Performance of a Linux-based Network Router

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Abstract

Today's routers have increasingly short life cycles. The short life cycle is due to the growing demand for bandwidth by users. High traffic under limited bandwidth conditions results in a significant number of dropped connections and excruciatingly slow speeds. Coupled with the practice of sporadic firmware updates for the majority of commercial routers, consumers usually have to purchase new hardware every two years to maintain consistent speeds. This project explores an alternative, building a home-built router suitable for use in senior projects and special projects. While our lab has made use of a "specimen" router built from an aging Dell Computer in the past; while this router has worked quite well when needed; it was decided to initiate a formal work that built home-built routers. The hardware basis of these is the PC. The PC runs a Linux distribution OS. The paper reports the building and configuration steps. The performance of the router is compared to existing devices and reported. Tests of the networks containing the home-built router and commercially built router were done and reported. Objective data-rate tests chosen allowed for the setting of test packet size, test duration, and traffic direction. The work also reports the cost of material for the home-built routers. Since the home-built routers do not implement a pseudo-Cisco IOS, they are not suitable for teaching Cisco Academy content. However, the home-built routers do implement well-understood router functions and capabilities. A review of these implementations appears in the paper for completeness.

I. Introduction

Based on the first-hand experience of converting an aging mini-tower PC into a network router, it was decided to change to a different form factor PC chassis. A form factor whereby the PC would meet general business criteria, such as being compact, disk-less, and fan-less. The computer used as the server in this project is a product marketed by Qotom [1]. Figure 1 shows the device front and back view. Note the width (6 inches) and the depth (5 inches) of the device.

Figure 1. Front and back view of the Qotom Mini-PC.

It contains a Quad-Core Intel Celeron J100 CPU running at a nominal 2 GHz. This machine was selected because it had a small form factor chassis that blends seamlessly into network cabinets and similar environments. It has four LAN network interfaces (RJ-45 jacks). It is designed for

advanced performance and built for multitasking. Table 1 shows the basic specification of the product.

Table 1. Qotom Mini-PC hardware specifications.

CPU	Intel Celeron Processor J1900 (Quad-Core 2M Cache, 2 GHz, up to 2.42 GHz)
Memory	4GB RAM, 32GB SSD
Architecture	64-bit computing/addressing
Network Cards	Four Interfaces, each one (1) Gbps

The Qotom's preloaded Operating System is PfSense [2]. This OS has excellent Firewall capabilities. However, Ubuntu's Linux-based v16.04 LTS 64-bit Server has robust Firewall capabilities and has excellent user forums and support. Therefore, Ubuntu [3] became the project OS.

Once the Qotom device was configured as a router and confirmed working, tests began. Three test categories total; two different measures of throughput, and one measure of data latency. Section VI shows side-by-side throughput-test comparisons for the Qotom-based home-built router and a set of commercial routers. Table 2 lists the names and models of the commercial routers and shows their publicly-reputed throughput rates.

Table 2. Commercial routers used for project comparison testing.

NETGEAR R7000 1 Gbps	Linksys EA6900 1 Gbps	TP-Link Archer C9 1 Gbps	Linksys E900 100Mbps
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II. OS Installation

For most Linux users, the days of a CD or DVD based OS installation is gone. Two factors are key to this development. First, the presence of needed high capacity (1 – 2 GB) pluggable USB memories. Second, the presence of PC system BIOS enabled boot from USB/Flash. Therefore, the OS install on the mini-PC is doable provided a bootable Ubuntu Install USB memory stick is available.

The install disk image (iso file) for Ubuntu 16.04 LTS 64-bit architecture server is on the Ubuntu website [4]. The workflow for installing an iso file onto a bootable USB memory stick is familiar to many.

Download iso install file onto an existing Ubuntu (or other) computer. Invoke a "startup" disk creator application. The disk creator uses the "*.iso" file as its input source. Disk creator uses the 2GB USB memory stick as its output target. The program completes. The result, the USB memory stick is bootable.

Before installing the OS, it is necessary to attach peripherals to the mini-PC. Remove keyboard and monitor after successful OS install and router configuration. The peripherals and connections are listed below.

VGA monitor (VGA cable)	Keyboard (USB cable)	USB memory stick	Internet (network cable)
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Powering on the mini-PC, with USB memory stick in place, forces the system to boot from the stick. Installation proceeds using the monitor and the keyboard. The installation “target” is the Qotom 32GB internal solid state memory device. Installation steps include specifying a common desktop environment (e.g., Ubuntu Unity). The Ubuntu website has excellent installation support materials [5].

