A beginner's guide to network troubleshooting in Linux

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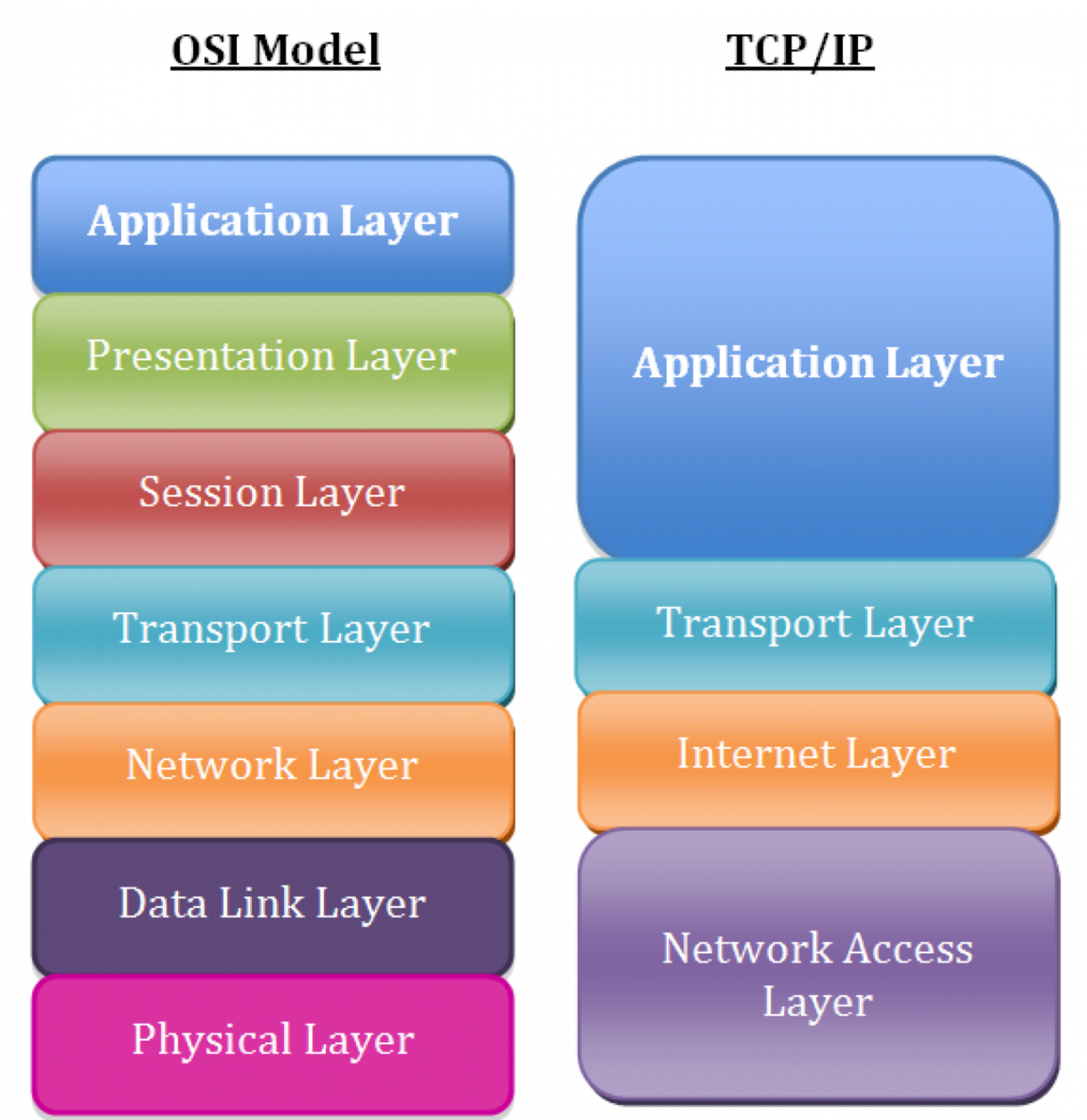
A quick review of the TCP/IP model

First, let's take a moment to review the fundamentals of the TCP/IP network model. While most people use the Open Systems Interconnection (OSI) model to discuss network theory, the TCP/IP model more accurately represents the suite of protocols that are deployed in modern networks.



The layers in the TCP/IP network model, in order, include:

- **Layer 5:** Application
- **Layer 4:** Transport
- **Layer 3:** Network/Internet
- **Layer 2:** Data Link
- **Layer 1:** Physical

I'll assume that you are familiar with this model, and will proceed by discussing ways to troubleshoot issues at stack Layers 1 through 4. Where to start troubleshooting is situation-dependent. For example, if you can SSH to a server, but the server can't connect to a MySQL database, the problem is unlikely to be the physical or data link layers on the local server. In general, it's a good idea to work your way down the stack. Start with the application, and then gradually troubleshoot each lower layer until you've isolated the problem.

