Low Cost System for Laboratory-based Course in IT Education using Raspberry Pi

Dr. Tae-Hoon Kim, Purdue University Northwest
Dr. Ricardo A. Calix, Purdue University Northwest
Dhruvkumar Patel

Low cost system for laboratory-based course in IT Education using Raspberry Pi

Abstract

In Information Technology (IT) education, hands-on experience through the lab is crucial because students tends to learn thing better when observing how practically it's been applied in real system. In general, the lab in IT education requires a variety of equipment such as PCs, servers, switches, and etc., which are relatively expensive. Due to this reason, virtual environment has played a big role in IT education since virtually multiple systems can be created, modified, tested, and deleted easily with little or no cost. However, virtual system still requires at least one PC and its capability is limited to providing additional Operating System (OS). Recently, emergence of Raspberry Pi provides a small and affordable computer, which is utilized in many different areas. This emerging technology has not been explored well to be adopted in IT education. In this paper, we will introduce and investigate Raspberry Pi and discuss its effectiveness in IT education. We will also introduce the building process of a low cost hands-on lab environment setup using Raspberry Pi.

1 Introduction

One of the key components in engineering and science education is a laboratory-based course, which includes a practical hand-on exercise. Many academic institutes developed the laboratory-based courses to help students to accelerate their learning in different types of laboratories such as real, simulation, or online [1]. Especially in Information Technology education, hands-on exercises through the laboratory became an essential component of the course because it provides students with an opportunity to learn and observe how to apply the concepts. Generally, the lab in IT education requires a variety of equipment such as PCs, servers, switches, and so forth. The variety of equipment usually incurs the cost, which becomes the main restriction to providing the lab with appropriate environment. Due to the cost restriction and ease of deployment and usage, virtualization technologies have been widely adopted in many areas. Since the virtual technology provides the isolated virtual environment from host or other virtual machines, it became very popular for development and education solution. Virtualization technology becomes an essential component in IT education because virtually isolated multiple systems can be created, modified, tested, and deleted easily with little or no additional cost. However, virtualization environment system still requires at least one relatively high-end host system to run concurrent multiple isolated virtual systems. In addition, since multiple isolated systems are deployed and internally connected on one host system virtually, system connection is not clearly shown.

Recently, affordable low cost small computer, Raspberry Pi, has been introduced. Due to its small and portable size, relatively high computing power with many available features provided by its Linux-based Operating System (OS), Raspberry Pi is widely adapted and utilized in many different industry sectors such as health care, monitoring system, home automation, Internet of Things (IoT), and etc. [2-7]. The performance of Raspberry Pi has been investigated by Maksimović and *et. al*, and it is shown as a perfect platform to interact with wide variety of external peripherals and access Internet using Wi-Fi, which makes it possible for remote communication [8]. In addition, several other advantages are discussed as following; small independent computer with Linux based with relatively high speed CPU, expansion with external devices by supporting USB and Bluetooth capability, possible expansion with various electronic

components via digital input and output, and etc. [8]. They also identified several features that are lack in Raspberry Pi, such as no real-time clock (RTC), diskless OS using micro-SD card, limited features from mini-Linux OS system, power consumption, and etc. [8,9]. These disadvantages may limit the usage and implementation in several applications.

This small affordable powerful system has been well adopted in many types of application. However, it is not well investigated how it is possibly adopted and/or utilized in IT education. In this paper, we will investigate Raspberry Pi as a component of lab environment and introduce its usage in laboratory-based course in IT education.

The rest of paper is organized as follows. Section 2 introduces Raspberry Pi, current features, system specifications, and applications. Section 3 describes the example of its usage in IT education and provide detail lab setup process. The lab setup is tested and discussed in Section 4. Finally, Section 5 concludes the paper.

2 Raspberry Pi

Raspberry Pi is a small computing device that can be adapted in many different field of area due to its portable small size with high performance computing. Besides, it includes other attractive features such as networking, I/O port, Wi-Fi, and etc. In this section, we will introduce Raspberry Pi in terms of specification, features, requirements, and its application fields.

2.1 Introducing Raspberry Pi

Raspberry Pi was developed by Raspberry Pi Foundation based in United Kingdom (UK) to help people to teach and learn basic Computer Science with low cost high-performance computer. Raspberry Pi is low cost, credit-card sized computer introduced in 2012 as shown in Figure 1.