After setup, removal of the USB memory stick and reboot, Ubuntu is ready for use. If desired, configure Ubuntu for remote Secure Shell (ssh) or remote desktop protocol (RDP) connections. For usability, a remote connection has its advantages in a small lab. Doing so avoids working adjacent to the clutter of laboratory equipment.

III. Basic Router Configuration

The first step is to (1) retrieve necessary information concerning the integrated network interfaces cards (NIC) and (2) initialize the system to make those interfaces “router usable” at boot. This work requires working from the Linux Command Line Interface (CLI). The “ifconfig” command is used to query the system about the internal NIC cards. Below, an excerpt of the ifconfig report concerning the “loopback” interface:

```
lo    Link encap:Local Loopback
      inet addr:127.0.0.1  Mask:255.0.0.0
      inet6 addr: ::1/128 Scope:Host
      UP LOOPBACK RUNNING  MTU:65536  Metric:1
      RX packets:4567 errors:0 dropped:0 overruns:0 frame:0
      TX packets:4567 errors:0 dropped:0 overruns:0 carrier:0
      collisions:0 txqueuelen:1
      RX bytes:599438 (599.4 KB)  TX bytes:599438 (599.4 KB)
```

The device name is “lo.” The IP address is 127.0.0.1, and the netmask is 255.0.0.0. The loopback device is a “virtual” device. No hardware is present. In the same manner, ipconfig reports all physical network interfaces information. The previously connected network interface device will have an active IP address and netmask values. The remaining unconnected interfaces will not report an IP address and netmask value.

The first two physical interface cards reported by ifconfig are (1) enp1s0 and (2) enp2s0. The enp1s0 device is the connection to the Internet (WAN). The enp2s0 will be the LAN side network interface. These are not initially present the “/etc/network/interfaces” file. They must be for future network operations.

The initial /etc/network/interfaces file content is:

```
# interfaces(5) file used by ifup(8) and ifdown(8)
auto lo
iface lo inet loopback
```

Notice the relative emptiness in the block above, only the loopback local interface (iface lo) device appears. It is missing the enp1s0 and enps1 devices. Edit the enp1s0 and enps1 devices into the file using a Linux editor. Shown in Figure 2 is the text editor “sublime” (subl). Any Linux text editor can be substituted. Figure 2 includes the edits in the /etc/network/interfaces file.

```
1 # This file describes the network interfaces available on your system
2 # and how to activate them. For more information, see interfaces(5).
3
4 source /etc/network/interfaces.d/*
5
6 # The loopback network interface
7 auto lo
8 iface lo inet loopback
9
10 # The WAN interface
11 auto enp1s0
12 iface enp1s0 inet dhcp
13
14 # The LAN interface
15 auto enp2s0
16 iface enp2s0 inet static
17     address 192.168.99.1
18     netmask 255.255.255.0
```

Figure 2. Edited WAN/LAN network interfaces in the Network Interface File.

The enp1s0 is the interface to the “outside” of the network, the WAN. The (editor created) additional /etc/network/interfaces text lines are (1) Auto enp1s0 and (2) iface enp1s0 inet dhcp. Adding these lines complete the enp1s0 device configuration.

The enp2s0 is the interface on the “inside” of the network, the LAN. The four (editor created) additional /etc/network/interfaces text lines are (1) Auto enp2s0, (2) iface enp2s0 inet static, (3) address 192.168.99.1, and (4) netmask 255.255.255.0. Adding these lines complete the enp1s0 device configuration. Now the interfaces are ready on every mini-PC router startup. Per the system directives, an external Dynamic Host Control Protocol (DHCP) server is expected to assign an IP address to the WAN interface (enp1s0). Static addressing assigns the fixed IP address to the LAN interface (enp2s0).

The next step was to enable forwarding of IP traffic between interfaces. Forwarding is a crucial step. Without this, the router will not work as required. The Linux network operations configuration file, “/etc/sysctl.conf” determines “forwarding” status (on/off).

Uncommenting the one line from the file turns forwarding “on” for IPv4 traffic. All these changes are applied by saving the file and rebooting the system. Figure 3 shows the now uncommented “net.ipv4.ip_forward=1” line.

```
# Uncomment the next line to enable packet forwarding for IPv4
net.ipv4.ip_forward=1

# Uncomment the next line to enable packet forwarding for IPv6
# Enabling this option disables Stateless Address Autoconfiguration
# based on Router Advertisements for this host
#net.ipv6.conf.all.forwarding=1
```

Figure 3. Forwarding IPv4 traffic enabled.

