SysAdmin Notes for RHCE

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Part I

Advanced System Management

Chapter 1

Configuring Authentication

1.1 Understanding RedHat Identity Management

RedHat Identity Management is based on the FreeIPA (Identity, Policy, Audit) Project. The project bundles together several services in one solution. Some of the services are:

Options	Description
389 Directory Server	This is an **LDAPv3** Directory Server – a replacement for *OpenLDAP*.
Single Sign-on	Provided by MIT **Kerberos** KDC.
Integrated Certificate System	Based on the *Dogtag* project.
Integrated NTP Server	*Chrony* must be disabled to use this!
Integrated DNS Server	Based on *ISC Bind* Service.

Thus, the Identity Management provided by IPA bundles up some pretty complicated projects together and provides an easy interface to manage them all. However, IPA conflicts with other products, such as other *LDAP, Kerberos, Certificate System, NTP or DNS* servers shouldn't be running on the same system. Thus, ideally Identity Management should be set up on a dedicated server.

Kerberos is a Network Authentication Protocol that makes clients prove their identity to the server, and vice versa. Other than the authentication tools, it also supports strong cryptography over the network to keep the data safe in-transit.

1.1.1 IdM Server Components and Requirements

An IdM server needs some from of *Host Name Resolution*, which can be either through a DNS server or via the `/etc/hosts` file. Note that the hostname of the Identity Management server itself must also be specified.

Next we need both the **ipa-server** package, which installs the server components, and the **ipa-client** package which installs the client components. While the client package isn't required to be installed on the server, while configuring a client that talks to an IPA server, then this is one of the solutions available. Another method would be to use **authconfig**.

After the required RPM packages have been installed, we will run **ipa-server-install** which provides an easy, scripted way to install an IPA server, and all we have to do is answer a few questions, at the end of which we get a fully-functional IPA server.

The **ipa** tool is a generic client interface, that's also the administration interface. Thus, it can perform several tasks such as adding users (`ipa user-add <username>`), set the password for an user (`ipa passwd <username>`), see the IPA properties for a user account (`ipa user-find <username>`), etc. *ipa-xxx* can be used instead as well, where *xxx* represents the different tasks. Authentication can also be configured using **authconfig**.

1.1.2 Preparing IdM Installation

First and foremost, the *host name resolution* must be set up, since the installation will fail if the host can't find its own name. Additionally, the DNS name must also be known since the Kerberos domain that we'll configure will be based on the DNS name.

Next, the **nscd** service must be disabled, along with any existing LDAP and Kerberos services. If NTP and ISC Bind must also be disabled if installed (due to possible conflicts). The LDAP, Kerberos, NTP, DNS and certificate system ports must be opened in the firewall.

1.1.3 Installing IdM

The **ipa-server**, **bind** and **nds-ldap** packages must be installed using, following which, we have to run the command **ipa-server-install**, which will perform a wizard-like scripted installation.

```
# yum -y install ipa-server bind nds-ldap
# ipa-server-install
```

If we don't want to enter the information interactively, we can also provide them as options. The hostname, the domain name, a realm name (domain name in upper-case).

```
# ipa-server-install --hostname=vmPrime.somuVMnet.local -n somuVMnet.local -r
 ↪  SOMUVMNET.COM -p password -a password -U --no-ntp
```

The appropriate flags needed are:

Options	Description
–hostname	The hostname of the server
-n	The Domain name of the server
-r	Realm Name (Domain name in All-Caps)
-p	Password for Directory Manager
-a	Password for admin user
-U	Unattended Install; Doesn't prompt for anything
–no-dns	Do not install the DNS Server

Now, the SSH Daemon must be restarted to ensure that SSH obtains Kerberos credentials:

```
# systemctl restart sshd
```

Then, we generate a new Kerberos ticket and then verify Kerberos authentication for the default admin user by using:

```
# kinit admin
Password for admin@SOMUVMNET.LOCAL:
```

```
# klist
Ticket cache: KEYRING:persistent:0:0
Default principal: admin@SOMUVMNET.LOCAL

Valid starting       Expires              Service principal
2017-12-26T15:44:09  2017-12-27T15:44:05  krbtgt/SOMUVMNET.LOCAL@SOMUVMNET.LOCAL
```

This will show us if we have a valid Kerberos ticket. For any administrative tasks on the IPA server, having a valid Kerberos ticket is mandatory. Finally, we need to verify IPA access using:

```
# ipa user-find admin
```

This will show us the details of the admin user as created in the LDAP directory, along with all of its properties.

1.1.4 Understanding Kerberos Tickets

Kerberos tickets are the keys to the proper functioning of Identity Management. To be able to manage the IdM server, we need to log in to the IdM Domain and generate a Kerberos ticket for the admin user, using the command:

```
# kinit admin
```

We can check the validity of the ticket at any time using:

```
# klist
```

1.1.5 Managing the IdM Server

After generating a Kerberos ticket with `kinit admin`, we use the **ipa** command to manage the IdM server. `ipa help commands` shows us a short overview of all the available commands and their usage. For any specific command, we have `ipa help <command>` (such as `ipa help user-add`).

Another method to manage the IdM server is to navigate, using our web browser, to `https://vmPrime.somuVMnet.local` (if our server is named *vmPrime.somuVMnet.local*). This will load the IPA management web interface. Through this interface, after we've authenticated as admin, we will be guided through the various aspects of setting up the IdM environment.

1.1.6 Creating User Accounts

The required commands to create an user called *lisa* and verify the account creation are:

```
# kinit admin
# ipa user-add lisa
# ipa passwd lisa
# ipa user-find lisa
```

1.2 Using authconfig to Setup External Authentication

There are the **authconfig** utilities to setup external authentication (via LDAP), which consist of: *authconfig, authconfig-tui* and *authconfig-gtk*. The GUI utility can be installed using `yum -y install authconfig-gtk`. The utility is started with `authconfig-gtk`.

In the **authconfig-gtk** utility, we have to choose LDAP as the User Account Database in the Identity and Authentication tab. This might prompt for the installation of two packages: *nss-pam-ldapd* (the package that integrates the three) and *pam_krb5* (the package that integrates PAM with Kerberos). Now, we can enter the details for the LDAP server to setup authentication.

In cases of servers which don't have a GUI (or there is some inconvienience with the GUI, such as the apply button hidden by the status bar, etc.), the **authconfig-tui** is a very good alternative. In case of automated scripts, however, the **authconfig** command line utility is the best option.

1.3 Configuring a System to Authenticate using Kerberos

To connect a system for authentication to an LDAP server using Kerberos credentials, a part of the configuration has to be done with authconfig. But even before that, certain things must be ensured. *First*, we need to make sure that the IP address of the server we're trying to connect to can be resolved from the hostname, using `/etc/hosts`:

```
127.0.0.1   localhost localhost.localdomain localhost4 localhost4.localdomain4
::1         localhost localhost.localdomain localhost6 localhost6.localdomain6
90.0.16.100    vmDeux.somuVMnet.com    vmDeux
```

This is important so that we can use the FQDN of the server later while using the `authconfig-tui` utility. Next, the system must be configured to use the DNS component hosted within the IPA server. For this, all we need to do is add the IP address of the IPA server as the first nameserver entry in `/etc/resolv.conf`:

```
# Generated by NetworkManager
search somuvmnet.local
nameserver 90.0.16.100 # IP Address of DNS Server @ vmDeux.somuVMnet.local
nameserver 8.8.8.8
nameserver 202.38.180.7
```

It is important to place the IP address of the DNS server for a nameserver as the first entry because that's the only one configured to *know* the custom FQDNs of the machines on our network. So, this connectivity is essential since the Kerberos client needs to be connected to the Kerberos server.

Finally, we can start the `authconfig-tui` utility, and enter the following details:

```
# In Authentication Configuration:
[*] Use LDAP
[*] User Kerberos Authentication

# LDAP Settings
[*] Use TLS
Server:    ldap://vmdeux.somuvmnet.local
Base DN:    dc=somuvmnet, dc=local
```

```

# Kerberos Settings
Realm:    SOMUVMNET.LOCAL
[*] Use DNS to resolve hosts to realms
[*] Use DNS to resolve KDCs for realms
```

First, we've just setup the system to use LDAP using Kerberos authentication. Next, we've made it necessary to use a TLS certificate to ensure the security of the connection. Then, the details of the LDAP server have to be entered.

In the Kerberos authentication step, the *Realm* refers to the Kerberos realm that the server is a part of. If we've setup the DNS component of the IPA server properly, then the system is able to detect the KDCs properly for each realm, as well as assign hosts to their realm appropriately. Now, the TLS Certificate for the IPA Server have to be downloaded and put in the `/etc/openldap/cacerts` directory (from whichever location the IPA Server stored them in, typically `/root/cacert.p12` for the root user):

```
# cd /etc/openldap/cacerts/
# scp vmdeux.somuvmnet.local:/root/cacert.p12 .
```

At this point, we should be good to go. We can verify the LDAP connectivity by trying to login as an LDAP user. For this we use (for an LDAP user lisa):

```
# su - lisa
Last login: Tue Dec 26 18:52:05 IST 2017 on pts/0
su: warning: cannot change directory to /home/lisa: No such file or directory
-sh-4.2$
```

The warning is natural if no home directory has been configured yet.

1.3.1 Troubleshooting Authentication

When authentication doesn't work, for some reason related to the certificates, then there is an easy fix as well. Depending on whether our LDAP and Kerberos credentials are being cached by **nslcd** or **sssd**, we can edit their configuration file to ignore the validity of the certificate. This is because the *self-signed cacert* may not meet the standards dictated and required by the program. For this, we can add to `/etc/nslcd.conf`:

```
tls_reqcert never
```

If SSSD is used instead, then we can edit `/etc/sssd/sssd.conf` and add the following line:

```
ldap_tls_reqcert = never
```

When using Certificates that are well signed from an External Certificate Authority, this of course becomes unnecessary.

1.4 Understanding authconfig Configuration Files

1.4.1 Authconfig Configuration

The primary configuration of the authconfig utitlity is located at `/etc/sysconfig/authconfig`. The contents of this file is used by other config files, such as `USELDAP=yes`.

```
CACHECREDENTIALS=yes
FAILLOCKARGS="deny=4 unlock_time=1200"
FORCELEGACY=no
FORCESMARTCARD=no
IPADOMAINJOINED=no
IPAV2NONTP=no
PASSWDALGORITHM=sha512
USEDB=no
USEECRYPTFS=no
USEFAILLOCK=no
USEFPRINTD=no
USEHESIOD=no
USEIPAV2=no
USEKERBEROS=yes
USELDAP=yes
USELDAPAUTH=no
USELOCAUTHORIZE=yes
USEMKHOMEDIR=no
USENIS=no
USEPAMACCESS=no
USEPASSWDQC=no
USEPWQUALITY=yes
USESHADOW=yes
USESMARTCARD=no
USESSSD=yes
USESSSDAUTH=no
USESYSNETAUTH=no
USEWINBIND=no
USEWINBINDAUTH=no
WINBINDKRB5=no
```

These are the settings we provided to the **authconfig** utility.

1.4.2 SSSD Configuration

Things like the Kerberos password, the LDAP search base, etc. and other IPA specific settings are stored in the `/etc/sssd/sssd.conf` file, to ensure that the connection to the IPA Server is successfully initiated and it's possible to login and use the services provided by it. Typical contents of this file look like:

```
[sssd]
config_file_version = 2
services = nss, pam
# SSSD will not start if you do not configure any domains.
# Add new domain configurations as [domain/<NAME>] sections, and
# then add the list of domains (in the order you want them to be
# queried) to the "domains" attribute below and uncomment it.
; domains = LDAP

```

```
[nss]

[pam]

# Example LDAP domain
; [domain/LDAP]
; id_provider = ldap
; auth_provider = ldap
# ldap_schema can be set to "rfc2307", which stores group member names in the
# "memberuid" attribute, or to "rfc2307bis", which stores group member DNs in
# the "member" attribute. If you do not know this value, ask your LDAP
# administrator.
; ldap_schema = rfc2307
; ldap_uri = ldap://ldap.mydomain.org
; ldap_search_base = dc=mydomain,dc=org
# Note that enabling enumeration will have a moderate performance impact.
# Consequently, the default value for enumeration is FALSE.
# Refer to the sssd.conf man page for full details.
; enumerate = false
# Allow offline logins by locally storing password hashes (default: false).
; cache_credentials = true

# An example Active Directory domain. Please note that this configuration
# works for AD 2003R2 and AD 2008, because they use pretty much RFC2307bis
# compliant attribute names. To support UNIX clients with AD 2003 or older,
# you must install Microsoft Services For Unix and map LDAP attributes onto
# msSFU30* attribute names.
; [domain/AD]
; id_provider = ldap
; auth_provider = krb5
; chpass_provider = krb5
;
; ldap_uri = ldap://your.ad.example.com
; ldap_search_base = dc=example,dc=com
; ldap_schema = rfc2307bis
; ldap_sasl_mech = GSSAPI
; ldap_user_object_class = user
; ldap_group_object_class = group
; ldap_user_home_directory = unixHomeDirectory
; ldap_user_principal = userPrincipalName
; ldap_account_expire_policy = ad
; ldap_force_upper_case_realm = true
;
; krb5_server = your.ad.example.com
; krb5_realm = EXAMPLE.COM
```

This is probably one of the most important configuration files when **SSSD** is being used. If **nslcd** is being used instead, then the config file of interest is `/etc/nslcd.conf`.

1.4.3 Kerberos Configuration File

The Kerberos configuration file (for connecting to a Kerberos Server) is stored in `/etc/krb5.conf` and typically has contents like:

```
# Configuration snippets may be placed in this directory as well
includedir /etc/krb5.conf.d/

includedir /var/lib/sss/pubconf/krb5.include.d/
```

```
[logging]
default = FILE:/var/log/krb5libs.log
kdc = FILE:/var/log/krb5kdc.log
admin_server = FILE:/var/log/kadmind.log

[libdefaults]
dns_lookup_realm = true
ticket_lifetime = 24h
renew_lifetime = 7d
forwardable = true
rdns = false
# default_realm = EXAMPLE.COM
default_ccache_name = KEYRING:persistent:%{uid}

dns_lookup_kdc = true
default_realm = SOMUVMNET.LOCAL
[realms]
# EXAMPLE.COM = {
#  kdc = kerberos.example.com
#  admin_server = kerberos.example.com
# }

SOMUVMNET.LOCAL = {
}

[domain_realm]
# .example.com = EXAMPLE.COM
# example.com = EXAMPLE.COM
somuvmnet.local = SOMUVMNET.LOCAL
.somuvmnet.local = SOMUVMNET.LOCAL
```

Here, the DNS domain to realm mapping is specified, to tell us which domain on the DNS belongs to which Kerberos realm.