Figure 1. Raspberry Pi 3 B plus

Initially two models are developed, Model A and Model B in Raspberry Pi version 1. The difference of two models is different number of supporting USB ports and size of memory (i.e., 256 MB and 512 MB). Raspberry Pi has been upgraded with Model B and there are three versions. The most recent version, Raspberry Pi 3 Model B plus, has CPU of 1.4GHz 64-bit quad-core processor, built in dual-band wireless LAN, Bluetooth, faster Ethernet, 4 USB ports, and etc. Table 1 compares the specifications of different versions in Raspberry Pi model B.

Table 1. Specification comparison of different versions of Raspberry Pi model B

	Raspberry Pi 1 B	**Raspberry Pi 2 B**	**Raspberry Pi 3 B**	**Raspberry Pi 3 B+**
Released	Feb. 2012	Feb. 2015	Feb. 2016	Mar. 2018
CPU	700 MHz with single core	900 MHz with quad core	1.2 GHz with quad core	1.4 GHz with quad core
RAM	512 MB	1 GB	1 GB	1 GB
Storage	SDHC	Micro SDHC	Micro SDHC	Micro SDHC
USB ports	2	4	4	4
Wi-Fi	No built-in	No built-in	Built-in Wi-Fi	Built-in dual-band Wi-Fi

(Note: SDHC – Secure Digital High Capacity)

The price of Raspberry Pi is between $25 and $35 depending on the version and it comes with only a board. Additionally it requires micro SD card to run OS, HDMI cable to display on monitor or TV, USB keyboard and mouse. Raspbian, Debian-based OS for Raspberry Pi, is provided as a default and several versions are available. Recently, other OS such as Ubuntu-mate is available. OS should be carefully selected, because each version of OS are suitable to specific version of Raspberry Pi. For example, Ubuntu-mate was built for Raspberry Pi model B. Depending on OS requirement, minimum of micro SD card size is 2 GB and portable external hard-drive can be used for additional storage through USB port. In addition, Raspberry Pi also includes GPIO (general purpose input and output) pins to connect with other electronic boards. Built-in Ethernet port allows up to 1 Gbps in latest version for Internet connection. Additional Ethernet ports can be added through USB ports. Wi-Fi is also available through built-in Wi-Fi supporting 802.11 b/g/n/ac in latest version while Wi-Fi dongle is used for the older versions.

2.2 Application area of Raspberry Pi

Once Raspberry Pi was developed and introduced, it has been widely adapted in many different sectors due to its small size, easy deployment with high performance computing power, and interaction with external peripherals. Gupta and *et. al.* used Raspberry Pi to store and update the collected data from health monitoring system and alert the doctors. They used it as a database and web server to grant an access for authorized person [2]. In [3], Zhao and et. al. used Raspberry Pi as an aggregator of data from multiple wireless sensors. Wi-Fi for connection between wireless node and Raspberry Pi and client-server communication for data transfer from wireless node to Raspberry Pi were used in their project. Raspberry Pi application was extended to home automation and Rao and Uma built the home automation system using Raspberry Pi [4]. Raspberry Pi is located between router and home IoT devices to provide the updated data and remote control through Internet. Another application is surveillance system. Prasad and *et. al.* used it to collect and store the data from surveillance cameras and updated data can be seen at the smartphone through cellular network [5]. In education, Raspberry Pi is mostly used to teach programming who cannot afford a high-end computer. It is also often combined with Arduino to teach control education [10].

3 Raspberry Pi in IT education

The main purpose of Raspberry Pi is to promote teaching and learning in computer programming. However, the usage of Raspberry Pi can be extended to replace the expensive lab equipment. In this section, we will introduce how Raspberry Pi can be used in IT education.

3.1 Lab setup with Raspberry Pi

Firewall is one of the topics in network security education, which blocks un-wanted data packet from outside of the network in general. One of the basic firewall labs is IPtables firewall, which requires router with IPtables capability. Figure 2 illustrates the lab setup, which requires one IPtables capable router, one multi-ports switch, and two PCs.
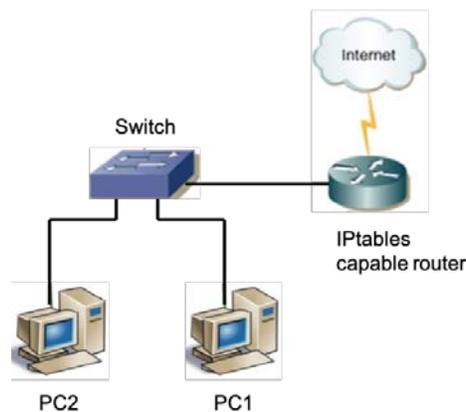