With that background out of the way, let's jump to the command line and start troubleshooting.

Layer 1: The physical layer

We often take the physical layer for granted ("did you make sure the cable is plugged in?"), but we can easily troubleshoot physical layer problems from the Linux command line. That is if you have console connectivity to the host, which might not be the case for some remote systems.

Let's start with the most basic question: Is our physical interface up? The `ip link show` command tells us:

```
# ip link show

1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN mode DEFAULT group
default qlen 1000
link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
2: eth0: <BROADCAST,MULTICAST> mtu 1500 qdisc pfifo_fast state DOWN mode DEFAULT group
default qlen 1000
link/ether 52:54:00:82:d6:6e brd ff:ff:ff:ff:ff:ff
```

Notice the indication of DOWN in the above output for the eth0 interface. This result means that Layer 1 isn't coming up. We might try troubleshooting by checking the cabling or the remote end of the connection (e.g., the switch) for problems.

Before you start checking cables, though, it's a good idea to make sure that the interface isn't just disabled. Issuing a command to bring the interface up can rule this problem out:

```
# ip link set eth0 up
```

The output of `ip link show` can be difficult to parse at a quick glance. Luckily, the `-br` switch prints this output in a much more readable table format:

```
# ip -br link show
lo UNKNOWN 00:00:00:00:00:00 <LOOPBACK,UP,LOWER_UP>
eth0 UP 52:54:00:82:d6:6e <BROADCAST,MULTICAST,UP,LOWER_UP>
```

It looks like `ip link set eth0 up` did the trick, and eth0 is back in business.

These commands are great for troubleshooting obvious physical issues, but what about more insidious issues? Interfaces can negotiate at the incorrect speed, or collisions and physical layer problems can cause packet loss or corruption that results in costly retransmissions. How do we start troubleshooting those issues?

We can use the `-s` flag with the `ip` command to print additional statistics about an interface. The output below shows a mostly clean interface, with only a few dropped receive packets and no other signs of physical layer issues:

```
# ip -s link show eth0
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP mode DEFAULT
group default qlen 1000
link/ether 52:54:00:82:d6:6e brd ff:ff:ff:ff:ff:ff
RX: bytes packets errors dropped overrun mcast
34107919 5808 0 6 0 0
TX: bytes packets errors dropped carrier collsns
434573 4487 0 0 0 0
```

For more advanced Layer 1 troubleshooting, the `ethtool` utility is an excellent option. A particularly good use case for this command is checking to see if an interface has negotiated the correct speed. An interface that has negotiated the wrong speed (e.g. a 10Gbps interface that only reports 1Gbps speeds) can be an indicator of a hardware/cabling issue, or a negotiation misconfiguration on one side of the link (e.g., a misconfigured switch port).

Our results might look like this:

```
# ethtool eth0
Settings for eth0:
Supported ports: [ TP ]
Supported link modes: 10baseT/Half 10baseT/Full
100baseT/Half 100baseT/Full
1000baseT/Full
Supported pause frame use: Symmetric
Supports auto-negotiation: Yes
Supported FEC modes: Not reported
Advertised link modes: 10baseT/Half 10baseT/Full
100baseT/Half 100baseT/Full
1000baseT/Full
Advertised pause frame use: Symmetric
Advertised auto-negotiation: Yes
Advertised FEC modes: Not reported
Speed: 1000Mb/s
Duplex: Full
Port: Twisted Pair
PHYAD: 1
Transceiver: internal
Auto-negotiation: on
MDI-X: on (auto)
Supports Wake-on: d
Wake-on: d
Current message level: 0x00000007 (7)
drv probe link
Link detected: yes
```

Note that the output above shows a link that has correctly negotiated to a speed of 1000Mbps and full-duplex.

Layer 2: The data link layer

The data link layer is responsible for *local* network connectivity; essentially, the communication of frames between hosts on the same Layer 2 domain (commonly called a local area network). The most relevant Layer 2 protocol for most sysadmins is the Address Resolution Protocol (ARP), which maps Layer 3 IP addresses to Layer 2 Ethernet MAC addresses. When a host tries to contact another host on its local network (such as the default gateway), it likely has the other host's IP address, but it doesn't know the other host's MAC address. ARP solves this issue and figures out the MAC address for us.