1.4.4 NSSwtich Configuration

This file specifies the locations and the order in which passwords are searched for authentication. This includes the order in which passwords, shadow and groups are searched. The order is typically like:

```
passwd:     files sss ldap
shadow:     files sss ldap
group:      files sss ldap
```

This instructs the system to look for passwd files in the local file system first, then SSS and finally LDAP. The same is true for the two following categories of shadow and group.

1.4.5 NSLCD Configuration

While this file may be missing from newer versions of RHEL, this is an older version of LDAP configuration file. This file is supposed to be replaced by the `/etc/sssd/sssd.conf` file, and thus, all relevant settings should be provided in that file.

Chapter 2

Configuring iSCSI Target and Initiator

2.1 Understanding iSCSI Target and Initiator

SCSI (Small Computer System Interface) [read as *scuzzy*] is an alternative to ATA (a.k.a. IDE) Hard drives, which most consumer computers stick to. While SCSI drives provide significantly more throughput for certain scenarios, IDE suffices for most home computer usage. However, in case of servers, SCSI proves to be a much better alternative, since they provide more reliability and data transfer speed (much higher than ATA), owing to the fact that data transfer occurs in full-duplex mode (i.e., data can be read and written at the same time at full speeds). They also boast higher speeds (such as 15,000 RPM) as compared to ATA speeds (7200 RPM). Another reason servers tend to use SCSI (or related technologies, such as Serially Attached SCSI or SAS) is that the protocol makes it easy to *daisy-chain* several SCSI devices to the same controller, several times that of IDE devices. In fact, in the pre-USB era, SCSI was the go-to common interface for connecting peripherals or even devices such as printers.

Traditional SCSI devices use a long cable and a SCSI **Command Descriptor Block (CDB)** command to interact with the SCSI devices. In case of iSCSI, the same CDBs are used, but they're transmitted over IP packets over a network, instead of the cable. Thus, the SCSI devices are emulated by using a storage backend and presenting them on the network using iSCSI targets. SCSI targets are typically storage devices, while the hosts they're connected to are the initiators. Thus, this technology enables us to share PVs or LVs on the network, represented by iSCSI targets.

A **Storage Area Network (SAN)** is a network that provides access to a consolidated, block level data storage. *Block devices* provide a buffered data storage method, where data is transferred from the kernel buffer to the physical device. Also, data can be read and written in entire blocks. SANs thus present devices such as disk arrays as locally attached storage to servers. **Fiber Channel** or **FC** is a high speed network technology developed to enable fast data transfers between servers and SANs. Ethernet structures utilizing iSCSI technology can be as fast as their FC structure counterparts, thus making the technology enterprise ready for SAN creation.

2.1.1 iSCSI Operation

In the case of iSCSI storage, we have the SAN, on which runs a *iSCSI target* which can provide access to the storage backend. For any server that needs to access the files hosted by the SAN, it needs to run an **iSCSI initiator**, which performs a discovery operation first. During this, the SAN tells it about the iSCSI devices it has to offer. Once this is complete, the iSCSI initiator can login to the devices.

2.1.2 iSCSI Components

Both the iSCSI targets and the storage backends need to be set up for the SAN to operate. The storage backend can be an entire disk, a dedicated partition, a logical volume or even a file! The servers, running the iSCSI initiators, will see the iSCSI targets as new storage devices after successfully logging in to them. This can be verified by viewing the output of the `/proc/partitions` file. A tool called *lsscsi* can also alternatively used, although it is not installed by default.

2.1.3 Basic iSCSI Terminology

Terms	Description
IQN	iSCSI Qualified Name - an unique name assigned to each iSCSI target and initiator, used to identify them.
Initiator	The iSCSI client that is identified by its IQN.
Target	The service on the iSCSI server that gives access to the storage backend.
ACLs	Access Control Lists that are based on the node's IQNs.
Portal	Also known as **nodes**, this is the combination of the IP address and the port that are used by both targets and initiators to establish connections.
discovery	The process through which an indicator finds the available targets that are configured for a given portal.
LUNs	The *Logical Unit Number* is a number used to identify the logical unit (i.e., block devices shared through the target) being addressed by the iSCSI Controller.
login	The act which gives an initiator the relevant LUNs.
TPG	The *Target Portal Group* is a collection of IP Addresses and TCP ports to which a particular iSCSI Target will listen.

So, there can be more than one portals per server, and more than one targets per portal.

2.1.4 After connecting an initiator to an iSCSI Target

The new block devices thus accessed will appear as local devices (/dev/sdb, /dev/sdc etc.) Note that if a LUN is available and used by multiple servers, multiple devices can access the LUN post connection, i.e., multiple servers can use the disk at the same time. This is a bit dangerous, since it requires using clustering, for providing multiple servers to use the storage. Otherwise for a file system like XFS or Ext4, two servers writing to the same file can cause data loss.

To avoid this, shared file systems such as GFS2 can be used. In GFS2, the file system cache is shared among all the nodes. Thus, all nodes writing to the file system know what all the other nodes are doing.

2.2 Setting up an iSCSI Target

The iSCSI target works with several storage backend devices on the SAN. These storage devices can be anything that can be used for PVs when using traditional LVM. All these devices are put together in a volume group, which is then subdivided into several LVs. These LVs are each assigned a LUN.

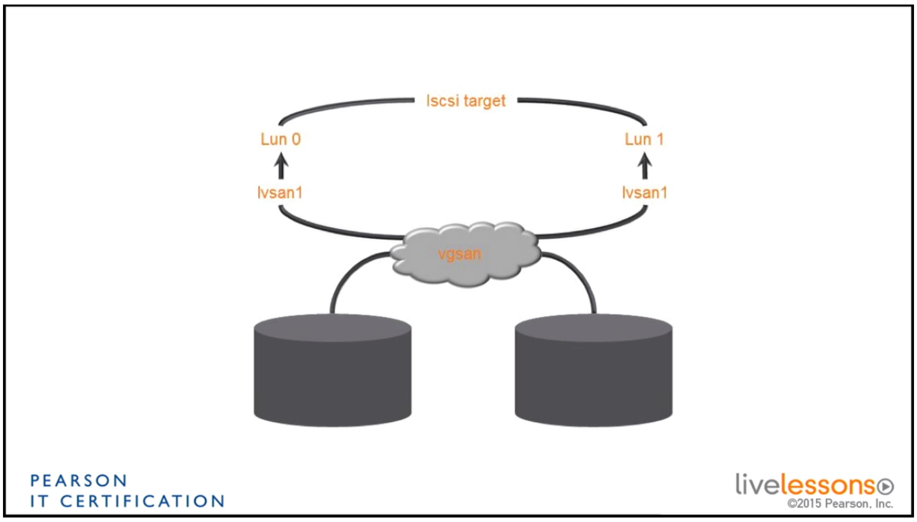


Figure 2.1: iSCSI Target Setup

These LUNs are presented using the iSCSI targets. Thus, the iSCSI configuration is created on top of a traditional LVM configuration.

2.2.1 Creating the LVM

Let us consider we have an empty disk of 1GB on which we want to build the iSCSI configuration. This can be verified using:

```
# lsblk
NAME            MAJ:MIN RM  SIZE RO TYPE MOUNTPOINT
sda               8:0    0   20G  0 disk
├─sda1            8:1    0    1G  0 part /boot
└─sda2            8:2    0   19G  0 part
├─centos-root 253:0    0   17G  0 lvm  /
└─centos-swap 253:1    0    2G  0 lvm  [SWAP]
sdb               8:16   0    1G  0 disk
sr0              11:0    1  8.1G  0 rom
```

We can directly create the VG `vgsan` on it, using:

```
# vgcreate vgSAN /dev/sdb
Physical volume "/dev/sdb" successfully created.
Volume group "vgSAN" successfully created
# pvs
PV         VG     Fmt  Attr PSize    PFree
/dev/sda2  centos lvm2 a--   <19.00g       0
/dev/sdb   vgSAN  lvm2 a--  1020.00m 1020.00m
# vgs
```

```
VG     #PV #LV #SN Attr   VSize    VFree
centos   1   2   0 wz--n-  <19.00g       0
vgSAN    1   0   0 wz--n- 1020.00m 1020.00m
```

The output of the `pvs` and `vgs` commands show that the PV `/dev/sdb` is now a part of *vgSAN*, which has a free space of 1020MB. Now we create two LVs *lvSAN1* and *lvSAN2* on the VG, using:

```
# lvcreate -L 500M -n lvSAN1 vgSAN
Logical volume "lvSAN1" created.
# lvcreate -l 100%FREE -n lvSAN2 vgSAN
Logical volume "lvSAN2" created.
# lvs
LV     VG     Attr       LSize   Pool Origin ... Convert
root   centos -wi-ao---- <17.00g
swap   centos -wi-ao----   2.00g
lvSAN1 vgSAN  -wi-a----- 500.00m
lvSAN2 vgSAN  -wi-a----- 520.00m
```

Now, our LVM setup is complete, and we can proceed with the iSCSI setup. For this, first of all we need to install the iSCSI software, called **targetcli**. The targetcli utility is a relatively new one capable of managing multiple types of storage devices.

2.2.2 Creating the iSCSI configuration using targetcli

We start the utility using:

```
# targetcli
Warning: Could not load preferences file /root/.targetcli/prefs.bin.
targetcli shell version 2.1.fb46
Copyright 2011-2013 by Datera, Inc and others.
For help on commands, type 'help'.

/>
```

This interface can be navigated using the same commands as the bash shell. Using the `cd` command produces the output:

```
/> ls
o- / ..................................................................... [...]
  o- backstores .......................................................... [...]
  | o- block .............................................. [Storage Objects: 0]
  | o- fileio ............................................. [Storage Objects: 0]
  | o- pscsi .............................................. [Storage Objects: 0]
  | o- ramdisk ............................................ [Storage Objects: 0]
  o- iscsi ........................................................ [Targets: 0]
  o- loopback ..................................................... [Targets: 0]
/>
```

The *backstores* part allow us to work with the different storage devices. To enter backstores, we simply enter `cd` command, and select it from the menu. This will change the prompt to `/backstores>`. Here, we can see it contains the *block*, the *fileio*, the *pSCSI* and the *ramdisk* devices. Their significance is explained below:

Types	Description
Block	Refers to any block device that we want to share using iSCSI. This includes all traditional disks, partitions and even LVMs.
fileio	Refers to a file that can be used as a storage source. This refers to a big file created using a tool such as `dd`.
pscsi	Physical SCSI - a SCSI pass-through backstore is created for such devices.
ramdisk	RAM storage, wiped with every reboot, and is thus a **very** bad idea.

Now, since all our LVs are block devices (by their very nature), we have to create our LUNs inside the block category. This we can do using:

```
/backstores> block/ create block1 /dev/vgSAN/lvSAN1
Created block storage object block1 using /dev/vgSAN/lvSAN1.
```

The command instructs the targetcli utility to enter the block category, and create a block device called *block1* from the `/dev/vgSAN/lvSAN1` device. We can create another block device for the partition and a 1G custom file device using:

```
/backstores> block/ create block2 /dev/vgSAN/lvSAN2
Created block storage object block2 using /dev/vgSAN/lvSAN2.
/backstores> fileio/ create file1 /root/diskFile1 1G
Created fileio file1 with size 1073741824
```

When creating a file, we can merely specify the size (1GB) and the name & location (/root/diskFile1) to have the `targetcli` utility create the file for us, instead of copying from `/dev/zero` to a file using `dd`. All the different devices thus added can be seen with:

```
/backstores> ls
o- backstores ........................................................... [...]
  o- block ............................................... [Storage Objects: 2]
  | o- block1 ........... [/dev/vgSAN/lvSAN1 (500.0MiB) write-thru deactivated]
  | | o- alua ................................................ [ALUA Groups: 1]
  | |   o- default_tg_pt_gp .................... [ALUA state: Active/optimized]
  | o- block2 ........... [/dev/vgSAN/lvSAN2 (520.0MiB) write-thru deactivated]
  |   o- alua ................................................ [ALUA Groups: 1]
  |     o- default_tg_pt_gp .................... [ALUA state: Active/optimized]
  o- fileio .............................................. [Storage Objects: 1]
  | o- file1 ................ [/root/diskFile1 (1.0GiB) write-back deactivated]
  |   o- alua ................................................ [ALUA Groups: 1]
  |     o- default_tg_pt_gp .................... [ALUA state: Active/optimized]
  o- pscsi ............................................... [Storage Objects: 0]
  o- ramdisk ............................................. [Storage Objects: 0]
```

Now that the block devices are ready, we can go to the `/iscsi` environment and prepare the iSCSI targets. Initially, there will be no targets:

```
/backstores> cd /iscsi
/iscsi> ls
o- iscsi ......................................................... [Targets: 0]
```

2.2.3 Target Creation

Now, we create a target that provides access to the backing storage devices called *block1*, *block2* and *file1*. This can be done using the `create` command, followed by an IQN. IQNs are typically created using a naming format:

`iqn.<yearOfCreation>-<monthOfCreation>.<reverseDomainName>:<targetName>`

Thus, ours will be named: `iqn.2018-01.local.somuvmnet:target1`. This can be done with:

```
/iscsi> create iqn.2018-01.local.somuvmnet:target1
Created target iqn.2018-01.local.somuvmnet:target1.
Created TPG 1.
Global pref auto_add_default_portal=true
Created default portal listening on all IPs (0.0.0.0), port 3260.
```

Thus, both a target and a TPG are created at the same time. The target thus created can be viewed with:

```
/iscsi> ls
o- iscsi .......................................................... [Targets: 1]
  o- iqn.2018-01.local.somuvmnet:target1 ............................. [TPGs: 1]
    o- tpg1 ............................................. [no-gen-acls, no-auth]
      o- acls ........................................................ [ACLs: 0]
      o- luns ........................................................ [LUNs: 0]
      o- portals ................................................... [Portals: 1]
        o- 0.0.0.0:3260 ................................................... [OK]
```

2.2.4 TPG Configuration

Within the target is a TPG (Target portal group), which represents the entire configuration of the target. This includes all the ACLs, the LUNs and the portals related to the target.

