARP table.

The students can run *ping* to test the connection to another computer, e.g.,

```
C:\> ping 192.168.0.101
```

Then run *arp* command to display the arp table

```
C:\> arp -a
```

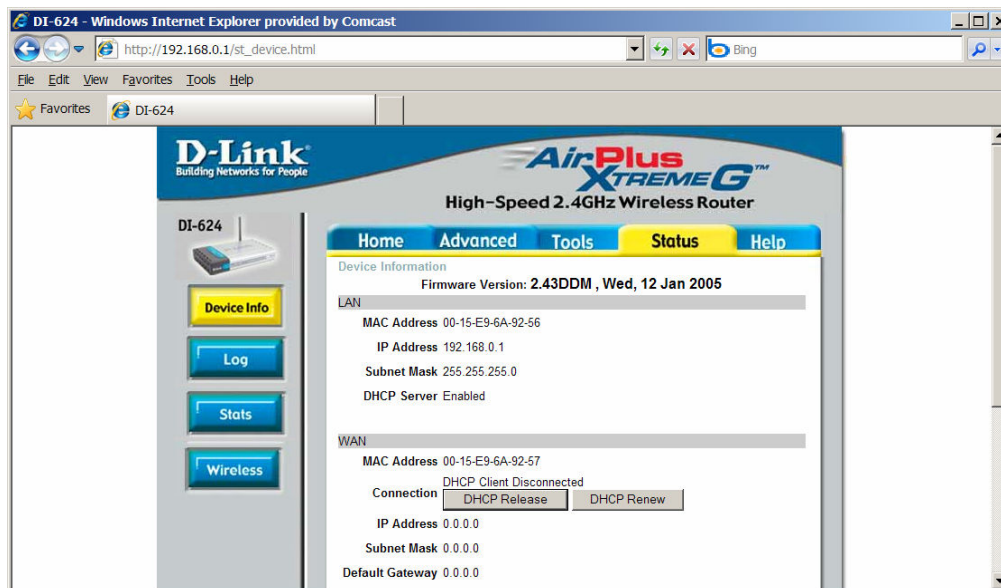


Figure 4. Web interface for the IP configuration of the wireless router

Lab 4: Network layer

The basic two functions of network layer covered in the lectures are IP addressing and routing. This lab assignment is designed to help students understand the various concepts of IP addressing, such as DHCP server, static IP address, dynamic IP address, private IP address, subnetting, network address and subnet mask. To understand the concept of routing, the students can view and modify the routing table of a computer or the router.

IP Address Allocation

The students use the Home/DHCP utility provided by the wireless router in Fig. 5 to allocate dynamic IP address or static IP address to computers connected to the wireless router. Some of the lab operations are

- Use DHCP Server for dynamic IP address allocation. Under this method, an IP address will be automatically selected from the pool of available IP addresses and allocated to the newly connected computer. For example, in Fig 5, the dynamic addresses will be

sequentially selected from 192.168.0.100 to 192.168.0.199. The lease time for the dynamic IP address is 1 week.

- Use static DHCP. An IP address can be specified and allocated to a computer with a particular MAC address.
- Each time after the IP address is allocated, the students can run *ipconfig* command to verify the IP address allocated to the computer.