Testing proceeded after a required mini-PC router reboot. Network connectivity from WAN to LAN was confirmed.

IV. Network Configuration

Next step, the network design work. Table 3 list the network design specifics for the router.

Table 3. Network design of router.

Subject/Task	Solution/Parameter	
WAN IP address of router	Dynamic Host Control Protocol (DHCP)	
LAN IP address of router	192.168.99.1	
LAN client IP addresses	Dynamic Host Control Protocol (DHCP)	
Number of hosts allowed on LAN and LAN Mask	100 hosts	Mask of LAN 255.255.255.0
IP address range of hosts on LAN	192.168.99.100 to 192.168.99.199	
Remapping Method WAN to LAN	Network Address Translation (NAT)	
IP to Fully Qualified Domain Name translation	DNS Server	

There are many DHCP server packages available online however the most common and stable is the ISC DHCPD. This server quickly installs from the terminal with the following command.

```
sudo apt-get install isc-dhcp-server
```

Once installed, the DHCP configuration file (dhcpd.conf) must be modified. It must contain subnet-specific information (Table 3). The Linux editor “vim” is used. Any Linux text editor can be substituted.

```
sudo vim /etc/dhcp/dhcpd.conf
```

```

36 # This is a very basic subnet declaration.
37
38 subnet 192.168.99.0 netmask 255.255.255.0 {
39     range 192.168.99.100 192.168.99.199;
40     option routers 192.168.99.1;
41     option domain-name-servers 192.168.99.1;
42     option broadcast-address 192.168.99.255;
43 }

```

Figure 4. IP address declarations in the dhcpd.conf file.

Figure 4 shows the edited dhcpd.conf file. The design values shown are from Table 3. The chosen router network IP address of 192.168.99.1 is arbitrary. The chosen span of 100 hosts is arbitrary. Addresses run between 192.168.99.100 and 192.168.99.199. After making the changes, manually restart the isc-dhcpd server:

```
sudo /etc/init.d/isc-dhcp-server restart
```

The Domain Name System (DNS) server install is even easier; this will allow access to websites, such as www.google.com, without the need of, or knowledge of, the website's numeric dotted decimal IP address.

```
sudo apt-get install bind9 bind9utils bind9-doc
```

V. Firewall Network Configuration

The primary network configuration in the previous section included only one “routing” directive. That directive was “forwarding enabled.” Stopping network feature development work at this point yields an extremely insecure and dangerous network. The next work will use a network firewall feature known as “iptables” [6] It establishes network traffic operating rules. The in-depth knowledge of iptable rule creation is beyond the scope of this work. However, discussion includes background information.

Good network administration practice requires “iptables” rules restoration from a saved configuration. A script file restores rules at boot. The “flow” of network startup operations ensures enforcement of rules before network interfaces are enabled. Figure 5 shows the creation of the “restoration” iptables script file used at boot. Figure 6 shows the /etc/network/iptables file content used in this project. The content determines the iptable rule application structure.

```
sudo vim /etc/network/if-pre-up.d/iptables
```

```

1 #!/bin/sh
2 /sbin/iptables-restore < /etc/network/iptables

```

Figure 5. Creation of restoration script file from /etc/network/if-pre-up.d/iptables.

System “housekeeping” requires execution of the next Linux Command Lines. They ensure needed file ownership and permissions for the script file /etc/network/if-pre-up.d/iptables.

```
sudo chown root /etc/network/if-pre-up.d/iptables
sudo chmod 755 /etc/network/if-pre-up.d/iptables
```