ACLs

Next, we need to create the ACLs for our target. For this, we need to cd into the ACL environment of our target using (Note that tab-autocompletion works for this tool):

```
/iscsi> cd iqn.2018-01.local.somuvmnet:target1/tpg1/acls
/iscsi/iqn.20...et1/tpg1/acls>
```

We create the ACL node using:

```
/iscsi/iqn.20...et1/tpg1/acls> create iqn.2018-01.local.somuvmnet:vmdeux
Created Node ACL for iqn.2018-01.local.somuvmnet:vmdeux
```

Note that the identifier provided to create the node ACL is the IQN that has been set on the second server. The structure now looks like:

```
/iscsi/iqn.20...et1/tpg1/acls> cd /iscsi
/iscsi> ls
  o- iscsi .......................................................... [Targets: 1]
    o- iqn.2018-01.local.somuvmnet:target1 ............................. [TPGs: 1]
      o- tpg1 ............................................. [no-gen-acls, no-auth]
        o- acls ........................................................ [ACLs: 1]
        | o- iqn.2018-01.local.somuvmnet:vmdeux ................. [Mapped LUNs: 0]
        o- luns ........................................................ [LUNs: 0]
        o- portals ................................................... [Portals: 1]
          o- 0.0.0.0:3260 ................................................... [OK]
```

LUNs

Now, inside the *tpg1* node, we create a LUN by using:

```
/iscsi/iqn.20...:target1/tpg1> luns/ create /backstores/block/block1
Created LUN 0.
Created LUN 0->0 mapping in node ACL iqn.2018-01.local.somuvmnet:vmdeux
```

Now, we can repeat the command a couple of times to create the LUNs for *block2* and *file1* as well:

```
/iscsi/iqn.20...:target1/tpg1> luns/ create /backstores/block/block2
Created LUN 1.
Created LUN 1->1 mapping in node ACL iqn.2018-01.local.somuvmnet:vmdeux
/iscsi/iqn.20...:target1/tpg1> luns/ create /backstores/fileio/file1
Created LUN 2.
Created LUN 2->2 mapping in node ACL iqn.2018-01.local.somuvmnet:vmdeux
```

The contents of *tpg1* should now look like:

```
/iscsi/iqn.20...:target1/tpg1> ls
o- tpg1 .................................................. [no-gen-acls, no-auth]
  o- acls ............................................................. [ACLs: 1]
  | o- iqn.2018-01.local.somuvmnet:vmdeux ...................... [Mapped LUNs: 3]
  |   o- mapped_lun0 .................................... [lun0 block/block1 (rw)]
  |   o- mapped_lun1 .................................... [lun1 block/block2 (rw)]
  |   o- mapped_lun2 .................................... [lun2 fileio/file1 (rw)]
  o- luns ............................................................. [LUNs: 3]
  | o- lun0 ............... [block/block1 (/dev/vgSAN/lvSAN1) (default_tg_pt_gp)]
  | o- lun1 ............... [block/block2 (/dev/vgSAN/lvSAN2) (default_tg_pt_gp)]
  | o- lun2 ................. [fileio/file1 (/root/diskFile1) (default_tg_pt_gp)]
  o- portals ....................................................... [Portals: 1]
    o- 0.0.0.0:3260 ........................................................ [OK]
```

We can see that not only have the LUNs been created, but they've been assigned to the ACL as well! Thus, it becomes critical to create ACLs before the LUNs because the default behaviour of `targetcli` is to automatically assign any LUN that's been created to the ACLs in the TPG. Now, we have to create a portal.

Portals

We can create portal which will bear the IP address of the server on which our SAN will advertise the LUNs for this particular target. We do this by:

```
iscsi/iqn.20...:target1/tpg1> portals/ create 90.0.16.27
Using default IP port 3260
```

The complete configuration of the iSCSI setup can be viewed with:

```
/iscsi/iqn.20...:target1/tpg1> cd
/> ls
o- / ...................................................................... [...]
  o- backstores ........................................................... [...]
  | o- block ............................................... [Storage Objects: 2]
  | | o- block1 ............. [/dev/vgSAN/lvSAN1 (500.0MiB) write-thru activated]
| | | o- alua ............................................... [ALUA Groups: 1]
| | |   o- default_tg_pt_gp ................... [ALUA state: Active/optimized]
| | o- block2 ............ [/dev/vgSAN/lvSAN2 (520.0MiB) write-thru activated]
| |   o- alua ............................................... [ALUA Groups: 1]
| |     o- default_tg_pt_gp ................... [ALUA state: Active/optimized]
| o- fileio ............................................. [Storage Objects: 1]
| | o- file1 ................. [/root/diskFile1 (1.0GiB) write-back activated]
| |   o- alua ............................................... [ALUA Groups: 1]
| |     o- default_tg_pt_gp ................... [ALUA state: Active/optimized]
| o- pscsi .............................................. [Storage Objects: 0]
| o- ramdisk ............................................ [Storage Objects: 0]
o- iscsi ........................................................ [Targets: 1]
| o- iqn.2018-01.local.somuvmnet:target1 ........................... [TPGs: 1]
|   o- tpg1 ........................................... [no-gen-acls, no-auth]
|     o- acls ...................................................... [ACLs: 1]
|     | o- iqn.2018-01.local.somuvmnet:vmdeux ............... [Mapped LUNs: 3]
|     |   o- mapped_lun0 ............................ [lun0 block/block1 (rw)]
|     |   o- mapped_lun1 ............................ [lun1 block/block2 (rw)]
|     |   o- mapped_lun2 ............................ [lun2 fileio/file1 (rw)]
|     o- luns ...................................................... [LUNs: 3]
|     | o- lun0 ........ [block/block1 (/dev/vgSAN/lvSAN1) (default_tg_pt_gp)]
|     | o- lun1 ........ [block/block2 (/dev/vgSAN/lvSAN2) (default_tg_pt_gp)]
|     | o- lun2 .......... [fileio/file1 (/root/diskFile1) (default_tg_pt_gp)]
|     o- portals ................................................ [Portals: 1]
|       o- 0.0.0.0:3260 ................................................. [OK]
o- loopback ..................................................... [Targets: 0]
```

2.2.5 Adding a rule to the firewall

Now, we need to allow the TCP connections through port 3260 to use for SAN, using:

```
# firewall-cmd --add-port=3260/tcp --permanent
success
# firewall-cmd --reload
success
```

2.2.6 Starting target.service

Even though **targetcli** saves the present configuration to disk, a service called *target.service* must be enabled to ensure that the saved configuration is loaded each time after reboots. This is done with:

```
# systemctl start target
# systemctl enable target
Created symlink from /etc/systemd/system/multi-user.target.wants/target.service to
 ↪  /usr/lib/systemd/system/target.service.
# systemctl status target
● target.service - Restore LIO kernel target configuration
Loaded: loaded (/usr/lib/systemd/system/target.service; enabled; vendor preset: disabled)
Active: active (exited) since Tue 2018-01-02 16:28:20 IST; 25s ago
Main PID: 4291 (code=exited, status=0/SUCCESS)

Jan 02 16:28:19 vmprime.somuvmnet.local systemd[1]: Starting Restore LIO kern...
Jan 02 16:28:20 vmprime.somuvmnet.local systemd[1]: Started Restore LIO kerne...
```

This particular services instructs the kernel of its responsibilities as a SAN server and how the iSCSI targets are configured, so that it can accept incoming connections from iSCSI initiators and act accordingly.

2.3 Connecting the iSCSI Initiator to an iSCSI SAN

Now that the iSCSI SAN server is setup, we need an iSCSI initiator on a different (remote) server that can use the SAN. For this, the very first requirement is to obtain the software in the `iscsi-initiator-utils` package, which help in creating the initiator. We do this by using:

```
# yum -y install iscsi-initiator-utils
```

2.3.1 Setting up an initiator name

Next, we need to setup an **initiator name**, which must be the one we used in the ACL for the iSCSI *target*. To do this, we edit the `/etc/iscsi/initiatorname.iscsi` file. It's contents should be:

```
InitiatorName=iqn.2018-02.com.somuVMnet:vmPrime
```

The iSCSI configuration file is located at `/etc/iscsi/iscsid.conf` and this can be used to optimize the iSCSI configuration for the server.

2.3.2 iscsiadm Command

Now, we're going to set up the initiator using the `iscsiadm` command. The syntax of this command can be a bit cryptic, and thus it's recommended to use the man page's example section for a jump start on the syntax of the command.

The primary purpose of the **iscsiadm** command is to discover iSCSI targets and login to them, as well as access and manage the open-iscsi configuration database.

2.3.3 Discovery

Now, the initiator is ready for discovery. For this, we use the command:

```
# iscsiadm --mode discoverydb --type sendtargets --portal 10.0.99.12 --discover
10.0.99.12:3260,1 iqn.2018-02.local.somuvmnet:vmdeux
```

The `--mode discoverydb` option instructs the iscsiadm command to operate on the *discoverydb* section of the configuration database. It can also be abbreviated to `-m discoverydb`. The `--type sendtargets` (or `-t st`) tells the action to perform, i.e., send a list of targets. The `--portal 10.0.99.12` (`-p 10.0.99.12`) specifies the portal to be used for the action. Finally, the `--discovery` (`-D`) flag tells the command to perform discovery and add records if necessary. The output returned is a list of the targets on that particular portal. The most important piece of information here is the IQN of the relevant target.

2.3.4 Login

The login is performed on a particular IQN at a particular portal/node. This is achieved using:

```
# iscsiadm --mode node --targetname iqn.2018-02.local.somuVMnet:vmDeux --portal
 ↪  10.0.99.12 --login
Logging in to [iface: default, target: iqn.2018-02.local.somuvmnet:vmdeux, portal:
 ↪  10.0.99.12,3260] (multiple)
Login to [iface: default, target: iqn.2018-02.local.somuvmnet:vmdeux, portal:
 ↪  10.0.99.12,3260] successful.
```

Now the *mode* has been changed to **node** since we're dealing with a particular portal to login. The `--targetname iqn.2018-02.local.somuVMnet:vmDeux` option can be shortened to `-T iqn.2018-02.local.somuVMnet:vmDeux` and the portal can have a port specified with `-p 10.0.99.12:3260`.

Note that if the iqn of the initiator hasn't been set properly then login won't succeed with a failure due to authentication message. In that case, probably the IQN of the initiator hasn't been set properly. We need to edit the `/etc/iscsi/initiatorname.iscsi` file again and ensure it's identical to that in the ACL of the target. After the change, the **iscsid** service needs to be restarted for the new IQN to be used by the initiator: `systemctl restart iscsid`.

The presence of the new partitions as locally connected devices can be verified using:

```
# cat /proc/partitions
major minor  #blocks  name

8        0   10485760 sda
8        1    1048576 sda1
8        2    9436160 sda2
11        0    3963904 sr0
253        0    8384512 dm-0
253        1    1048576 dm-1
8       16     520192 sdb
8       32     520192 sdc
8       48      10240 sdd
[root@vmPrime ~]# lsblk
NAME          MAJ:MIN RM  SIZE RO TYPE MOUNTPOINT
sda             8:0    0   10G  0 disk
├─sda1          8:1    0    1G  0 part /boot
└─sda2          8:2    0    9G  0 part
  ├─rhel-root 253:0    0    8G  0 lvm  /
  └─rhel-swap 253:1    0    1G  0 lvm  [SWAP]
sdb             8:16   0  508M  0 disk
sdc             8:32   0  508M  0 disk
sdd             8:48   0   10M  0 disk
```

The sdb, sdc and sdd devices are all LUNs on the iSCSI target. The `lsscsi` tool provides the iSCSI information for the target in even greater depth:

```
# lsscsi
[0:0:0:0]    disk    VMware,  VMware Virtual S 1.0   /dev/sda
[4:0:0:0]    cd/dvd  NECVMWar VMware SATA CD01 1.00  /dev/sr0
[40:0:0:0]   disk    LIO-ORG  block1           4.0   /dev/sdb
[40:0:0:1]   disk    LIO-ORG  block2           4.0   /dev/sdc
[40:0:0:2]   disk    LIO-ORG  file1            4.0   /dev/sdd
```

All the details of this connection to the IQN via the node is stored in the file `/var/lib/iscsi/nodes/iqn.2018-02.local.somuvmnet:vmdeux/10.0.99.12,3260,1/default`. Once logged in, after every reboot, the iSCSI initiator will automatically login to the SAN and present the LUNs of the target as locally mounted devices. To prevent that, we need to explicitly logout.

2.3.5 Logout

The logout operation needs the exact same parameters to be passed, other than `--login` which of course gets changed to `--logout`.

```
# iscsiadm -m node -T iqn.2018-02.local.somuvmnet:vmdeux -p 10.0.99.12 --logout
Logging out of session [sid: 7, target: iqn.2018-02.local.somuvmnet:vmdeux, portal:
 ↪  10.0.99.12,3260]
Logout of [sid: 7, target: iqn.2018-02.local.somuvmnet:vmdeux, portal: 10.0.99.12,3260]
 ↪  successful.
```

2.3.6 Deleting node information

To delete all the information pertaining to an iSCSI target we use:

```
# iscsiadm -m node -T iqn.2018-02.local.somuvmnet:vmdeux -o delete
```

Another option would be to delete the folder with the IQN name of the target from `/var/lib/iscsi/nodes/`.

2.4 Verifying the iSCSI Connection

2.4.1 Verification on the iSCSI Initiator

To verify the iSCSI connection we use the **iscsiadm** command. The `-P` command is used to specify the print-level which means that the information is shown as a tree of varying levels of information (the higher the print level, more information is given).