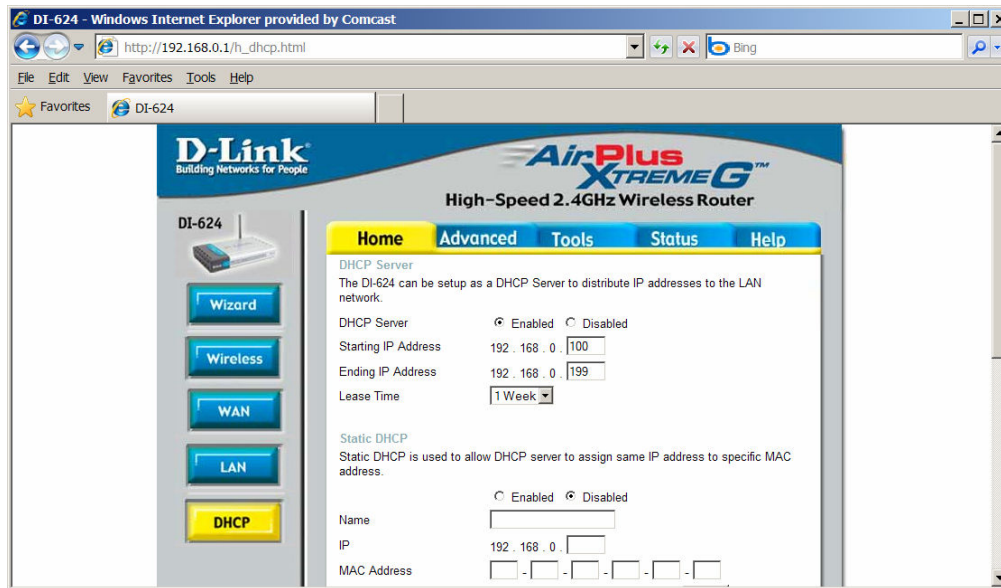


Figure 5. web interface for IP address allocation

Routing

Each network device, a computer or a router, has its own routing table. The routing table defines which interface an IP packet should be forwarded based on the destination IP address of the packet. The students learn to check the routing information of a computer or a router.

```
C:\WINDOWS\system32\cmd.exe
C:\>route print
=====
Interface List
0x1 ..... MS TCP Loopback interface
0x60002 ...00 18 f3 a8 a8 79 ..... Dell Wireless 1390 WLAN Mini-Card - Packet Scheduler Miniport
=====
Active Routes:
Network Destination        Netmask          Gateway          Interface        Metric
0.0.0.0                    0.0.0.0          192.168.0.1      192.168.0.101    25
127.0.0.0                  255.0.0.0        127.0.0.1        127.0.0.1        1
192.168.0.0                255.255.255.0    192.168.0.101    192.168.0.101    25
192.168.0.101             255.255.255.255  127.0.0.1        127.0.0.1        25
192.168.0.255             255.255.255.255  192.168.0.101    192.168.0.101    25
224.0.0.0                 240.0.0.0        192.168.0.101    192.168.0.101    25
255.255.255.255           255.255.255.255  192.168.0.101    192.168.0.101    1
Default Gateway:          192.168.0.1
=====
Persistent Routes:
None
C:\>_
```

Figure 6. Output of *route print* running on 192.168.0.101

To view the routing table of a computer, run the command
C:\> route print

As can be seen from Fig. 6, the default gateway for the computer inside the home network is actually the wireless router with the IP address 192.168.0.1. Users can also run *route add/change/delete* to manually add, modify or delete an entry in the routing table.

To view the routing table of the wireless router, the students can use the Advanced/Routing provided by the router as in Fig 7. This web page also allows the user to add routing entries to the routing table.

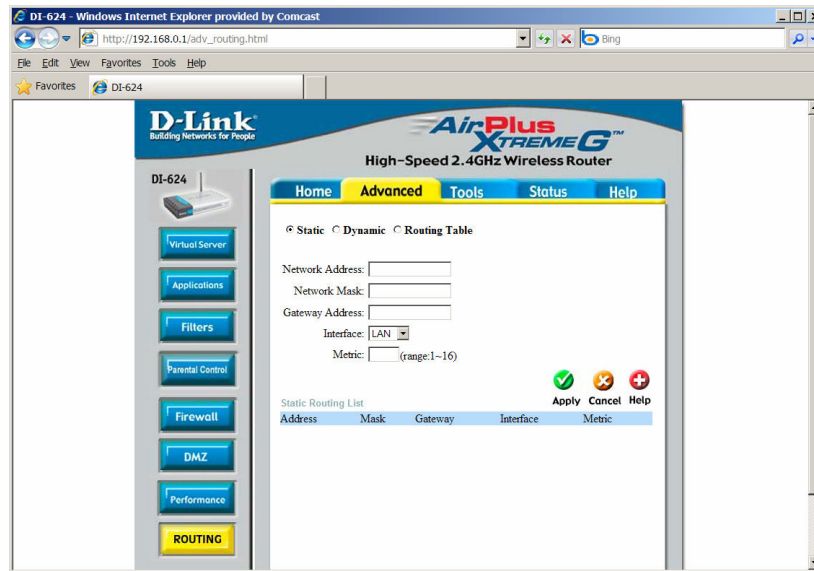


Figure 7. Web interface for routing information of the router


Lab 5: Transport layer

The lab covers the addresses and protocols used at the transport layer. Port addresses are used at the transport layer together with IP addresses to realize process to process communication. TCP and UDP are the two major protocols at the transport layer. The lab helps the students to understand the concept of process to process communication at the transport layer. The process to process communication is implemented using the socket addresses, which are the combinations of IP address and port address.