A common problem you might encounter is an ARP entry that won't populate, particularly for your host's default gateway. If your localhost can't successfully resolve its gateway's Layer 2 MAC address, then it won't be able to send any traffic to remote networks. This problem might be caused by having the wrong IP address configured for the gateway, or it may be another issue, such as a misconfigured switch port.

We can check the entries in our ARP table with the `ip neighbor` command:

```
# ip neighbor show
192.168.122.1 dev eth0 lladdr 52:54:00:11:23:84 REACHABLE
```

Note that the gateway's MAC address is populated (we'll talk more about how to find your gateway in the next section). If there was a problem with ARP, then we would see a resolution failure:

```
# ip neighbor show
192.168.122.1 dev eth0 FAILED
```

Another common use of the `ip neighbor` command involves manipulating the ARP table. Imagine that your networking team just replaced the upstream router (which is your server's default gateway). The MAC address may have changed as well since MAC addresses are hardware addresses that are assigned at the factory.

Note: While unique MAC addresses are assigned to devices at the factory, it is possible to change or spoof these. Many modern networks often also use protocols such as the Virtual Router Redundancy Protocol (VRRP), which use a generated MAC address.

Linux caches the ARP entry for a period of time, so you may not be able to send traffic to your default gateway until the ARP entry for your gateway times out. For highly important systems, this result is undesirable. Luckily, you can manually delete an ARP entry, which will force a new ARP discovery process:

```
# ip neighbor show
192.168.122.170 dev eth0 lladdr 52:54:00:04:2c:5d REACHABLE
192.168.122.1 dev eth0 lladdr 52:54:00:11:23:84 REACHABLE
# ip neighbor delete 192.168.122.170 dev eth0
# ip neighbor show
192.168.122.1 dev eth0 lladdr 52:54:00:11:23:84 REACHABLE
```

In the above example, we see a populated ARP entry for 192.168.122.70 on eth0. We then delete the ARP entry and can see that it has been removed from the table.

Layer 3: The network/internet layer

Layer 3 involves working with IP addresses, which should be familiar to any sysadmin. IP addressing provides hosts with a way to reach other hosts that are outside of their local network (though we often use them on local networks as well). One of the first steps to troubleshooting is checking a machine's local IP address, which can be done with the `ip address` command, again making use of the `-br` flag to simplify the output:

```
# ip -br address show
lo UNKNOWN 127.0.0.1/8 ::1/128
eth0 UP 192.168.122.135/24 fe80::184e:a34d:1d37:441a/64 fe80::c52f:d96e:a4a2:743/64
```

We can see that our eth0 interface has an IPv4 address of 192.168.122.135. If we didn't have an IP address, then we'd want to troubleshoot that issue. The lack of an IP address can be caused by a local misconfiguration, such as an incorrect network interface config file, or it can be caused by problems with DHCP.

The most common frontline tool that most sysadmins use to troubleshoot Layer 3 is the `ping` utility. Ping sends an ICMP Echo Request packet to a remote host, and it expects an ICMP Echo Reply in return. If you're having connectivity issues to a remote host, `ping` is a common utility to begin your troubleshooting. Executing a simple ping from the command line sends ICMP echoes to the remote host indefinitely; you'll need to CTRL+C to end the ping or pass the `-c <num pings>` flag, like so:

```
# ping www.google.com
PING www.google.com (172.217.165.4) 56(84) bytes of data.
64 bytes from yyz12s06-in-f4.1e100.net (172.217.165.4): icmp_seq=1 ttl=54 time=12.5 ms
64 bytes from yyz12s06-in-f4.1e100.net (172.217.165.4): icmp_seq=2 ttl=54 time=12.6 ms
64 bytes from yyz12s06-in-f4.1e100.net (172.217.165.4): icmp_seq=3 ttl=54 time=12.5 ms
^C
--- www.google.com ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2002ms
rtt min/avg/max/mdev = 12.527/12.567/12.615/0.036 ms
```

Notice that each ping includes the amount of time it took to receive a response. While `ping` can be an easy way to tell if a host is alive and responding, it is by no means definitive. Many network operators block ICMP packets as a security precaution, although many others disagree with this practice. Another common gotcha is relying on the time field as an accurate indicator of network latency. ICMP packets can be rate limited by intermediate network gear, and they shouldn't be relied upon to provide true representations of application latency.