To verify the iSCSI connection, we need information about the session, acquired using:

```
# iscsiadm -m session -P 1
Target: iqn.2018-02.local.somuvmnet:vmdeux (non-flash)
Current Portal: 10.0.99.12:3260,1
Persistent Portal: 10.0.99.12:3260,1
**********
Interface:
**********
Iface Name: default
Iface Transport: tcp
Iface Initiatorname: iqn.2018-02.local.somuvmnet:vmprime
Iface IPaddress: 10.0.99.11
Iface HWaddress: <empty>
Iface Netdev: <empty>
SID: 8
```

```
iSCSI Connection State: LOGGED IN
iSCSI Session State: LOGGED_IN
Internal iscsid Session State: NO CHANGE
# iscsiadm -m session -P 2
Target: iqn.2018-02.local.somuvmnet:vmdeux (non-flash)
Current Portal: 10.0.99.12:3260,1
Persistent Portal: 10.0.99.12:3260,1
**********
Interface:
**********
Iface Name: default
Iface Transport: tcp
Iface Initiatorname: iqn.2018-02.local.somuvmnet:vmprime
Iface IPaddress: 10.0.99.11
Iface HWaddress: <empty>
Iface Netdev: <empty>
SID: 8
iSCSI Connection State: LOGGED IN
iSCSI Session State: LOGGED_IN
Internal iscsid Session State: NO CHANGE
*********
Timeouts:
*********
Recovery Timeout: 120
Target Reset Timeout: 30
LUN Reset Timeout: 30
Abort Timeout: 15
*****
CHAP:
*****
username: <empty>
password: ********
username_in: <empty>
password_in: ********
************************
Negotiated iSCSI params:
************************
HeaderDigest: None
DataDigest: None
MaxRecvDataSegmentLength: 262144
MaxXmitDataSegmentLength: 262144
FirstBurstLength: 65536
MaxBurstLength: 262144
ImmediateData: Yes
InitialR2T: Yes
MaxOutstandingR2T: 1
# iscsiadm -m session -P 3
iSCSI Transport Class version 2.0-870
version 6.2.0.874-2
Target: iqn.2018-02.local.somuvmnet:vmdeux (non-flash)
Current Portal: 10.0.99.12:3260,1
Persistent Portal: 10.0.99.12:3260,1
**********
Interface:
**********
Iface Name: default
Iface Transport: tcp
Iface Initiatorname: iqn.2018-02.local.somuvmnet:vmprime
Iface IPaddress: 10.0.99.11
Iface HWaddress: <empty>
Iface Netdev: <empty>
```

```
SID: 8
iSCSI Connection State: LOGGED IN
iSCSI Session State: LOGGED_IN
Internal iscsid Session State: NO CHANGE
*********
Timeouts:
*********
Recovery Timeout: 120
Target Reset Timeout: 30
LUN Reset Timeout: 30
Abort Timeout: 15
*****
CHAP:
*****
username: <empty>
password: ********
username_in: <empty>
password_in: ********
************************
Negotiated iSCSI params:
************************
HeaderDigest: None
DataDigest: None
MaxRecvDataSegmentLength: 262144
MaxXmitDataSegmentLength: 262144
FirstBurstLength: 65536
MaxBurstLength: 262144
ImmediateData: Yes
InitialR2T: Yes
MaxOutstandingR2T: 1
************************
Attached SCSI devices:
************************
Host Number: 40        State: running
scsi40 Channel 00 Id 0 Lun: 0
Attached scsi disk sdb                State: running
scsi40 Channel 00 Id 0 Lun: 1
Attached scsi disk sdc                State: running
scsi40 Channel 00 Id 0 Lun: 2
Attached scsi disk sdd                State: running
```

2.4.2 Verification on the iSCSI Target

To verify the iSCSI config on the target, we need only check the contents of the targetcli command:

```
# targetcli
targetcli shell version 2.1.fb46
Copyright 2011-2013 by Datera, Inc and others.
For help on commands, type 'help'.

/> ls
o- / ..................................................................... [...]
  o- backstores .......................................................... [...]
  | o- block .............................................. [Storage Objects: 2]
  | | o- block1 ............ [/dev/vgSAN/lvSAN1 (508.0MiB) write-thru activated]
  | | | o- alua ............................................... [ALUA Groups: 1]
  | | |   o- default_tg_pt_gp ................... [ALUA state: Active/optimized]
| | o- block2 ........... [/dev/vgSAN/lvSAN2 (508.0MiB) write-thru activated]
| |   o- alua .............................................. [ALUA Groups: 1]
| |     o- default_tg_pt_gp .................. [ALUA state: Active/optimized]
| o- fileio ............................................ [Storage Objects: 1]
| | o- file1 ............... [/root/diskFile1 (10.0MiB) write-back activated]
| |   o- alua .............................................. [ALUA Groups: 1]
| |     o- default_tg_pt_gp .................. [ALUA state: Active/optimized]
| o- pscsi ............................................. [Storage Objects: 0]
| o- ramdisk ........................................... [Storage Objects: 0]
o- iscsi ....................................................... [Targets: 1]
| o- iqn.2018-02.local.somuvmnet:vmdeux ........................... [TPGs: 1]
|   o- tpg1 .......................................... [no-gen-acls, no-auth]
|     o- acls ..................................................... [ACLs: 1]
|     | o- iqn.2018-02.local.somuvmnet:vmprime ............. [Mapped LUNs: 3]
|     |   o- mapped_lun0 ........................... [lun0 block/block1 (rw)]
|     |   o- mapped_lun1 ........................... [lun1 block/block2 (rw)]
|     |   o- mapped_lun2 ........................... [lun2 fileio/file1 (rw)]
|     o- luns ..................................................... [LUNs: 3]
|     | o- lun0 ....... [block/block1 (/dev/vgSAN/lvSAN1) (default_tg_pt_gp)]
|     | o- lun1 ....... [block/block2 (/dev/vgSAN/lvSAN2) (default_tg_pt_gp)]
|     | o- lun2 ......... [fileio/file1 (/root/diskFile1) (default_tg_pt_gp)]
|     o- portals ............................................... [Portals: 1]
|       o- 10.0.99.12:3260 ............................................. [OK]
o- loopback .................................................... [Targets: 0]
```

Chapter 3

System Performance Reporting

3.1 Understanding System Performance Parameters

The definition of performance of a system is dependent upon the expectations from a system. For example, **low latency** is desired from *database servers*, while **high throughput** is needed from *file servers*.

Actual performance has to be judged on the basis of performance level agreements. This has to be clearly defined for anyone - "*The web server should always react within 10 seconds*" is better than "*generic load should be less than 60%*", because that's what the end user will care about!

Thus, first we need to decide upon which metrics we want to measure, and then collect baseline data for it via monitoring systems.

3.1.1 Typical Performance Focus Areas

Factor	Description
Memory	The single most important factor that affects server performance. When enough memory isn't available, swap has to be used to house the excess pages and then the IO performance suffers, thus bogging down the entire system. It even affects the network throughput.
Disk	Another very important factor in overall server performance. When the disk is slow, too much memory is wasted to buffer data that's waiting to be written to disk. Processes will also have to wait longer to access data from the disk.
Network	Network is no longer a significant bottleneck, since most network connections aren't 10Mbps anymore - enterprise infrastructure uses Gigabit connections as a standard.
CPU	While the CPU has many tunables, in general it is not a very significant factor in performance deterioration. It is only for certain workloads that CPU becomes a factor in performance. The gain from CPU optimizations can be expressed in nanoseconds.

3.1.2 Common Performance Monitoring Tools

Terms	Description
top	While it's a very basic tool, it's also very rich in features. It provides an excellent generic overview of everything going on in the system. Typical use case for `top` is to detect problems and then use a more specialized tool to diagnose further.
iostat	A dedicated tool to detect Input/Output problems. It shows statistics about I/O. To detect which process is creating a high I/O load, a valuable tool is **iotop**.
vmstat	This tool shows statistics about virtual memory usage.
sar	The **System Activity Reporter** specializes in providing long-term data about what the system has been doing and long term performance statistics.

3.2 Understanding top

This is perhaps the single most important performance monitoring utility due to the kind of data it provides. There are alternatives to top such as `htop`, but top is programmed efficiently and doesn't have too much overhead. Comparing the two - htop uses about 5 times as much system resources as top!

The first feature of interest in the output of top is the **load average**, which consists of three numbers: the load average for the last 1, 5 and 15 minutes. The load average is the average of the number of processes in a runnable state, i.e., currently being executed by the CPU or waiting for CPU, over the concerned period of time. Optimally, all CPUs should be utilized as much as possible, but no process should be waiting for the CPU. The output of the `nproc` command tells us the effective number of CPUs available (= Physical CPUs × logical cores per CPU).

The individual CPU utilization per CPU core can be shown by pressing the `1` key. A typical output is:

```
# top
%Cpu0  :  5.5 us,  3.3 sy,  0.0 ni, 90.7 id,  0.0 wa,  0.5 hi,  0.0 si,  0.0 st
```

Here, the number after the CPU indicates the core number. The *us* value refers to CPU usage in percentage in user space, i.e., by processes started by the end user without administrative privileges. The *sy* does the same, but for processes started by the users with root privileges. The *id* value is the percentage of time the processor remains idle. The next important metric is the number before *wa* which represents the waiting time, i.e., percentage of time processes spend waiting for I/O. A high value here indicates that the there's something wrong with the I/O channel and may indicate imminent disk failure.

Next, the memory statistics are shown, which includes the amount of memory completely free and amount of memory used to cache files that are frequently requested. Buffers contain data that needs to be written to disk during high I/O loads. While these are technically *non-essential*, it's suggested that 30% of the total memory be dedicated to buffers/cache usage.

We can also toggle the fields being shown by pressing the `f` key. If we quit top using the `q` key, the edits to the configuration are gone the moment we quit. However, if we quit using `Shift + W`, then the configuration is written to the `.toprc` file.

3.3 Understanding iostat

The iostat tool is a part of the `sysstat` package, which needs to be installed to use the `iostat` command. The command by itself provides a snapshot of the I/O statistics at the time of the invocation of the command. However, it takes two arguments in the syntax: `iostat <interval> <loops>`. The interval refers to the gap between displaying statistics and the loops refer to the number of times the command should show its output. Typical output for the command is:

```
# iostat 3 2
Linux 3.10.0-693.17.1.el7.x86_64 (vmPrime.somuVMnet.local)        Tuesday 27 February
 ↪  2018         _x86_64_        (1 CPU)

avg-cpu:  %user   %nice %system %iowait  %steal   %idle
0.50    0.00    0.64    0.49    0.00   98.37

Device:            tps    kB_read/s    kB_wrtn/s    kB_read    kB_wrtn
sda               1.20        54.56         3.33     584199      35622
scd0              0.00         0.10         0.00       1054          0
dm-0              1.11        51.31         3.13     549442      33537
dm-1              0.01         0.21         0.00       2228          0
sdb               0.00         0.10         0.00       1044          0
sdc               0.00         0.10         0.00       1044          0
sdd               0.00         0.03         0.00        336          0

avg-cpu:  %user   %nice %system %iowait  %steal   %idle
5.44    0.00    1.36    0.00    0.00   93.20

Device:            tps    kB_read/s    kB_wrtn/s    kB_read    kB_wrtn
sda               0.68         0.00        10.88          0         32
scd0              0.00         0.00         0.00          0          0
dm-0              2.04         0.00        32.48          0         95
dm-1              0.00         0.00         0.00          0          0
sdb               0.00         0.00         0.00          0          0
sdc               0.00         0.00         0.00          0          0
sdd               0.00         0.00         0.00          0          0
```

In the output, **tps** refers to the number of transactions per second. The *kB_read/s* and the *kB_wrtn/s* values are self explanatory. The next two columns show the total kBs read and written respectively.

3.3.1 Usage scenario

Let us consider a scenario where top shows us that processes spend 60% of their execution time waiting for I/O. Let us consider that the concerned server is connected to 6 different disks or other storage devices. We can use the output of the iostat command to determine which disk is so slow.

If we consult the output from the command, we can see that dm-0 has the greatest tps. To find out which device is dm-0, we can simply go to the `/dev/mapper` directory and see what links to it:

```
# \ls -l /dev/mapper
total 0
crw-------. 1 root root 10, 236 Feb 27 20:53 control
lrwxrwxrwx. 1 root root       7 Feb 27 20:53 rhel-root -> ../dm-0
lrwxrwxrwx. 1 root root       7 Feb 27 20:53 rhel-swap -> ../dm-1
```

3.3.2 iotop

The **iotop** command needs to be installed using `yum -y install iotop`. It shows the processes that are doing the most amount of I/O in descending order. Typical output looks like:

```
# iotop
Total DISK READ :      45.37 M/s | Total DISK WRITE :       0.00 B/s
Actual DISK READ:      45.37 M/s | Actual DISK WRITE:       0.00 B/s
TID  PRIO  USER     DISK READ  DISK WRITE  SWAPIN     IO>    COMMAND
5696 be/4 root       45.37 M/s    0.00 B/s  0.00 % 73.97 % dd if=/dev/sda of=/dev/null
5450 be/4 root        0.00 B/s    0.00 B/s  0.00 % 12.66 % [kworker/0:2]
1 be/4 root        0.00 B/s    0.00 B/s  0.00 %  0.00 % systemd --switched-root --system
 ↪  --deserialize 21
...
```

Here we can see that the `dd if=/dev/sda of=/dev/null` is performing the most amount of I/O by copying the entire hard disk to `/dev/null`.

3.4 Understanding vmstat

3.4.1 Virtual Memory

Let us consider the typical output of top sorted on the basis of the Virtual Memory being used:

```
# top
 PID USER      PR  NI    VIRT    RES    SHR S %CPU %MEM     TIME+ COMMAND
1920 somu      20   0 1901016 215552  47856 S  0.7 11.6   0:47.79 gnome-shell
...
```

We can see that the `gnome-shell` is using 1901016 KiB of virtual memory, which is $\approx$ 1.82 GiB of virtual memory. Virtual Memory in Linux is memory that doesn't really exist. If we take a look at the `/proc/meminfo` file, we see:

```
VmallocTotal:   34359738367 kB
```

If we convert the VmallocTotal (Total amount of virtual memory that is possible for the kernel to allocate) to human readable units, it comes up to 32PB! That's not possible on most enterprise gear, let alone consumer hardware. Thus, the memory here doesn't really exist.