This lab also illustrates the concept of client/server diagram in network applications. Two simple Java programs⁹ are provided to demonstrate the usage of TCP socket programming, one working as the server program and the other as client program. The client program accepts a string from user input and sends it to the server program. The server program converts the string to all capital letters and transmits it back to the client program.

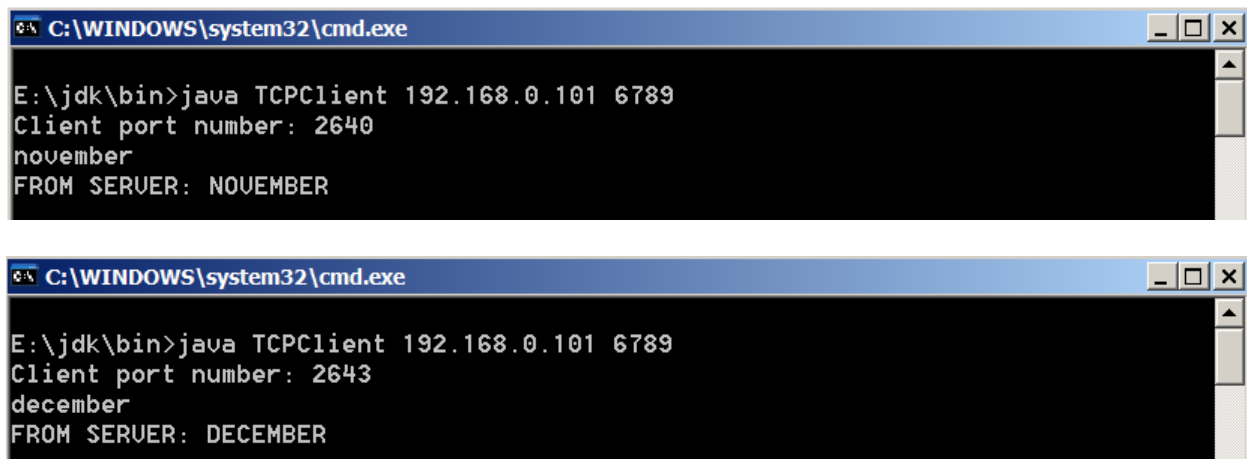
The students are required to download Java², compile and run the programs. The server program is running on the computer 192.168.0.101, with the port number specified at the command line. The command `java TCPServer 6789` starts the server process with the port number 6789. Two client processes are running at the computer 192.168.0.100. The command `java TCPClient`

192.168.0.101 6789 starts the client process to connect server 192.168.0.101 with port number 6789. Figure 8 and Figure 9 display the outputs of the two programs. As can be seen from the Figure 9, each client process is assigned a different port number for the process-to-process communication.



```
C:\WINDOWS\system32\cmd.exe - java TCPServer 6789
E:\jdk\bin>java TCPServer 6789
Server port number: 6789
Server port number: 6789
```

Figure 8. Server process running on 192.168.0.101



```
C:\WINDOWS\system32\cmd.exe
E:\jdk\bin>java TCPCClient 192.168.0.101 6789
Client port number: 2640
november
FROM SERVER: NOVEMBER

C:\WINDOWS\system32\cmd.exe
E:\jdk\bin>java TCPCClient 192.168.0.101 6789
Client port number: 2643
december
FROM SERVER: DECEMBER
```

Figure 9. Client processes running on 192.168.0.100

Lab 6: Application layer

Wireshark⁶ is a free downloaded packet analyzer that can be used for network troubleshooting and traffic analysis. In this lab, the students are required to use Wireshark to capture the traffic generated by different kinds of applications. The screenshot in Fig 10 shows the trace of traffic generated when a web browser is opened to view the URL <http://192.168.0.1>, which is the web page of the wireless router. The sequence of packets shows that the web page is transferred using HTTP protocol at the application layer and TCP protocol at the transport layer. The information of data unit at each layer can be viewed, e.g., Ethernet frame at the data link layer, IP datagram at the network layer, and TCP segment or UDP datagram at the transport layer. The sequence of the packets demonstrates the mechanisms of TCP, such as three-way hand-shaking of the TCP connection, SYN-ACK and ACK. Similarly, the students can use other network applications, such as SSH and FTP, to view the generated trace of traffic and better understand how the packets are exchanged between the client and the server.