The next tool in the Layer 3 troubleshooting tool belt is the `traceroute` command. Traceroute takes advantage of the Time to Live (TTL) field in IP packets to determine the path that traffic takes to its destination. Traceroute will send out one packet at a time, beginning with a TTL of one. Since the packet expires in transit, the upstream router sends back an ICMP Time-to-Live Exceeded packet. Traceroute then increments the TTL to determine the next hop. The resulting output is a list of intermediate routers that a packet traversed on its way to the destination:

```
# traceroute www.google.com
traceroute to www.google.com (172.217.10.36), 30 hops max, 60 byte packets
1 acritelli-laptop (192.168.122.1) 0.103 ms 0.057 ms 0.027 ms
2 192.168.1.1 (192.168.1.1) 5.302 ms 8.024 ms 8.021 ms
3 142.254.218.133 (142.254.218.133) 20.754 ms 25.862 ms 25.826 ms
4 agg58.rochnyei01h.northeast.rr.com (24.58.233.117) 35.770 ms 35.772 ms 35.754 ms
5 agg62.hnrtnyaf02r.northeast.rr.com (24.58.52.46) 25.983 ms 32.833 ms 32.864 ms
6 be28.albynyyf01r.northeast.rr.com (24.58.32.70) 43.963 ms 43.067 ms 43.084 ms
7 bu-ether16.nycmny837aw-bcr00.tbone.rr.com (66.109.6.74) 47.566 ms 32.169 ms 32.995 ms
8 0.ae1.pr0.nyc20.tbone.rr.com (66.109.6.163) 27.277 ms * 0.ae4.pr0.nyc20.tbone.rr.com
(66.109.1.35) 32.270 ms
9 ix-ae-6-0.tcore1.n75-new-york.as6453.net (66.110.96.53) 32.224 ms ix-ae-10-0.tcore1.n75-
new-york.as6453.net (66.110.96.13) 36.775 ms 36.701 ms
10 72.14.195.232 (72.14.195.232) 32.041 ms 31.935 ms 31.843 ms
11 * * *
12 216.239.62.20 (216.239.62.20) 70.011 ms 172.253.69.220 (172.253.69.220) 83.370 ms
lga34s13-in-f4.1e100.net (172.217.10.36) 38.067 ms
```

Traceroute seems like a great tool, but it’s important to understand its limitations. As with ICMP, intermediate routers may filter the packets that `traceroute` relies on, such as the ICMP Time-to-Live Exceeded message. But more importantly, the path that traffic takes to and from a destination is not necessarily symmetric, and it’s not always the same. Traceroute can mislead you into thinking that your traffic takes a nice, linear path to and from its destination. However, this situation is rarely the case. Traffic may follow a different return path, and paths can change dynamically for many reasons. While `traceroute` may provide accurate path representations in small corporate networks, it often isn’t accurate when trying to trace across large networks or the internet.

Another common issue that you’ll likely run into is a lack of an upstream gateway for a particular route or a lack of a default route. When an IP packet is sent to a different network, it must be sent to a gateway for further processing. The gateway should know how to route the packet to its final destination. The list of gateways for different routes is stored in a *routing table*, which can be inspected and manipulated using `ip route` commands.

We can print the routing table using the `ip route show` command:

```
# ip route show
default via 192.168.122.1 dev eth0 proto dhcp metric 100
192.168.122.0/24 dev eth0 proto kernel scope link src 192.168.122.135 metric 100
```

Simple topologies often just have a default gateway configured, represented by the "default" entry at the top of the table. A missing or incorrect default gateway is a common issue.

If our topology is more complex and we require different routes for different networks, we can check the route for a specific prefix:

```
# ip route show 10.0.0.0/8
10.0.0.0/8 via 192.168.122.200 dev eth0
```

In the example above, we are sending all traffic destined to the 10.0.0.0/8 network to a different gateway (192.168.122.200).

While not a Layer 3 protocol, it's worth mentioning DNS while we're talking about IP addressing. Among other things, the Domain Name System (DNS) translates IP addresses into human-readable names, such as `www.redhat.com` . DNS problems are extremely common, and they are sometimes opaque to troubleshoot. Plenty of books and online guides have been written on DNS, but we'll focus on the basics here.

A telltale sign of DNS trouble is the ability to connect to a remote host by IP address but not its hostname. Performing a quick `nslookup` on the hostname can tell us quite a bit (`nslookup` is part of the `bind-utils` package on Red Hat Enterprise Linux-based systems):

```
# nslookup www.google.com
Server: 192.168.122.1
Address: 192.168.122.1#53

Non-authoritative answer:
Name: www.google.com
Address: 172.217.3.100
```

The output above shows the server that the lookup was performed against 192.168.122.1 and the resulting IP address was 172.217.3.100.