The key point here is that the kernel frequently needs to dish out unique memory address pointers to programs that demand it, but not actually assign any real memory till it's needed, i.e., the program tries to write to that location.

The kernel, instead of assigning real memory locations to programs, assigns memory in a virtual address space, which it then maps on to real memory on demand. The program itself remains blissfully oblivious to the knowledge of whether the memory it is referencing is virtual or real. All the trouble of fetching data on requirement and saving data falls on the kernel.

3.4.2 Resident Memory

A much more important concept is that of Resident Memory. Contrastingly to the Virtual Memory, the Resident memory is really used and is the total amount RAM being assigned to the process.

3.4.3 vmstat

The `vmstat` command when used without arguments shows various statistics pertaining to the resource consumption on the system:

```
# vmstat
procs -----------memory---------- ---swap-- -----io---- -system-- ------cpu-----
 r  b   swpd   free   buff  cache   si   so    bi    bo   in   cs us sy id wa st
 3  0      0 269904   2116 860396    0    0   176    25  124  129  2  2 95  2  0
```

The significance of each is:

Terms	Description
proc	This part shows information about the processes: the **r** shows the number of running processes, **b** shows the number of blocking processes. A blocking process is a process that's waiting for something (e.g., I/O).
memory	This is the total amount of memory in swap, as well as real physical memory (RAM) used for buffers and cache.
swap	The two sub-categories are *swap-in*(`si`) and *swap-out*(`so`). If at any time we see that the system is utilizing swap memory, we can use `vmstat` to find out if the swap is being used actively, i.e., whether data is being written to or read from it actively.
io	The IO section deals with the number of blocks of I/O that's being performed - *blocks-in*(`bi`) and *blocks-out*(`bo`) provide a way to measure the real I/O activity at the moment, thus helping us discern if the server is spending a lot of time reading or writing during high I/O waits.
system	The metrics shown are *interrupts*(`in`) and *context switches*(`cs`). Interrupts are generally generated when a piece of hardware demands CPU attention. Context switches occur when the CPU switches the present task it's working on after being triggered by the scheduler. It is critical to the multi-tasking ability of a server since multiple processes need to coordinate and divide the CPU cycles. A high number of context-switches would indicate that the CPU isn't getting enough time per process.
cpu	These metrics refer to the percentage of CPU time spent executing programs in the *user-space*(`us`), *system space*(`sy`), *idle*(`id`) or *waiting* (`wa`).

Just like `iostat`, the `vmstat` provides an option to show the information at multiple points in time - the first argument is the time delay and the second the number of loops. To re-run vmstat every 2 seconds for 5 times we use:

```
# vmstat 2 5
procs -----------memory---------- ---swap-- -----io---- -system-- ------cpu-----
 r  b   swpd   free   buff  cache   si   so    bi    bo   in   cs us sy id wa st
 2  0      0 255824   2116 877492    0    0   135    20  118  122  1  1 96  2  0
 0  0      0 255576   2116 877492    0    0     0     0  174  178  6  3 91  0  0
 0  0      0 255576   2116 877492    0    0     0     0  152  145  6  2 92  0  0
 1  0      0 255384   2116 877492    0    0     0     0  179   161   8   2 90  0  0
 0  0      0 255452   2116 877492    0    0     0     0  256   406   9   8 83  0  0
```

Just like in `iostat` output, the first line has higher values of certain metrics because it gives a generic overview of the system operations where applicable. The next lines portray the activity within the delay time frame.

For detailed memory utilization statistics, we use `vmstat -s`:

```
# vmstat -s
1865964 K total memory
730672 K used memory
902516 K active memory
466968 K inactive memory
255684 K free memory
2116 K buffer memory
877492 K swap cache
1048572 K total swap
0 K used swap
1048572 K free swap
6813 non-nice user cpu ticks
1125 nice user cpu ticks
7128 system cpu ticks
543996 idle cpu ticks
8383 IO-wait cpu ticks
0 IRQ cpu ticks
180 softirq cpu ticks
0 stolen cpu ticks
734741 pages paged in
106795 pages paged out
0 pages swapped in
0 pages swapped out
667859 interrupts
685758 CPU context switches
1519798095 boot time
4208 forks
```

To change the display unit being used, we use the `-S (k/K/m/M)` option to change units. (where K=KiB and k=kB).

3.5 Understanding sar components

`sar` stands for the **System Activity Reporter**. It is a part of the *sysstat* package (like `iostat` and `vmstat`), and it collects data on an interval of 10 minutes by default. However, it can also be used to collect instantaneous data about the system as well.

What truly distinguishes `sar` from the other tools is the fact that it can be tasked to data collection for an extended period of time and the queried for information about a very specific period.

To make sorting and finding data in `sar` easier, it is recommended to set `LANG=C` before starting sar. Every Linux OS has an environment variable called **LANG** that affects the behavior of several utilities as well as setting the language. POSIX standard mandates that a locale called either POSIX or C be defined. Thus, it disables localization and makes the output predictable. Unless the option is set, timestamps are formatted in AM/PM which makes filtering said data harder. With the `LANG=C` option however, the timestamps use the military time format (24-hour format). A handy option is to generate an alias such as:

```
# echo "alias sar='LANG=C sar'" >> /etc/bashrc
```

sar data is collected via cron jobs in `/etc/cron.d/sysstat`. The collected data is written to `/var/log/sa`. The file `/etc/sysconfig/sysstat` has a `HISTORY` variable which dictates how long data should be stored. Typically, it's on a monthly basis.

3.5.1 /etc/cron.d/sysstat

This cronjob launches two different jobs are launched: **sa1** and **sa2**. The *sa1* job is for collecting short term statistics data while the *sa2* job executes once a day to collect data for long term statistics. Both of these write the results of their monitoring in a file in the `/var/log` directory.

3.5.2 /var/log/sa/sa[dd]

These are actually a bunch of files that start with the prefix `sa` and end with the date in `dd` format. Thus, typical file names are: *sa01, sa25, sa31,* etc. These files are unreadable by typical pagers like `less` and needs to be read by using the `sar` utility itself, by issuing commands like `sar -q` to get information about disk statistics, etc. One common mistake while accustoming to `sar` is to forget to start the sysstat services, since without them the data for the sar log files aren't populated and the utility has no data to work with.

3.6 Setting up sar

If the **sysstat** package isn't already installed, we first need to install it using `yum -y install sysstat`. Next, we ensure that the cron job for data collection via *sa1* and *sa2* were set up properly in `/etc/cron.d/sysstat` file, which should have the contents:

```
# Run system activity accounting tool every 10 minutes
*/10 * * * * root /usr/lib64/sa/sa1 1 1
# Generate a daily summary of process accounting at 23:53
53 23 * * * root /usr/lib64/sa/sa2 -A
```

Thus, *sa1* is collecting data every 10 mins and *sa2* executes everyday at 11:53PM to collect long term data for the day. Now sar is ready to collect data, but if we were to query the sar already, we'd come up empty, since `sar` hasn't had the opportunity to log data yet!

Next, we check the config in `/etc/sysconfig/sysstat` file, which typically looks like:

```
# sysstat-10.1.5 configuration file.

# How long to keep log files (in days).
# If value is greater than 28, then log files are kept in
# multiple directories, one for each month.
HISTORY=28

# Compress (using gzip or bzip2) sa and sar files older than (in days):
COMPRESSAFTER=31

# Parameters for the system activity data collector (see sadc manual page)
# which are used for the generation of log files.
SADC_OPTIONS="-S DISK"

# Compression program to use.
ZIP="bzip2"
```

The primary feature of interest in this file is the value of the HISTORY variable which decides how long the collected data is stored.

Now, we have to wait for the sadc (*System Activity Data Collector*) utility to collect data for **sar** to analyse.

3.7 Analyzing sar data

Some of the most common options that print certain categories of the collected data are:

3.7.1 I/O operations

The sar -b command shows us the total transfers per second (tps), read tps(rtps), write tps(wtps), blocks read per second (bread)(1 block = 512B) and blocks written to per second (bwrtn). Typical output of the command looks like:

```
# sar -b
00:00:02          tps      rtps      wtps   bread/s   bwrtn/s
00:10:01         2.70      1.15      1.55     64.96    995.40
00:20:01         0.47      0.27      0.20     12.97      8.26
00:30:01         0.07      0.00      0.07      0.00      0.86
00:40:01         0.08      0.00      0.08      0.00      1.04
...
```

Thus, the use of military time makes the output a lot easier to process.

3.7.2 Processor information

It is possible to get the information about a single processor (i.e., a single logical core on a physical CPU, since linux considers each a separate processor) using the sar -P <processorNumber> command. Typical usage is (to find the usage of processor 0):

```
# sar -P 0
00:00:02         CPU     %user     %nice   %system   %iowait    %steal     %idle
00:10:01           0      5.21      0.00      3.09      0.59      0.00     91.11
00:20:01           0      0.12      0.00      0.24      0.15      0.00     99.48
...
04:10:01           0      0.29      0.00      0.36      0.10      0.00     99.25
Average:           0      1.04      0.00      1.03      0.31      0.00     97.62
```

3.7.3 Network Statistics

The sar -n DEV command shows the network statistics for each interface:

```
# sar -n DEV
Linux 3.10.0-693.17.1.el7.x86_64 (vmPrime.somuVMnet.local)         02/28/18
 ↪          _x86_64_        (1 CPU)

00:00:02        IFACE   rxpck/s   txpck/s    rxkB/s    txkB/s   rxcmp/s   txcmp/s
 ↪  rxmcst/s
00:10:01           lo      0.00      0.00      0.00      0.00      0.00      0.00
 ↪  0.00
00:10:01    virbr0-nic      0.00      0.00      0.00      0.00      0.00      0.00
 ↪  0.00
00:10:01       virbr0      0.00      0.00      0.00      0.00      0.00      0.00
 ↪  0.00
00:10:01        ens33     63.83     19.03     90.10      1.19      0.00      0.00
 ↪  0.00
...
16:40:01        ens33      1.28      1.13      0.15      0.36      0.00      0.00
 ↪  0.00

Average:        IFACE   rxpck/s   txpck/s    rxkB/s    txkB/s   rxcmp/s   txcmp/s
 ↪  rxmcst/s
Average:           lo      0.00      0.00      0.00      0.00      0.00      0.00
 ↪  0.00
Average:    virbr0-nic      0.00      0.00      0.00      0.00      0.00      0.00
 ↪  0.00
Average:       virbr0      0.00      0.00      0.00      0.00      0.00      0.00
 ↪  0.00
Average:        ens33      1.19      0.92      0.83      0.12      0.00      0.00
 ↪  0.00
```

To view the statistics for just one interface, we can use `sar -n DEV \` grep <interfaceName>|:

```
# sar -n DEV | grep ens33
00:10:01        ens33     63.83     19.03     90.10      1.19      0.00      0.00
 ↪  0.00
...
16:40:01        ens33      1.28      1.13      0.15      0.36      0.00      0.00
 ↪  0.00
Average:        ens33      1.19      0.92      0.83      0.12      0.00      0.00
 ↪  0.00
```

Chapter 4

System Optimization Basics

4.1 Understanding /proc contents

To optimize a Linux system, we should know in depth about the `/proc` file system. This file system provides an interface to the kernel using which we can take a look at the present state of the system as well as optimize it as per our requirements.

The `/proc` file system is filled with several **status files** which tell us about many operational system parameters. In fact, may performance monitoring utilities get their data from the `/proc` file system itself!

In older versions of Linux, there were several hard-coded parameters that needed to be changed to optimize the system, and thus required a recompilation of the kernel. Modern Linux kernels however, get many of these parameters from the `/proc/sys` file system and thus offer optimization in a flexible manner!

The `/proc/sys` file system offers different interfaces that are related to different aspects of the file system which can be tuned through their corresponding interface.

4.2 Analysing the /proc filesystem

4.2.1 Process Directories

The `/proc` file system has a process directory named with a number corresponding to the *PID* of every running process on the system:

```
# ls /proc
1     17    2064  2514  333  362  465  7    93           locks
10    1759  2070  2530  334  363  466  732  acpi         mdstat
1180  1764  2093  26    335  364  479  734  asound       meminfo
1186  18    2094  2611  336  365  480  736  buddyinfo    misc
1187  1856  2109  2616  337  366  481  757  bus          modules
1191  1875  2116  2664  338  367  482  758  cgroups      mounts
1195  1880  212   2665  339  368  483  760  cmdline      mpt
1196  1884  2128  27    340  369  484  762  consoles     mtrr
1199  19    2147  273   341  370  485  766  cpuinfo      net
12    1903  2150  274   342  371  486  767  crypto       pagetypeinfo
1297  1907  2151  275   343  372  487  768  devices      partitions
```

```
1298  1921  2164  278   344  373  488  772  diskstats    sched_debug
1299  1933  2167  279   345  374  489  773  dma          schedstat
13    1938  2175  28    346  375  5    779  driver       scsi
1331  1940  2180  284   347  376  560  791  execdomains  self
1336  1948  2181  286   348  377  561  793  fb           slabinfo
1337  1953  2186  287   349  378  587  794  filesystems  softirqs
1338  1954  2188  288   350  379  589  795  fs           stat
1344  1961  2208  295   351  38   590  8    interrupts   swaps
1383  1962  2243  3     352  380  60   800  iomem        sys
14    1970  2250  323   353  381  601  801  ioports      sysrq-trigger
15    1973  2321  324   354  382  616  802  irq          sysvipc
1569  1979  2322  325   355  39   638  803  kallsyms     timer_list
1584  1983  2358  326   356  4    640  818  kcore        timer_stats
1586  2     2426  327   357  40   641  827  keys         tty
16    2001  2454  328   358  406  642  831  key-users    uptime
1640  2043  2460  329   359  407  645  835  kmsg         version
1643  2048  2462  330   36   41   646  852  kpagecount   vmallocinfo
1686  2053  2481  331   360  453  647  869  kpageflags   vmstat
1691  2059  25    332   361  454  648  9    loadavg      zoneinfo
```