Assuming the /etc/network/iptables file exists, its basic rules are in the “saved configuration” iptables file at boot.

```
1 |nat
2 |:PREROUTING ACCEPT [0:0]
3 |:INPUT ACCEPT [0:0]
4 |:OUTPUT ACCEPT [0:0]
5 |:POSTROUTING ACCEPT [0:0]
6
7 # enp1s0 is WAN interface, #enp2s0 is LAN interface
8 -A POSTROUTING -o enp1s0 -j MASQUERADE
9
10 # NAT pinhole: HTTP from WAN to LAN
11 -A PREROUTING -p tcp -m tcp -i enp1s0 --dport 80 -j DNAT --to-destination 192.168.99.100:80
12
13 COMMIT
14
15 *filter
16 :INPUT ACCEPT [0:0]
17 :FORWARD ACCEPT [0:0]
18 :OUTPUT ACCEPT [0:0]
19
20 # Service rules
21
22 # basic global accept rules - ICMP, loopback, traceroute, established all accepted
23 -A INPUT -s 127.0.0.0/8 -d 127.0.0.0/8 -i lo -j ACCEPT
24 -A INPUT -p icmp -j ACCEPT
25 -A INPUT -m state --state ESTABLISHED -j ACCEPT
26
27 # enable traceroute rejections to get sent out
28 -A INPUT -p udp -m udp --dport 33434:33523 -j REJECT --reject-with icmp-port-unreachable
29
30 # DNS - accept from LAN
31 -A INPUT -i enp2s0 -p tcp --dport 53 -j ACCEPT
32 -A INPUT -i enp2s0 -p udp --dport 53 -j ACCEPT
33
34 # SSH - accept from LAN
35 -A INPUT -i enp2s0 -p tcp --dport 22 -j ACCEPT
36
37 # DHCP client requests - accept from LAN
38 -A INPUT -i enp2s0 -p udp --dport 67:68 -j ACCEPT
39
40 # drop all other inbound traffic
41 -A INPUT -j DROP
42
43 # Forwarding rules
44
45 # forward packets along established/related connections
46 -A FORWARD -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
47
48 # forward from LAN (enp2s0) to WAN (enp1s0)
49 -A FORWARD -i enp2s0 -o enp1s0 -j ACCEPT
50
51 # allow traffic from our NAT pinhole
52 -A FORWARD -p tcp -d 192.168.99.100 --dport 80 -j ACCEPT
53
54 # drop all other forwarded traffic
55 -A FORWARD -j DROP
56
57 COMMIT
58
```

Figure 6. Rule contents of the /etc/network/iptables file.

As stated earlier, the in-depth knowledge of iptable rule creation is beyond the scope of this work. However, the general form, shown in Figure 6, is (1) start of a table denoted by name and (2) end of a table denoted by COMMIT. Above the COMMIT statement, reside any IP traffic handling rules. Each table contents contain "chains." Rules belong to chains.

Two iptables tables exist in Figure 6, (1) the Network Address Translation table named “nat,” and the global/general table named “filter.” Shown below, left, is the "nat" table chains. Shown below, right, is the "filter" table chains.

:PREROUTING ACCEPT [0:0]	:INPUT ACCEPT [0:0]
:INPUT ACCEPT[0:0]	:FORWARD ACCEPT [0:0]
:OUTPUT ACCEPT [0:0]	:OUTPUT ACCEPT [0:0]
:POSTROUTING ACCEPT [0:0]	

Highlighted rows indicate chains that are filled out by rule statements in Figure 6. The other chains do not have rule statements. The rules begin with the “-A” symbol. All IP traffic navigates the iptables structure for rule testing, as indicated in Figure 7. The nat table rules are specific to acting on Network Address Translation directives. The filter table’s principle role is security. That is, determining whether to drop network packets or not.

Figure 7. IP traffic navigation using the IPTABLE structure.

Figure 6 shows the Filter rules (navigated as shown in Figure 7), they represent excellent networking practices. Here are two examples (Table 4 and Table 5):

Table 4. A Postrouting chain and rule in an IPTABLE structure.

The “Postrouting” chain (*nat) contains the following rule:
-A POSTROUTING -o enp1s0 -j MASQUERADE
Which is interpreted as: replace the LAN IP address of a host with the WAN IP address of the mini-PC router. Output network interface is the WAN port. It is an unconditional rule.

Table 5. An Input chain and rule in an IPTABLE structure.

The “Input” chain (*filter) contains the following rule:
The -A INPUT -i enp2s0 -p tcp --dport 22 -j ACCEPT
Which is interpreted as: the SSH port 22 accepts traffic from the mini-PC router’s LAN network interface. SSH connections are accepted. Therefore, SSH service is available.

VI. Testing

There are many possible ways to test a router, and there are benchmarks to consider. For home use, most customers do not have network connect speeds exceeding 100 Mbps [7]. Most commercially available routers can easily meet these connection speeds. However, in business applications, higher capacities are required.

The first measurement considered by many is throughput. The chosen network tool “iperf” [8] tested channel throughput. Figure 8 shows the test setup, with the mini-PC router in place. Testing included the commercial routers.

Figure 8. Network measurement testbed.

Figure 9. “Iperf” router throughput (Mbps) test results (chart).

The recorded test throughput of each commercial device equaled their advertised throughput. The Ubuntu-based mini-PC router’s test result equaled the advertised throughput ratings of their network interfaces. See Figure 9. These results show that the Iperf throughput test does not provide the full picture. Another common statistic Internet users look at is latency. Tests showed latency for all devices were less than one (1) mS. This latency is well below other latencies found in typical network paths. Therefore, the latency values seen are acceptable for all routers tested.