Figure 2. Iptables firewall lab setup

In IPtables firewall lab setup, IPtables capable router is a key component and student will add and remove the rules on firewall to observe how the firewall protects the network from attack. Since IPtables is a firewall in Linux system, it requires Linux based or related tiny OS. In general, Linux installed PC or router installed with IPtables firewall capable firmware. Instead of PC or router, we use low cost small size portable computer, Raspberry Pi as shown in Figure 3.
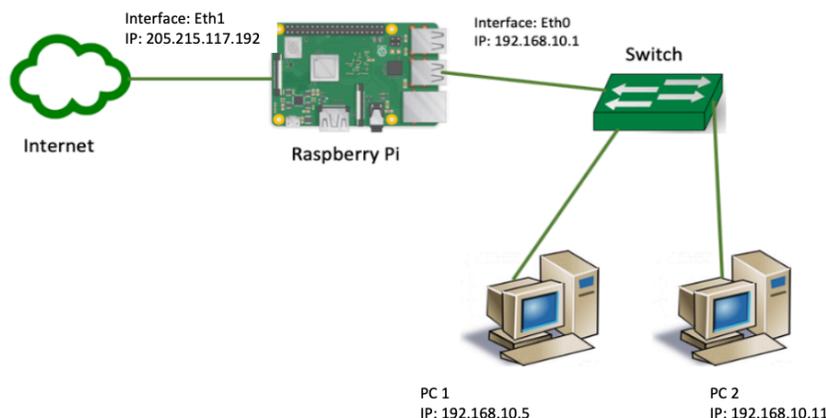

Figure 3. Iptables firewall lab setup with Raspberry Pi

3.2 Raspberry Pi configuration

As a router replacement, we used Raspberry Pi 3 model B+ with following specifications;
- SoC: Broadcome BCM2837B0 quad-core A53 (ARMv8) 64-bit @ 1.4GHz
- GPU: Broadcom Videocore-IV
- RAM: 1 GB LPDDR SDRAM
- Networking: 1 of Gigabit Ethernet and 1 of dual-band 802.11 b/g/n/ac Wi-Fi
- Bluetooth: Bluetooth 4.2 (BLE)
- Storage: Micro-SD
- GPIO: 40 pin GPIO header, populated
- Ports: 4 USB 2.0, HDMI, 3.5mm analogue audio-video jack, Camera Serial Interface (CSI), Display Serial Interface (DSI)
- Dimension: 82mm x 56mm x 19.5mm, 50g.

For the lab setup, two (2) Ethernet interfaces are required, one to the Internet and the other to the switch, and we used additional USB Ethernet adapter. Then, Raspberry Pi should be configured to be replace with IPtable capable router. For this purpose, several software should be installed such as DHCP server and IPtables. OS used in Raspberry Pi is Linux based Raspbian Stretch with Desktop and recommended software version 4.14.

First, required package such as udhcpd, udhcpc, IPtables, IPtables-persistant, and dnsmasq are required. Udhcpd is to setup a Dynamic Host Configuration Protocol (DHCP) server to assign IP address for the PCs in internal network. Udhcpc is a DHCP client program to acquire IP address from existing DHCP server. IPtables and IPtables-persistant enable Raspberry Pi to implement, apply, and save the IPtables firewall rules. Dnsmasq is to run the DHCP service. These software packages can be easily installed with following commands at the terminal.

```
sudo apt-get install udhcpd -y
sudo apt-get install udhcpc -y
sudo apt-get install dnsmasq -y
sudo apt-get install iptables -y
sudo apt-get install iptables-persistant -y
```

Once all software are installed, next step is configuring the required services. At DHCP server, the range of IP address should be determined for dynamic address assignment and implementing interface should be selected. We use the non-routable IP address block (i.e., 192.168.10.2/24 to 192.168.10.20/24) for internal network use. DHCP server will be running on the interface to the internal network (i.e., eth0). Gateway address should be provided and we use 192.168.10.1/24. Following configuration should be added in "/etc/udhcpd.conf" file.

```
start 192.168.10.2
end 192.168.10.20
interface eht0
remaining yes
opt  dns  8.8.8.8  4.2.2.2
opt  subnet  255.255.255.0
```

```
opt  router  192.168.10.1
opt  lease  864000
```

In the file of "/etc/default/udhcpd", use following configuration to enable the DHCP server and log to syslog.

```
# Comment the following line to enable
# DHCP_ENABLED="no"
# Options to pass to busybox' udhcpd.
# -S Log to syslog
# -f    run in foreground
DHCP_OPTS="-S"
```