Inside each of these process directories, there are several files that tell us about the present status of the process, and provide other necessary details about it. For example, inside the directory for the process with *PID 881*, we find:

```
# ls /proc/561/
attr             cpuset   limits      net            projid_map  stat
autogroup        cwd      loginuid    ns             root        statm
auxv             environ  map_files   numa_maps      sched       status
cgroup           exe      maps        oom_adj        schedstat   syscall
clear_refs       fd       mem         oom_score      sessionid   task
cmdline          fdinfo   mountinfo   oom_score_adj  setgroups   timers
comm             gid_map  mounts      pagemap        smaps       uid_map
coredump_filter  io       mountstats  personality    stack       wchan
```

The **cmdline** file in this directory tells us about the command that is being run in the process. For example, the command that spawned the process with PID 561 is:

```
# cat /proc/561/cmdline
/usr/lib/systemd/systemd-journald
```

4.2.2 Status files

The `/proc` directory also houses several files that tell us about the different aspects of what our Operating System is doing and how it's performing. For example, the `/proc/partitions` file contains a list of all the storage devices that our system can access, as well as all the partitions that are housed on those devices:

```
# cat /proc/partitions
major  minor    #blocks name
8        0   10485760 sda
8        1    1048576 sda1
8        2    9436160 sda2
11        0    1048575 sr0
253        0    8384512 dm-0
253        1    1048576 dm-1
```

Similarly, the /proc/cpuinfo file has information about the CPU configuration, and the /proc/meminfo has information about the memory configuration. A list of all the file systems supported by the currently running operating systems (that have a kernel module presently loaded) can be found in /proc/filesystems:

```
# cat /proc/filesystems
nodev        sysfs
nodev        rootfs
nodev        ramfs
nodev        bdev
nodev        proc
nodev        cgroup
nodev        cpuset
nodev        tmpfs
nodev        devtmpfs
nodev        debugfs
nodev        securityfs
nodev        sockfs
nodev        pipefs
nodev        anon_inodefs
nodev        configfs
nodev        devpts
nodev        hugetlbfs
nodev        autofs
nodev        pstore
nodev        mqueue
nodev        selinuxfs
             xfs
nodev        rpc_pipefs
nodev        nfsd
             fuseblk
nodev        fuse
nodev        fusectl
```

Thus, if we insert the module for vFat or ext4 into the kernel, it'll show up in the /proc/filesystems listing:

```
# modprobe vfat
[root@vmPrime proc]# modprobe ext4
[root@vmPrime proc]# cat /proc/filesystems
nodev        sysfs
nodev        rootfs
...
nodev        selinuxfs
             xfs
nodev        nfsd
             fuseblk
nodev        fusectl
             vfat
             ext3
             ext2
             ext4
```

4.2.3 /proc/sys

The /proc/sys file system is our interface to optimization of the system. It has folders related to the different aspects of the kernel's functions:

```
# ls /proc/sys
abi  crypto  debug  dev  fs  kernel  net  sunrpc  user  vm
```

Among these, the most important ones are **fs** for *file systems*, **kernel** for *kernel optimizations*, **net** for *networking* and **vm** for the *virtual memory*.

For example, the /proc/sys/vm directory contains several files that help tune the kernel for memory optimization:

```
# ls /proc/sys/vm
admin_reserve_kbytes        lowmem_reserve_ratio       oom_dump_tasks
block_dump                  max_map_count              oom_kill_allocating_task
compact_memory              memory_failure_early_kill  overcommit_kbytes
dirty_background_bytes      memory_failure_recovery    overcommit_memory
dirty_background_ratio      min_free_kbytes            overcommit_ratio
dirty_bytes                 min_slab_ratio             page-cluster
dirty_expire_centisecs      min_unmapped_ratio         panic_on_oom
dirty_ratio                 mmap_min_addr              percpu_pagelist_fraction
dirty_writeback_centisecs   mmap_rnd_bits              stat_interval
drop_caches                 mmap_rnd_compat_bits       swappiness
extfrag_threshold           nr_hugepages               user_reserve_kbytes
hugepages_treat_as_movable  nr_hugepages_mempolicy     vfs_cache_pressure
hugetlb_shm_group           nr_overcommit_hugepages    zone_reclaim_mode
laptop_mode                 nr_pdflush_threads
legacy_va_layout            numa_zonelist_order
# cat swappiness
30
```

One such file is the swappiness file - which defines the willingness of a server to write data to the swap. The default value of *30* means it isn't very willing. If we were to increase the value set in the file, we would make it more likely for the kernel to use swap in cases where it normally wouldn't have.

4.3 Optimizing through /proc

Optimization through the /proc/sys file system is an easy affair that needs us to only change the value contained in certain files to tune the associated aspect. Let us consider the /proc/sys/net/ipv4 directory, which deals with IPv4 networking on the system:

```
# cd /proc/sys/net/ipv4
# ls
# ls ip_*
ip_default_ttl  ip_forward           ip_local_reserved_ports
ip_dynaddr      ip_forward_use_pmtu  ip_nonlocal_bind
ip_early_demux  ip_local_port_range  ip_no_pmtu_disc
# cat ip_forward
0
```

The value of 0 in the *ip_forward* file shows that this system doesn't do IP forwarding, i.e., it doesn't forward specific IP packets for other IPs, i.e., it doesn't act as a router. To change this, we use:

```
# echo 1 > ip_forward
# cat ip_forward
1
```

When we echo values into the proc file system, it is only temporary and is wiped with every reboot - thus giving us an opportunity to test our settings directly before making anything permanent. If we like the results, we can make it permanent - otherwise reboot to restore the original values.

4.3.1 Sysctl

The utility `sysctl` can be used to display as well as control all the tunables that exist for a system:

```
# sysctl -a
abi.vsyscall32 = 1
crypto.fips_enabled = 0
debug.exception-trace = 1
...
vm.swappiness = 30
vm.user_reserve_kbytes = 55126
vm.vfs_cache_pressure = 100
vm.zone_reclaim_mode = 0
```

Thus, there is no need to manually traverse the file system hierarchy in the `proc` file system. We can directly set the values using `sysctl` command. Further, it can help us find every single tunable that is related to a keyword very easily by piping the output to *grep*. For example, if we want to tune ICMP (the protocol behind Ping and other control messages that can be sent over IP packets) , we can use:

```
# sysctl -a | grep icmp
sysctl: reading key "net.ipv6.conf.all.stable_secret"
sysctl: reading key "net.ipv6.conf.default.stable_secret"
net.ipv4.icmp_echo_ignore_all = 0
net.ipv4.icmp_echo_ignore_broadcasts = 1
net.ipv4.icmp_errors_use_inbound_ifaddr = 0
net.ipv4.icmp_ignore_bogus_error_responses = 1
net.ipv4.icmp_msgs_burst = 50
net.ipv4.icmp_msgs_per_sec = 1000
net.ipv4.icmp_ratelimit = 1000
net.ipv4.icmp_ratemask = 6168
sysctl: reading key "net.ipv6.conf.ens33.stable_secret"
sysctl: reading key "net.ipv6.conf.lo.stable_secret"
sysctl: reading key "net.ipv6.conf.virbr0.stable_secret"
sysctl: reading key "net.ipv6.conf.virbr0-nic.stable_secret"
net.ipv6.icmp.ratelimit = 1000
net.netfilter.nf_conntrack_icmp_timeout = 30
net.netfilter.nf_conntrack_icmpv6_timeout = 30
```

Thus, `sysctl -a` and `grep` together make it extremely easy to discover the tunable we need to optimize any facet pertaining to our current needs.

4.4 Introducing sysctl

The purpose of the **sysctl** utility is that it can act as an interface to control the entirity of the `/proc/sys` file system, including making **permanent** changes to the tunables for system optimization. Thus, it's an invaluable tool to handle kernel runtime parameters.

We can put our parameters in /etc/sysctl.conf or the related directory /etc/sysctl.d. All of these parameters are read by **sysctl** and then passed on to the /proc/sys file system (also known as **procfs**). It is encouraged to thoroughly test out the changes by first echoing the parameter values to the concerned file in /proc/sys first so that any errors can be weeded out and then making the changes permanent by creating a .conf file in the /etc/sysctl.d directory.

4.5 Using sysctl

Any user changes to kernel runtime parameters should be put inside the /etc/sysctl.d directory. Anything put in this directory overwrites the vendor presets in the /usr/lib/sysctl.d directory, and of course, the default kernel parameter values. One such file containing vendor preset kernel parameters is the /usr/lib/sysctl.d/00-system.conf:

```
# Kernel sysctl configuration file
#
# For binary values, 0 is disabled, 1 is enabled.  See sysctl(8) and
# sysctl.conf(5) for more details.

# Disable netfilter on bridges.
net.bridge.bridge-nf-call-ip6tables = 0
net.bridge.bridge-nf-call-iptables = 0
net.bridge.bridge-nf-call-arptables = 0
```

The files in the /usr/lib/ directory in general shouldn't be touched since they're mostly vendor presets and thus get overwritten with every update. The only way to have our settings overwrite theirs is via configuring the settings in the concerned directory in the /etc directory.

The kernel parameters controllable through the sysctl utility are all named according to the convention : if the file is /proc/sys/net/ipv4/ip_local_port_range, then its equivalent sysctl setting will be net.ipv4.ip_local_port_range, i.e., each directory in the path name of the file after /proc/sys seperated by a '.', terminating with the file name. This can be demonstrated with:

```
# cat /proc/sys/net/ipv4/ip_local_port_range
32768        60999
# sysctl -a | grep net.ipv4.ip_local_port_range
net.ipv4.ip_local_port_range = 32768        60999
```

Thus, to change the swappiness permanently, we write the setting in /etc/sysctl.conf (or a new configuration file in /etc/sysctl.d) and then reboot to see the changes:

```
vm.swappiness = 60
```

4.5.1 sysctl -w

To directly load a sysctl setting immediately without reading it from the /proc/sys file system, we use: sysctl -w <parameter=value>.

4.5.2 sysctl -p

To load an entire configuration file and set all of the kernel parameters mentioned in it, we use `sysctl -p <configFile.conf>`.

4.6 Modifying Network Behaviour through /proc and sysctl

We can see our IP address(es) and ping it via:

```
# ip a
1: ens33: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
link/ether 00:0c:29:3b:b9:1c brd ff:ff:ff:ff:ff:ff
inet 10.0.99.11/24 brd 10.0.99.255 scope global ens33
valid_lft forever preferred_lft forever
inet6 fe80::f408:1ebf:7742:9fd8/64 scope link
valid_lft forever preferred_lft forever
# ping -c 2 10.0.99.11
PING 10.0.99.11 (10.0.99.11) 56(84) bytes of data.
64 bytes from 10.0.99.11: icmp_seq=1 ttl=64 time=0.420 ms
64 bytes from 10.0.99.11: icmp_seq=2 ttl=64 time=0.135 ms

--- 10.0.99.11 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1001ms
rtt min/avg/max/mdev = 0.135/0.277/0.420/0.143 ms
```

Now, ping is an ICMP control message, and ICMP control messages can be blocked by changing an associated kernel parameter. To find the parameter responsible for ignoring ICMP echo requests that ping needs, we use:

```
# sysctl -a | grep icmp
net.ipv4.icmp_echo_ignore_all = 0
net.ipv4.icmp_echo_ignore_broadcasts = 1
net.ipv4.icmp_errors_use_inbound_ifaddr = 0
net.ipv4.icmp_ignore_bogus_error_responses = 1
net.ipv4.icmp_msgs_burst = 50
net.ipv4.icmp_msgs_per_sec = 1000
net.ipv4.icmp_ratelimit = 1000
net.ipv4.icmp_ratemask = 6168
net.ipv6.icmp.ratelimit = 1000
net.netfilter.nf_conntrack_icmp_timeout = 30
net.netfilter.nf_conntrack_icmpv6_timeout = 30
```

The very first displayed parameter is exactly what we need. So, we first test it with:

```
# echo 1 > /proc/sys/net/ipv4/icmp_echo_ignore_all
[root@vmPrime ~]# ping 10.0.99.11
PING 10.0.99.11 (10.0.99.11) 56(84) bytes of data.
^C
--- 10.0.99.11 ping statistics ---
4 packets transmitted, 0 received, 100% packet loss, time 3000ms
```

Now that our host has stopped replying to pings, we can make the changes permanent by adding to the `/etc/sysctl.conf` file (and then rebooting):

```
net.ipv4.icmp_echo_ignore_all = 1
```

Chapter 5

Configuring Logging

5.1 Understandig Logging In RHEL 7

Due to the introduction of Systemd several services of the older Unix System V now have a counter part in their systemd equivalent. Such is the case for rsyslogd and journald. The former is responsible for logging in System V systems while journald does it in systemd systems. However, due to the concern of backwards compatibility (i.e., being able to use tools written for older versions of Linux which may have used System V utilities), modern distros like RHEL 7 also have rsyslogd installed.

There can be thus, three different ways of logging application information in RHEL 7:

- Directly write to a log file somewhere - no standardized way of accessing logs.
- Write to Systemd's *Journald* - logs are accessible via **journalctl**
- Write to *rsyslogd* - logs are accessible via `/var/log`.

An important point to note here is that **rsyslog** is still the central logging authority, but journald simply adds features to the way that logging is organized. Thus, journald doesn't really replace rsyslog.

This however means that there's scope for confusion on part of the user (or admin) who's handling the system - to understand exactly where a certain programs might write it's logs to. Thus, we can connect the two together to show the same information.

5.2 Connecting Journald to Rsyslogd

We merely need to add a few lines of configuration to have both services report their own logs to each other:

```
# To connect Journald to rsyslogd:
## In /etc/rsyslog.conf:
$ModLoad imuxsock
$OmitLocalLogging off
## In /etc/rsyslog.d/listend.conf:
$SystemLogSocketName /run/systemd/journal/syslog

```

```
# To connect rsyslogd to journald:
## In /etc/rsyslog.conf:
$ModLoad omjournal
*.* :omjournal:
```

NOTE - *this is legacy syntax and will probably not work anymore. Plus, it causes errors in journalctl. Further investigation is needed.*

rsyslog messages are sent to **journald**, and vice versa. However, sending to journald is disabled by default in rsyslog.conf. To fix this we add the load the module omjournal (*output module journal*) using `$ModLoad omjournal`. Next, we use rsyslog's notation for indicating the facility, priority and destination. The statement `*.* :omjournal:` means for any facility and any priority, we want the log to be forwarded to *omjournal*.