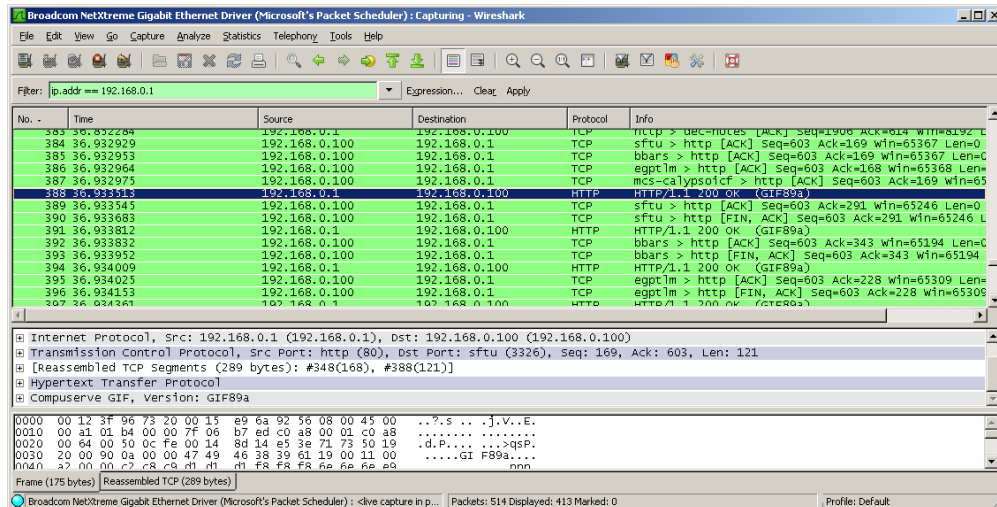


Figure 10. Screenshot of Wireshark

Lab 7: Network security

This lab is designed to help the students understand the concepts of firewall and how it can enhance the security of networks. DI-624 router provides two utilities to configure the firewall to control the traffic: Advanced/Filters and Advanced/Firewalls. The lab also illustrates the well-known port addresses associated with different applications, since port addresses are widely used to create the access control rules of firewall.

Advanced/Filters utility in Fig 11 is used to allow or deny LAN users from accessing the Internet. Alternatively speaking, it can be used to control the outgoing traffic originated from the home LAN to the Internet. The students are required to block traffic from a certain application that is originated from an IP address or MAC address. For example,

- Block the port 80 from the computer with IP 192.168.0.101. Then verify that this computer can not access the Internet web services. If the same computer is given another IP using static IP address allocation, the computer can access the Internet web service again.
- Block the port 22 from the computer with IP 192.168.0.101. Then verify that this computer can not use SSH to connect to an Internet host.
- Block the port 80 from the computer with a certain MAC. Then verify that this computer can not access the Internet web services no matter what IP address it is assigned to.

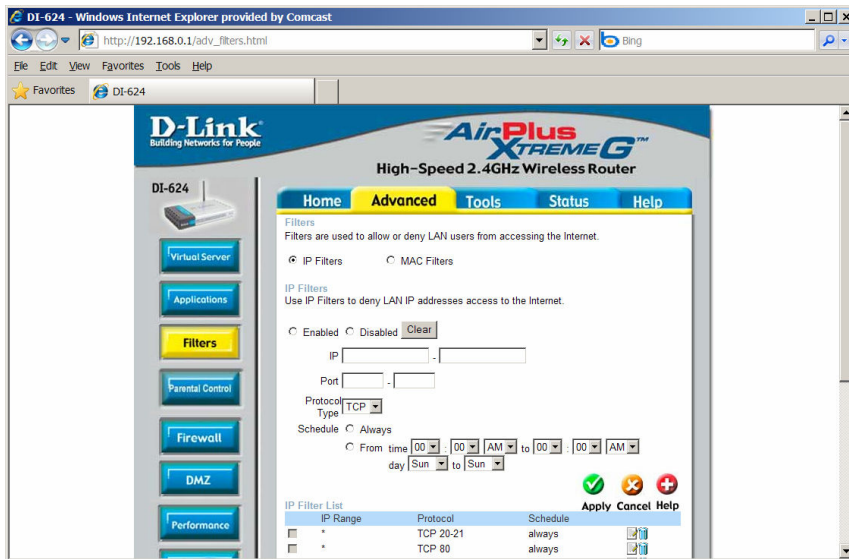


Figure 11. Web interface for Filters

Advanced/Firewall utility in Fig 12 allows users to create firewall rules which allow or deny traffic from passing through the wireless router. This utility can be used to protect a computer inside the home network via blocking certain types of traffic destined to it.