Now we need to assign IP address on both Ethernet interfaces (eth1 and eth0). "eth0" is for internet network as a default gateway and static IP address should be assigned as mentioned above. "eth1" is an interface to the outside of network (i.e., WAN) and IP address should be assigned from DHCP server at network provider. Use following lines to configure the file "/etc/network/interfaces".

```
Source-directory /etc/network/interfaces.d
auto lo
iface lo inet loopback

auto  eth1
iface  eth1 inet  dhcp

iface  eth0  inet  static
    address  192.168.10.1
    netmask  255.255.255.0

iface  default  inet  manual
up iptables-restore < /etc/iptables.ipv2.nat
```

In order to allow IP forwarding, it should add 1 at "/proc/sys/net/ipv4/ip_forward" file. In addition, one line should be uncommented to enable packet forwarding for IPv4 in "/etc/sysctl.conf" file as shown below.

```
net.ipv4.ip_forward=1
```

Next step is to configure the forwarding rules at Raspberry Pi for internal network so that it can communicate through Internet. This process will set Raspberry Pi as a router, which can route the packets between internal network and Internet. The following IPtables rules will allow IP MASQUERADE for packet forwarding between two interfaces (eth0 and eth1 in our case) using NAT (Network Address Translation). Add following lines of commands in "/etc/iptables/rules.v4" file to be executed when system starts.

```
sudo iptables -t nat -A POSTROUTING -o eth1 -j MASQUERADE
```

```
sudo iptables -A FORWARD -i eth1 -o eth0 -m state –state RELATED, ESTABLISHED -j ACCEPT
sudo iptables -A FORWARD -i eth0 -o eth1 -j ACCEPT
sudo sh -c "iptables-save >> /etc/iptables/rules.v4"
```

Final step is to start the services. To start the services, use following

```
#! /bin/bash
sudo /etc/init.d/udhcpd stop
sudo /etc/init.d/dnsmasq stop
sudo service dhcpd stop
sudo ifdown eth0
sudo ifconfig eth0 down
sudo ifconfig eth0 up
sudo ifup eth0
sudo /etc/init.d/udhcpd restart
sudo /etc/init.d/dnsmasq restart
```

4 Test and Discussion

After we finished the Raspberry Pi configuration, we performed three tests for network security education use. In this session, we will describe each test with required configuration on Raspberry Pi. Then, we will discuss the results of each test and usage of Raspberry Pi in IT education.

The first test was to block the ping to the gateway of internal network (i.e., 192.168.10.1/24). Ping uses ICMP packet to test the network connectivity and it can be blocked using IPtables. We applied following rule on Raspberry Pi.

```
sudo iptables -I INPUT -p icmp --icmp-type echo-request -j DROP
```

Once above rule was applied to Raspberry Pi, we used PC1 (i.e., 192.168.10.5/24) to ping gateway (i.e., 192.168.10.1/24). All ping results showed "request timeout", indicating all ICMP packets were successfully blocked. Then, we deleted the rule using following command.

```
sudo iptables -D INPUT -p icmp --icmp-type echo-request -j DROP
```

Now, all PCs in internal network (i.e., PC1 and PC2) should be able to ping gateway (i.e., eth0 at Raspberry Pi).

The next test is to block all outgoing SSH (Secure Shell) connection to specific SSH server from specific PC. In other word, PC1 cannot establish connection to specific SSH server in any location. We add following rule to block SSH connection setup from PC1 to specific address (i.e., 184.168.26.138). Once this rule was added on Raspberry Pi, SSH connection request from PC1 to specific server was successfully blocked.

```
sudo iptables -I FORWARD -s 192.168.10.5 -d 184.168.26.138 -p tcp --dport 22 -j DROP
```

Port forwarding is one of the techniques to make the sever in the internal network accessible from external network. In this test, we use SSH server running on PC1 and make it accessible from PC in external network. External PC should use port number 8000 with IP address of "eth1" of Raspberry Pi (i.e., 205.215.117.192 in our network). When SSH connection request arrives with port number of 8000, Raspberry Pi will forward it to PC1 with replaced port number 22. We applied following rules and it could successfully establish the SSH connection from external PC to PC1.

```
sudo iptables -t nat -A PREROUTING -p tcp -i eth1  --dport 8000 -j DNAT --to 192.168.10.5:22
sudo iptables -A FORWARD -p tcp --dport 22 -d 192.168.10.5 -j ACCEPT
```