Receiving from journal is enabled by default in `rsyslog.conf`. This is done via: `$ModLoad imuxsock` (Input Module UniX SOCKet), which instructs rsyslog to listen to a socket. Now, local logging has to be enabled using the `$OmitLocalLogging off` option. Finally, the socket name on which rsyslog will listen will have to be specified in the `/etc/rsyslog.d/listend.conf` file, and has to be set to the value `/run/systemd/journal/syslog`. Everything on the systemd end is already configured and needs no manual intervention. This completes the integration of the two.

5.2.1 Modules

Thus, the connection between rsyslog and journald is facilitated by modules. There are several types of modules, which can be identified and classified by:

Prefix	Type	Description
im*	Input Module	Source of information for the rsyslog journal; Loaded in `/etc/rsyslog.conf` and socket name specified in `/etc/rsyslog.d/listend.conf`.
om*	Output Module	Destination to which data from rsyslog will be sent; Configured in `/etc/rsyslog.conf`
		Other modules such as parser modules, message modification modules, etc.

Together these modules lets us manipulate the log messages any way we want.

5.2.2 Importing text files to log : httpd error log

To import the HTTPD error log to rsyslog, the following needs to be added to the file `/etc/rsyslog.conf`:

```
$ModLoad imfile
$InputFileName /var/log/httpd/error_log
$InputFileTag apache-error:
$InputFileState state-apache-error
$InputRunFileMontitor
```

This takes the error log read and maintained by apache and inserts the data into rsyslog. The `$InputRunFileMonitor` enables monitoring of the specified file.

5.2.3 Exporting data to an output module : exporting to a database

Since rsyslog writes the data to a simple text file, and for managing log information the ability to query is very important, we may choose to export the data to a database. Assuming we're using a MySQL database:

```
$ModLoad ommysql
$ActionOmmysqlServerPort 1234
*.* :ommysql:database-serverName,database-name,database-userid,database-password
```

The first line loads the MySQL Output module for rsyslog. Then, we define the server port on which the logs will be forwarded. Then, finally, we configure the output module using the *facility, priority :destination* method where we send everything (all facilities and every priority[*.*]) to the output module, while also providing the database details.

5.3 Setting up Remote Logging

It is via the use of modules that remote logging can be configured. This can be done using two types of protocols: TCP and UDP. UDP is the classical solution and is backwards compatible, but due to the very nature of the protocol, the message transfer isn't connection oriented. What this means is that messages may get lost in transit, and thus data loss may occur. Contrastingly, TCP only does data exchange after a connection has been established, and thus provides more reliable logging. So, if everything in our syslog configuration is compatible with TCP, then we should definitely opt for TCP syslog reception. Example usage for both are provided in a commented section in the /etc/rsyslog.conf file:

```
# Provides UDP syslog reception
#$ModLoad imudp
#$UDPServerRun 514

# Provides TCP syslog reception
#$ModLoad imtcp
#$InputTCPServerRun 514
```

The TCP syslog reception needs to be done exactly as the example states and so uncommenting the lines is all we need to do. The **imtcp** module enables the reception of log information via TCP connection and the InputTCPServerRun option chooses port 514 to use as incoming port for the messages (the IP is the IP of the server itself).

Now, for the other servers, the configuration has to be such that they send their own logging data to the same IP and port as we just configured. If our logging server is running on 10.0.50.11:514, then the *forwarding rule* configuration (an example of which is present in the rsyslog.conf file itself) becomes:

```
# ### begin forwarding rule ###
# The statement between the begin ... end define a SINGLE forwarding
# rule. They belong together, do NOT split them. If you create multiple
# forwarding rules, duplicate the whole block!
# Remote Logging (we use TCP for reliable delivery)
#
# An on-disk queue is created for this action. If the remote host is
# down, messages are spooled to disk and sent when it is up again.
#$ActionQueueFileName fwdRule1 # unique name prefix for spool files
#$ActionQueueMaxDiskSpace 1g   # 1gb space limit (use as much as possible)
```

```
#$ActionQueueSaveOnShutdown on # save messages to disk on shutdown
#$ActionQueueType LinkedList   # run asynchronously
#$ActionResumeRetryCount -1    # infinite retries if host is down
# remote host is: name/ip:port, e.g. 192.168.0.1:514, port optional
*.* @@10.0.50.11:514
# ### end of the forwarding rule ###
```

Note that the `@@` sign in the line `*.* @@10.0.50.11:514` statement signifies the use of TCP. If UDP is to be used instead, we replace it with a single `@` sign, thus making the statement: `*.* @10.0.50.11:514`. The forwarding rule asks rsyslogd to forward logs from any facility of any priority should be sent to the server over at 10.0.50.11 on port 514 via TCP. Now, after rsyslog service has been restarted on both the server and the client, remote logging should work.

An additional thing to remember is that on the logging server, i.e., the server accepting the logs, the port 514 needs to be unblocked for TCP traffic using:

```
# firewall-cmd --add-port=514/tcp --permanent
# firewall-cmd --reload
```

If SELinux blocks TCP traffic or the port isn't the standard port for remote logging, i.e., port 514, then the associated port needs to be given the right security context of `syslogd_port_t`. For the TCP port 514, the command to allow logging on the server is:

```
# semanage port -a -t syslogd_port_t -p tcp 514
```

Part II

Networking and Apache

Chapter 6

Configuring Advanced Networking

6.1 Networking Basics Resumed

6.1.1 Network configuration tools

Terms	Description
ip addr show	Shows address information about all network interfaces.
ip -s link show ens33	Shows statistics about packets but for interface `ens33`. Same as `ip -s link`, but for a specific interface.
ip route	Shows routing information
traceroute / **tracepath**	For analysing a particular route or path.
netstat / **ss**	Analyse ports and services currently listening for incoming connections.

6.1.2 Network Manager

NetworkManager is used to both manage and monitor network settings. While the settings made with the IP tool act directly on the NICs, they're temporary and wiped with every boot or even bringing the interface down and up again. The network manager uses config scripts in `/etc/sysconfig/network-scripts` to store our configs and use them after every boot. The settings can be managed using either `nmcli` or `nmtui`. The former is preferred for scripts while `nmtui` is preferred for manual configs.

nmcli concepts

- A **device** or an **interface** is a network interface, corresponding to the hardware NIC (Network Interface Card).
- A **connection** is a collection of configuration settings for a *device*.
- Multiple connections can exist for the same device, but since they operate on the same settings for the device, only one of them can be active.

- All the connections (and some details) can be shown with the command `nmcli con show`.

- To show all the details for a particular connection, we have to use the command `nmcli con show <interface name>` like `nmcli con show wlo1` (where *wlo1* is the name of the connection).

- To see the connection status for a device, we use `nmcli dev status`. This shows us which devices are connected and which connection they're presently using.

- To see the details of the actual NIC device, we use `nmcli dev show <deviceName>`.

6.1.3 Creating Network Interfaces with nmcli

To add a new connection using `nmcli` that has the name *dhcp* that auto-connects using dynamic IP on interface *eno1*, we use:

```
# nmcli con add con-name "dhcp" type ethernet ifname eno1
```

To add a new connection *static* that uses a static ip that doesn't connect automatically, we use:

```
# nmcli con add con-name "static" type ethernet ifname eno1 autoconnect no ip4
 ↪  192.168.122.102 gw4 192.168.122.1
```

Now, the available connections can be checked with `nmcli dev status`. The we can connect the *static* connection using `nmcli con up static` and then switch back to the original connection *dhcp* using `nmcli con up dhcp`.

6.1.4 Modifying Network Interfaces using nmcli

To see the details of the *static* connection, we use `nmcli con show static`. Then, to add/modify the DNS server address for that connection, we use the `con mod` keywords, which makes the command:

```
# nmcli con mod "static" ipv4.dns 192.168.122.1
```

Note that the modification requires the `ipv4` keyword instead `ip4`. To define a second IPv4 DNS for the *static* connection, we use the + symbol to denote that a new value for the item should be added and the old value shouldn't be overwritten. The command then becomes:

```
# nmcli con mod "static" +ipv4.dns 8.8.8.8
```

An existing static IP address and gateway can be edited using:

```
# nmcli con mod "static" ipv4.addresses "192.168.100.10/24 192.168.100.1"
```

A secondary IPv4 address can be added using:

```
# nmcli con mod "static" +ipv4.addresses "10.0.0.10/24"
```

Finally, to activate all the above settings, we use: `nmcli con up static`.

6.1.5 Working directly with Configuration Files

All the `nmcli` tool really does while adding or modifying settings is write the changes to the configuration files in `/etc/sysconfig/network-scripts/ifcfg-<interfaceName>`. We may choose to edit them directly if needed. Then, after making the necessary modifications, we ask the NetworkManager service to reload the configuration using `nmcli con reload`.

6.1.6 Managing Hostname and DNS

The hostname is stored in the file `/etc/hostname` and can be edited directly or using the `hostnamectl set-hostname <newHostName>` command. The current hostname can then be viewed using `hostnamectl status`.

The value of the search domain and preferred nameserver (i.e., the one that the NetworkManager uses by default) is auto-pushed from `/etc/sysconfif/network-scripts/ifcfg-<connectionName>` to the file `/etc/resolv.conf`.

6.2 Understanding Routing

Let us consider the following network:

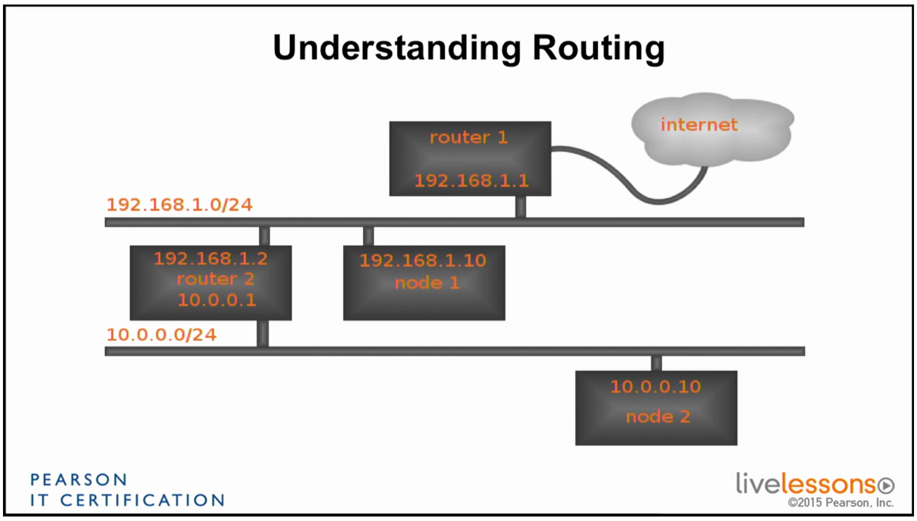


Figure 6.1: Sample Network

Here, we see two different networks - the `10.0.0.0/24` network connected to the inner `192.168.1.0/24` network via *router 2* (`10.0.0.1`), which in turn connects to the internet via the edge router with IP `192.168.1.1` - *router 1*.

For any packet headed to the internet on network 2, i.e., any packet originating from *node 2*, the default gateway will have to be *router 2* (`10.0.0.1`). This gets the packet on to the `192.168.1.0/24` network, where the default gateway is *router 1* (`192.168.1.1`), which passes it on to the internet.

However, when the packets originate from node 1 (`192.168.1.10`), there are two possible routes - if the packet is destined for the `10.0.0.0/24` network, then the gateway should be *router 2* (`192.168.1.2`). But if the packet is for any other network, then the default gateway of *router 1* (192.168.1.1) should be used. Thus, a static route should be defined on node 1 for the 10.0.0.0/24 network.

6.3 Setting up Static Routing

The most convenient way to set up static routes is to use `nmtui`. Let's assume we're setting up static routing for node 2 in our last example.

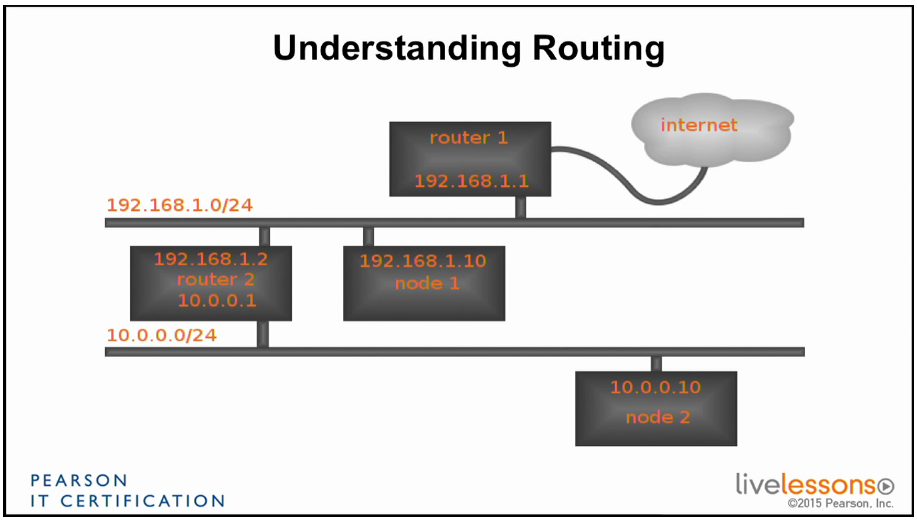


Figure 6.2: Network Diagram

We need to edit the existing connection to include the new static route. For this, we select the options: `Edit a Connection` → Select the connection to use → `Edit...` → `Routing` section → `Edit...` → `Add...` → Type the address of the network for which the static route will be defined in `Destination/Prefix` (with the Network ID and prefix, like, 10.0.0.0/24) → Add the IP address of the router that leads to the network in the `Next Hop` section (192.168.1.2 in our case).