The two computers in the home network can be used to simulate the client/server environment. Assume the computer with IP address 192.168.0.101 is the server. Firewalls can be created at the router to protect the services running on the server. To simplify the procedure, no real server applications such as web server or ftp server are required to install on the server computer. Instead, the Java server program used in the Lab 5 is running on the computer to simulate the service provided by the server.

The students can use the Advanced/Firewall to create the following access control rules to protect the server computer. For example,

- Disable the ping traffic to the server via disabling the ICMP protocol. This is a simple solution to protect a server from Denial of Service attacks. To verify the results, *ping* the server from another computer. There is no response from the server.
- Disable the port number used by the Java server program in Lab 5. To verify the results, run the Java client program at another computer. It can not connect to the server program.

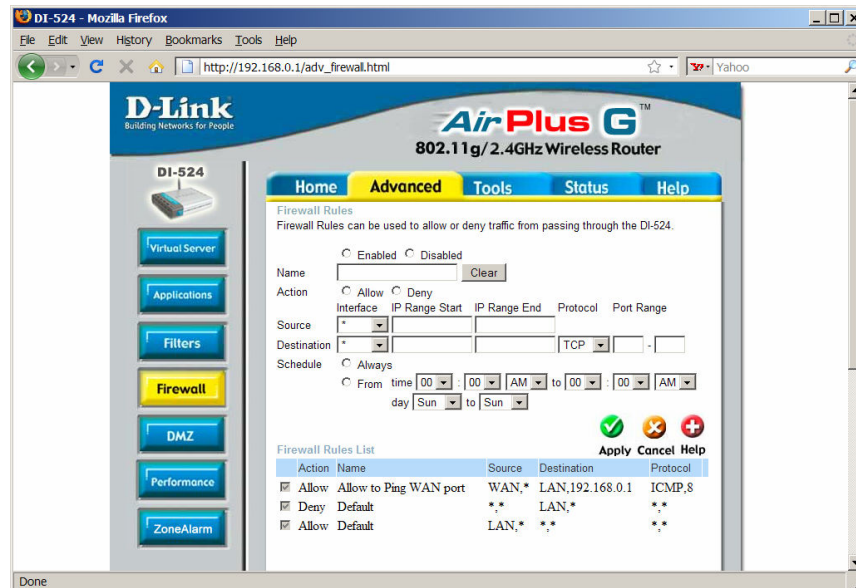


Figure 12. Web interface for Firewall

Other advanced capabilities of the router

Some advanced wireless router, such as Wireless-G Broadband Router WRT54GL from Cisco, has the Quality of Service (QoS) capability. QoS-enabled router can provide better service to high-priority types of network traffic generated by real-time applications, e.g., videoconferencing. The router allows the user to specify different priorities to device, Ethernet port, and application⁴. Those features are designed to provide QoS for real-time multimedia applications, for example, Voice over IP (VoIP), video streaming, and interactive gaming.

Assessment

The assessment of this lab design is based on the feedback from the students and self-evaluation of learning outcomes. Learning outcomes of the lab assignments are:

- Learn how to build and maintain a home or small business network
- Understand the fundamental concepts of data communication and networking
- Understand the OSI and TCP/IP network models
- Know about the current network infrastructure, network devices and transmission medium
- Know about the functionalities, protocols and addressing at each layer
- Provide simple network security management

Some of the labs have been used as lab assignments or demonstrations in our Data Communication and Networking course. It is observed that the students can finish the experiments very quickly since each student has its own network and has full access to it. The students find it easy to use and it helps them gain a better understanding of computer networking fundamentals. Seeing the results is appealing to students with different learning styles. Visual

learners find it especially helpful since they can work on the real device and see the results. After the students get familiar with the home network, they are motivated to perform more experiments and try on different operations on it. To further assess the learning outcomes of the design of labs, this set of assignments will be introduced to the online course of Data Communication and Networking in the future. Student feedback will be collected and analyzed for assessment.

5. Conclusion

Home network provides a convenient environment for the students to explore the networking operations. This paper introduced a set of lab assignments that can be performed in a home network. The labs emphasize the practical experience with real networks at home to enhance the learning of the basic concepts covered in the lectures. The practice not only enhances the understanding of the fundamental concepts of networking, but also helps the students gain experiences of managing a local area network. The lab assignments can also be used for the online courses since the student have easy and full access to the home network.

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