If you perform an `nslookup` for a host but `ping` or `traceroute` try to use a different IP address, you're probably looking at a host file entry problem. As a result, inspect the host file for problems:

```
# nslookup www.google.com
Server: 192.168.122.1
Address: 192.168.122.1#53

Non-authoritative answer:
Name: www.google.com
Address: 172.217.12.132

# ping -c 1 www.google.com
PING www.google.com (1.2.3.4) 56(84) bytes of data.
^C
--- www.google.com ping statistics ---
1 packets transmitted, 0 received, 100% packet loss, time 0ms

# cat /etc/hosts
127.0.0.1 localhost localhost.localdomain localhost4 localhost4.localdomain4
::1 localhost localhost.localdomain localhost6 localhost6.localdomain6

1.2.3.4 www.google.com
```

Notice that in the example above, the address for `www.google.com` resolved to 172.217.12.132. However, when we tried to ping the host, traffic was being sent to 1.2.3.4. Taking a look at the `/etc/hosts` file, we can see an override that someone must have carelessly added. Host file override issues are *extremely* common, especially if you work with application developers who often need to make these overrides to test their code during development.

Layer 4: The transport layer

The transport layer consists of the TCP and UDP protocols, with TCP being a connection-oriented protocol and UDP being connectionless. Applications listen on *sockets*, which consist of an IP address and a port. Traffic destined to an IP address on a specific port will be directed to the listening application by the kernel. A full discussion of these protocols is beyond the scope of this article, so we'll focus on how to troubleshoot connectivity issues at these layers.

The first thing that you may want to do is see what ports are listening on the localhost. The result can be useful if you can't connect to a particular service on the machine, such as a web or SSH server. Another common issue occurs when a daemon or service won't start because of something else listening on a port. The `ss` command is invaluable for performing these types of actions:

```
# ss -tunlp4
Netid State Recv-Q Send-Q Local Address:Port Peer Address:Port
udp UNCONN 0 0 *:68 *:* users:(("dhclient",pid=3167,fd=6))
udp UNCONN 0 0 127.0.0.1:323 *:* users:(("chronyd",pid=2821,fd=1))
tcp LISTEN 0 128 *:22 *:* users:(("sshd",pid=3366,fd=3))
tcp LISTEN 0 100 127.0.0.1:25 *:* users:(("master",pid=3600,fd=13))
```

Let's break down these flags:

- **-t** - Show TCP ports.
- **-u** - Show UDP ports.
- **-n** - Do not try to resolve hostnames.
- **-l** - Show only listening ports.
- **-p** - Show the processes that are using a particular socket.
- **-4** - Show only IPv4 sockets.

Taking a look at the output, we can see several listening services. The `sshd` application is listening on port 22 on all IP addresses, denoted by the `*:22` output.

The `ss` command is a powerful tool, and a review of its brief man page can help you locate flags and options to find whatever you're looking for.

Another common troubleshooting scenario involves remote connectivity. Imagine that your local machine can't connect to a remote port, such as MySQL on port 3306. An unlikely, but commonly installed tool can be your friend when troubleshooting these types of issues: `telnet`. The `telnet` command attempts to establish a TCP connection with whatever host and port you give it. This feature is perfect for testing remote TCP connectivity:

```
# telnet database.example.com 3306

Trying 192.168.1.10...
^C
```

In the output above, `telnet` hangs until we kill it. This result tells us that we can't get to port 3306 on the remote machine. Maybe the application isn't listening, and we need to employ the previous troubleshooting steps using `ss` on the remote host—if we have access. Another possibility is a host or intermediate firewall that is filtering the traffic. We may need to work with the network team to verify Layer 4 connectivity across the path.

Telnet works fine for TCP, but what about UDP? The `netcat` tool provides a simple way to check a remote UDP port:

```
# nc 192.168.122.1 -u 80
test
Ncat: Connection refused.
```

The `netcat` utility can be used for many other things, including testing TCP connectivity. Note that `netcat` may not be installed on your system, and it's often considered a security risk to leave lying around. You may want to consider uninstalling it when you're done troubleshooting.

The examples above discussed common, simple utilities. However, a much more powerful tool is `nmap`. Entire books have been devoted to `nmap` functionality, so we won't cover it in this beginner's article, but you should know some of the things that it's capable of doing:

- TCP and UDP port scanning remote machines.
- OS fingerprinting.
- Determining if remote ports are closed or simply filtered.

As you progress in your network troubleshooting journey, you'll undoubtedly come across previously unknown command flags, fancy one-liners, and powerful new tools (`tcpdump` and Wireshark are my favorites) to dig into the causes of your network issues. Have fun, and remember: The packets don't lie!