The final test set used the free network measurement tool LANBench [9]. This product tests unidirectional traffic as well as bidirectional traffic. Deploy LANBench on both machines. Machine 2 acted as the server (see Figure 8). Machine 1 acted as the client. Figure 10 shows the server user-interface window at Machine 2.

The image shows a 'LANBench Config' window with two main sections: 'Server Settings' and 'Test Settings'. In the 'Server Settings' section, the 'Server Address' is set to '192.168.0.1' and the 'Server Port' is set to '80'. In the 'Test Settings' section, the 'Test Duration' is '20' seconds, the 'Packet Size' is '10' KB, and the 'Connections' are set to '20'. The 'Transfer Mode' is set to 'Send And Receive' (indicated by a selected radio button). There are also 'Send Only' and 'Receive Only' options. At the bottom right, there are 'OK' and 'Cancel' buttons.

Figure 10. LANBench server graphic user interface.

All transfer modes were exercised for each router; repeated five times on each router tested. Packet size set at 10 KB. Test duration set at 20 seconds. Table 6 shows the calculated averages. Figure 11 charts the same data.

Table 6. Calculated average data rates for LANBench test.

Test Description	Ubuntu Router	NETGEAR R7000	Linksys EA6900	TP-LINK Archer C9	Linksys E900
WAN -> LAN	939.6 Mbps	931.4 Mbps	923.6 Mbps	756.0 Mbps	94.1 Mbps
LAN -> WAN	957.2 Mbps	941.7 Mbps	844.2 Mbps	755.9 Mbps	94.0 Mbps
Total Simultaneous	1463.3 Mbps	1378.3 Mbps	1135.1 Mbps	1189.7 Mbps	149.6 Mbps

Figure 11. Calculated average data rates (Mbps) for LANBench test (chart).

VII. Conclusion

The conversion of the Qotom mini-PC from a PfSense OS to Ubuntu OS went without difficulty. Organizational skills are required; stepping through the creation of an Ubuntu boot installation USB memory stick (2 GB stick) requires attention to details. The boot install requires plugging in a USB keyboard and the borrowing of a VGA monitor. Once Ubuntu is installed, work proceeds centered on installing and configuring networking features. First router achievement was the creation of an “unprotected” router. Creating a Firewall is more challenging because of the nuances of the Iptables network feature. However, use of standard Iptable tables, chains, and rules statements makes the task easier.

The custom built router consistently performed well against a set of commercially available routers. The results make it apparent that the mini PC router can efficiently compete with those routers. The unidirectional results make it apparent that the device is operating near the limits of its hardware network interfaces. Further, Ubuntu’s ability to process network transactions are not a limiting factor in the tests. Increasing mini-PC memory is an option if real-life results indicate the router is operating below test results.

The price of the Qotom mini-PC was \$200. The price of the commercial routers, when new, was near \$200. The laboratory/classroom educational potential is present in the mini-PC. The Linux world holds a remarkable market share of the server industry. Learning the Linux Command Line Interface, the network connections, and Linux-based network administration tools have advantages. Its educational potential makes it well suited for use in senior projects and special projects.

References

1. “Qotom Technology Company, LTD.”, *Q190G4N Mini PC 4 LAN sales information*, [online] Available: <http://www.qotom.net/goods-133-Q190G4N+Mini+PC+4+LAN.html>
2. “Netgate”, *pfSense open source firewall project*, [online] Available: <https://www.netgate.com/solutions/pfsense/features.html>
3. “Ubuntu”, *Ubuntu main web page*, [online] Available: <https://www.ubuntu.com/>
4. “Ubuntu”, *Ubuntu 16.04 Server Installation Download*, [online] Available: <https://www.ubuntu.com/download/serverReferences>
5. “Ubuntu”, *Ubuntu Community Support*, [online] Available: <https://www.ubuntu.com/support/community-support>
6. “Ubuntu”, *Ubuntu Firewall Documentation Iptables*, [online] Available: <https://help.ubuntu.com/community/IptablesHowTo>
7. “Statista Inc.”, *Average internet connection speed in the United States from 2007 to 2017 (in Mbps), by quarter*, [online] Available: <https://www.statista.com/statistics/616210/average-internet-connection-speed-in-the-us/>
8. “Wikipedia”, *Iperf Wikipedia Entry*, [online] Available: <https://en.wikipedia.org/wiki/Iperf>
9. Saw, Z., *LANBench*, [online] Available: http://www.zachsaw.com/?pg=lanbench_tcp_network_benchmark