We performed three tests, ICMP blocking, SSH blocking, and port forwarding. When required rules were added for each test, it could successfully accomplish the task. According to three tests, it is shown that Raspberry Pi can be configured and replace the router in the lab setup. Raspberry Pi can be used as other components in IT education such as wireless router, Access Point (AP), server, computer, and etc. In addition, it can replace the virtual machine for education purpose. Currently, virtual machine is commonly used for hands-on lab in IT education. SEED labs, developed by Professor Du at Syracuse University [11], is the most popular security labs used in many Academic Institutes, which use virtual machine to emulate the Linux based computer system for security educations. The main purpose of using virtual machine is to use isolated multiple computer systems with low or no cost, which generally requires 2 or 3 computer systems in the field of network security education. In addition, isolated computer system can be easily created, tested, saved, and deleted. However, it still requires at least one physical computer, which may require even high-end host computer system to run isolated multiple number of virtual computer systems concurrently. In addition, it is running in the one machine and network topology is not physically shown. Comparing Raspberry Pi with virtual machine, Raspberry Pi is a Linux based low cost small computer and multiple of them are still relatively more cost effective and affordable than high-end computer. And Raspberry Pi is running at the micro-SD card, which makes it easily created, tested, saved and deleted. Therefore, Raspberry Pi may be a better selection instead of virtual machine in IT education.

However, Raspberry Pi also has several disadvantages and limitations. First, it requires several other accessories such as HDMI cable, USB keyboard and mouse, monitor or TV, Ethernet cable and switch for some lab setup, and etc. Second is limited OS and some restriction. Only Linux based OSes such as (Raspbian, Ubuntu-mate, and etc.) are available. In addition, some OS, for example Ubuntu-mate, only works with specific version of Raspberry Pi. Some external device, such as wireless dongle, requires exact driver information to be used. Lastly, it may require several configurations to be used as one of lab components such as router, wireless router, AP, and etc.

5 Conclusions

Raspberry Pi is a low cost small size computer that can interact with variety of external peripherals, which led it to be widely adopted in various applications such as health care, monitoring system, home automation, Internet of Things (IoT), and etc. Although it is widely adopted and utilized in many sectors, it is limitedly used in education purpose. In this paper, we investigate if this small low cost portable computer is suitable for IT education use. We select

one of network security labs, Linux firewall, and use Raspberry Pi as one of lab component, a router with IPtable capability. We introduced step by step configurations to create Raspberry Pi as one of lab component and test the lab environment. Our results show that Raspberry Pi works perfect in the network security lab setup. However, the usage of Raspberry Pi is not limited in the network security labs, but it can be also used for practical hands-on labs in IT education. Currently, virtual machine is mainly used for hand-on labs in security education due to advantages of virtualization. Though Raspberry Pi has several disadvantages and limitations, such as other accessory requirement, low compatibility with some OS, and not well-known drivers, it could be one of selections for hands-on labs in security education besides virtual machine. In addition, it can be used for many types of lab components, wireless router, AP, router, servers, PC, and etc., in IT education.

References

[1] Ma, Jing, and Jeffrey V. Nickerson. "Hands-on, simulated, and remote laboratories: A comparative literature review." *ACM Computing Surveys (CSUR)* 38.3 (2006): 7.

[2] Gupta, M. Surya Deekshith, Vamsikrishna Patchava, and Virginia Menezes. "Healthcare based on IoT using Raspberry Pi." *2015 International Conference on Green Computing and Internet of Things (ICGCIoT)*. IEEE, 2015.

[3] Zhao, Cheah Wai, Jayanand Jegatheesan, and Son Chee Loon. "Exploring iot application using raspberry pi." *International Journal of Computer Networks and Applications* 2.1 (2015): 27-34.

[4] P. B. Rao and S.K. Uma, "Raspberry Pi Home Automation with Wireless Sensors using Smart Phone", *International Journal of Computer Science and Mobile Computing*, *Vol. 4*, *Issue. 5*, May 2015.

[5] Prasad, Sanjana, et al. "Smart surveillance monitoring system using Raspberry Pi and PIR sensor." *Int. J. Comput. Sci. Inf. Technol* 5.6 (2014): 7107-7109.

[6] Maksimović, Mirjana, et al. "Raspberry Pi as Internet of things hardware: performances and constraints." *design issues* 3 (2014): 8.

[7] Ferdoush, Sheikh, and Xinrong Li. "Wireless sensor network system design using Raspberry Pi and Arduino for environmental monitoring applications." *Procedia Computer Science* 34 (2014): 103-110.

[8] Vujovic, Vladimir, and Mirjana Maksimovic. "Raspberry Pi as a Wireless Sensor node: Performances and constraints." *Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2014 37th International Convention on*. IEEE, 2014.

[9] M. Schmidt, "Raspberry Pi –A Quick Start Guide." The Pragmatic Bookshelf, 2013.

[10] Sobota, Jaroslav, et al. "Raspberry Pi and Arduino boards in control education." *IFAC Proceedings Volumes* 46.17 (2013): 7-12.

[11] Hands-on Labs for Security Education (SEED labs), http://www.cis.syr.edu/~wedu/seed/