The **metric** of the connection is how a router chooses which route to take when there are multiple routes available to another network. Thus, it's only useful when there are multiple routes available for the same network, and is irrelevant to us right now. We now choose `<Ok>` → `<Ok>` → `<Quit>`.

Note however, that the new route won't be added to the network configuration till either the connection is *refreshed* (by reactivating the connection) or the NetworkManager service is restarted. We could do this by `nmtui` → `Activate a Connection` → Select the connection which we edited → `Activate`. Now the output of `ip route show` will show the static route as well.

If the interface name was *ens33*, The `/etc/sysconfig/network-scripts` directory now has a new file called : `route-ens33` with the following contents:

```
ADDRESS0=10.0.0.0
NETMASK0=255.255.255.0
GATEWAY0=192.168.1.2
```

Note that the nmtui utility has translated the /24 prefix from the **CIDR** (Classless Inter-Domain Routing) notation 10.0.0.0/24 to the standard Network IP and Network Masks, where /24 translates to the network mask of 255.255.255.0.

6.4 Understanding Network Bridges

A network bridge is a device that connects two or more networks to form one extended network. For example, an Ethernet bridge connects two or more LANs to create a unified, extended LAN. Virtual bridges are special purpose network interfaces used in virtualized environments.

Let us consider that the physical host has a NIC called `eno1`. The entire virtualized network in the diagram then has to communicate with any external networks via this interface. However, they can't all just send their packets to the driver of the NIC. Thus, they need a virtual bridge `virbr0`. There can be multiple virtual bridges too.

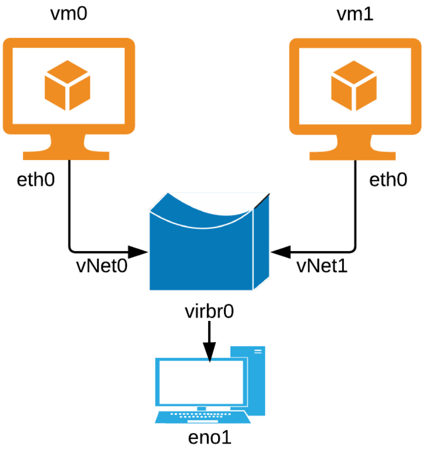


Figure 6.3: A virtualized network

The virtual bridge acts like a physical switch in the network and merely passes data between the networks. Note that it is incapable of routing decisions. All network traffic - even the traffic that originates from the physical KVM host are handled by it and thus, the virtual bridge decides who can send their packets at a specific moment.

Each of the virtual machines have their own virtualized Ethernet interface called `eth0` which have to be connected to an interface (port) on the virtual bridge. The virtual bridge names them `vnet0` and `vnet1` accordingly.

6.4.1 Working with Network Bridges

Let us consider a physical host with two KVM virtual machines running on it. Then, we can see their details using:

```
# virsh list --all
Id    Name                          State
----------------------------------------------------
3     vm0                           running
4     vm1                           running
```

Linux has an inbuilt layer 2 Ethernet bridge. This can be controlled using the `brctl` command. The status of the devices (VMs) connected to the bridge can be viewed with:

```
# brctl show
bridge name         bridge id               STP enabled         interfaces
virbr0              8000.525400683445       yes                 virbr0-nic
                                                                vnet0
                                                                vnet1
```

The `vnet0` and `vnet1` interfaces are from the `vm0` and `vm1` virtual machines that are running on the host machine. The details of these interfaces can be seen with:

```
# ip link show
...
2: ens33: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP mode DEFAULT qlen 1000
link/ether 00:0c:29:d8:97:c2 brd ff:ff:ff:ff:ff:ff
3: virbr0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP mode DEFAULT qlen 1000
link/ether 52:54:00:68:34:45 brd ff:ff:ff:ff:ff:ff
...
7: vnet0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast master virbr0 state UNKNOWN mode DEFAULT qlen 1000
link/ether fe:54:00:0d:4a:d5 brd ff:ff:ff:ff:ff:ff
8: vnet1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast master virbr0 state UNKNOWN mode DEFAULT qlen 1000
link/ether fe:54:00:21:93:04 brd ff:ff:ff:ff:ff:ff
```

The virtual bridge `virbr0` connects several devices together: the virtual ethernet interfaces from the VMs, `vmnet0` and `vmnet1` to the external LAN via interface `ens33`, which is the NIC for the physical host. The virtual bridge only shows active interfaces connected to it, i.e., only when the VMs are running will they appear on the output of `brctl show`.

6.4.2 Difference between network device and interface

In terms of hardware, a device refers to the physical NIC that's connected to the host, while an interface refers to the physical port that an Ethernet cable is plugged into, i.e., the hardware Ethernet port. Back when each NIC had only one interface, the terms *device* and *hardware* meant the same thing. However, with the advent of NICs with multiple interfaces on the same NIC, for example dual or quad port configurations, interfaces refer to each separate hardware port that's capable of accepting a network cable. Thus, for a NIC with 4 hardware ports, the single device has 4 interfaces.

Linux however, doesn't see these interfaces as connected devices (unless configured to do so) and treat them like separate hardware devices, even though they're on the same card! So, there can be multiple interfaces per hardware device. However, from Linux's perspective, they're all separate network devices, thus making the terms *interface* and *device* synonymous.

6.5 Setting up Network Bridges

The roles of the interfaces on the bridge are defined by the connections (profiles) for the available interfaces. Thus, we generate new profiles for the interfaces that we want to act as slaves, and one connection for the interface that we intend to act as master.

6.5.1 Creating a slave interface on the bridge

The package needed to set up software bridges on RHEL 7 is called `bridge-utils`. To set up bridging all connected interfaces need to be disconnected and then connected to the bridge. The connected interface can be viewed with:

```
# nmcli dev show
GENERAL.DEVICE:                         ens33
GENERAL.TYPE:                           ethernet
GENERAL.HWADDR:                         00:0C:29:3B:B9:1C
GENERAL.MTU:                            1500
GENERAL.STATE:                          100 (connected)
GENERAL.CONNECTION:                     ens33
GENERAL.CON-PATH:
 ↪  /org/freedesktop/NetworkManager/ActiveConnection/1
WIRED-PROPERTIES.CARRIER:               on
IP4.ADDRESS[1]:                         10.0.99.11/24
IP4.GATEWAY:                            10.0.99.2
IP4.DNS[1]:                             10.0.99.2
IP6.ADDRESS[1]:                         fe80::f408:1ebf:7742:9fd8/64
...
```

Now, we disconnect the devices using:

```
# nmcli dev disconnect ens33
Device 'ens33' successfully disconnected.
```

Once the disconnection is complete, we can now start defining the bridge, by adding an interface connection with:

```
# nmcli con add con-name br0-port1 type bridge-slave master br0 ifname ens33
Warning: master='br0' doesn't refer to any existing profile.
Connection 'br0-port1' (3dee7b9b-6197-4eb7-be8d-46290361b9fd) successfully added.
```

In this command, we have created a new connection with the name `br0-port1` and connected it to the interface *ens33*, which refers to the hardware NIC of the host. We've set the connection type to **bridge-slave**, which refers to the fact that the details of the incoming connection to the *slave* interface (*ens33*) will be configured at the bridge. The master of the new slave connection is set to a connection called *br0* (which doesn't yet exist, leading to the warnings).

The advantage of the master-slave configuration in network bridges is that if there are many connected slave interfaces, we need not set up their properties individually, and the master (bridge) thus provides a central point of configuration. The above slave configuration has to be repeated for every slave interface that we wish to connect to the bridge.

6.5.2 Creating a master interface on the bridge

The connection for the master interface will determine the settings for all the slave interfaces connected to it. We create the master connection by setting the type to `bridge` (instead of `bridge-slave`, unlike the previous cases):

```
# nmcli con add con-name br0 type bridge ifname br0
Connection 'br0' (493c6288-7f40-4a9b-9ac0-aee7a7aebe71) successfully added.
# brctl show
bridge name         bridge id               STP enabled         interfaces
br0                 8000.000000000000       yes
```

The NetworkManager must be restarted to be actually able to use any of this, since these only refer to the configuration in scripts `/etc/sysconfig/network-scripts` that need to be created by the NetworkManager.

```
# cd /etc/sysconfig/network-scripts/
# ls ifcfg-*
ifcfg-br0  ifcfg-br0-1  ifcfg-br0-port1  ifcfg-ens33  ifcfg-lo
```

The contents of the interface configuration file for the br0 master port:

```
DEVICE=br0
STP=yes
BRIDGING_OPTS=priority=32768
TYPE=Bridge
PROXY_METHOD=none
BROWSER_ONLY=no
BOOTPROTO=dhcp
DEFROUTE=yes
IPV4_FAILURE_FATAL=no
IPV6INIT=yes
IPV6_AUTOCONF=yes
IPV6_DEFROUTE=yes
IPV6_FAILURE_FATAL=no
IPV6_ADDR_GEN_MODE=stable-privacy
NAME=br0
UUID=5da1229d-27f1-4261-8491-e30046b9d03d
ONBOOT=yes
```

Since no information about IPs were provided, the boot protocol was chosen to be *DHCP* automatically. The slave interfaces only have the configuration:

```
TYPE=Ethernet
NAME=br0-port1
UUID=3dee7b9b-6197-4eb7-be8d-46290361b9fd
DEVICE=ens33
ONBOOT=yes
BRIDGE=br0
```

Since the configuration via the `nmcli` utility is hard to remember, it's man page has a link to the *nmcli-examples* man page, which has specific examples on setting up a bridge connection, as well as much more of the `nmcli` functionality.

6.6 Understanding Network Bonds and Teams

Both network bonds and teams accomplish roughly the same goal - the aggregation of links or network interfaces to form Link Aggregation Groups (LAG) or virtual links. This means several physical/logical interfaces can be combined to form a *team* that together fulfil a responsibility. Thus, one link may be set up as a primary connection to the WAN while the other may act as a backup or they both may be configured to act together while load balancing. Network bonding has been deprecated in RHEL 7 and thus we'll concentrate on Network teaming.

Network bonding used to perform the same responsibility as network teaming, but in the user space. Contrastingly, network teaming works with a kernel driver but also has a user space daemon, called **teamd**. This *teamd* daemon has several modes of operation called *runners*. These determine the function of the ports in the team and have possible values of: *broadcast, roundrobin, activebackup, loadbalance* and *lacp*.

Terms	Description
broadcast	Any packet is broadcast all over the interfaces.
roundrobin	The port which can transmit data is chosen in a roundrobin fashion.
activebackup	One of the interfaces stays active while the other is backup, ready to kick in the moment the active interface fails.
loadbalance	The network load (i.e., the packets in the network) is split between the interfaces so as to not overload any single interface.
lacp	Link Aggregation Control Protocol - allows formation of LAGs on a peer by automatically negotiating by transmitting LACP packets.

The command to control and manage teams is called `teamdctl`. Thus, to show the state of the team called *team0*, we'd use: `teamdctl team0 state`.

6.7 Configuring Network Teams

There are four parts to creating a team:

- Creating a team interface
- Determining the network configuration
- Assigning the port interfaces
- Bring team and port interfaces up and down respectively.

Once the above has been taken care of, the team connection can be verified with `teamdctl team0 status` (assuming *team0* is the name of the team).

6.7.1 Creating the team interface

We have to create the new team connection, preferably with the same interface name as the team:

```
# nmcli con add type team con-name team0 ifname team0 config '{"runner": {"name":
↪  "loadbalance"}}'
Connection 'team0' (d0eba200-591c-4ce3-a089-12d8a5692243) successfully added.
```

In this command, we have created a connection of type *team*, which indicates that it'll be a link aggregate. We provide a name to it called *team0* and connect it to an interface called team0 (which is logical - the interface that'll act as the aggregate of the member links). Finally, we provide the configuration as a JSON array: `'{"runner": {"name": "loadbalance"}}'`. This sets the team to act as a load balancer, and thus split the load of the packets over all the interfaces configured in the team.

6.7.2 Determining the network configuration

The team needs to be configured to use an IP address to use as its interface (i.e., team interface). This is specified using the CIDR (Classless Inter-Domain Routing) notation with a Network IP address and a prefix. From this both the Network ID and the Subnet mask can be determined.

```
# nmcli con mod team0 ipv4.addresses 10.0.0.10/24
# nmcli con mod team0 ipv4.method manual
```

Note that the `mod` command uses `ipv4` instead of `ip4`, unlike the `nmcli add` command. The IP assignment method also needs to be switched to manual since DHCP isn't involved here.

6.7.3 Assigning the port interfaces

Now that the master (team) interface has a port defined for it, we also need to assign the individual interfaces that are going to be slaves to the team. This is done using:

```
# nmcli con add type team-slave con-name team0-ens33 ifname ens33 master team0
Connection ’team0-ens33’ (78e706bd-395c-456f-b16a-75430c48be2c) successfully added.
# nmcli con add type team-slave con-name team0-enss37 ifname ens37 master team0
Connection ’team0-enss37’ (d17ad2f5-9a55-422a-ad5d-f4b327674393) successfully added.
```

The command defines two interfaces (*eth0* and *eth1*) to be slaves to the team interface. They are named according to the format `<teamName>-<interfaceName>`. Now we only need to define a master for them from which they can be controlled.

6.7.4 Bringing the team and port interfaces up/down

Once the above sections have been handled, the team is basically ready for operation. However, we still need to bring the physical devices (that are slaves to the team) to be disconnected and then reconnected as part of the team. Since we've already defined them as a part of the team, we just need to:

```
# nmcli con up team0
Connection successfully activated (master waiting for slaves) (D-Bus active path:
 ↪  /org/freedesktop/NetworkManager/ActiveConnection/7)
# nmcli dev disconnect ens33; nmcli dev dis ens37
Device ’ens33’ successfully disconnected.
Device ’ens37’ successfully disconnected.
```

The devices *eth0* and *eth1* needed to be disconnected because they're slaves to the team now, and thus, their operation should only be influenced by the team itself. Thus, there's no point in having them exist as separate individual devices (network interfaces).

6.7.5 Verifying the team connection

We can verify the team connection by:

```
# teamdctl team0 state
setup:
  runner: loadbalance
ports:
  ens33
    link watches:
      link summary: up
      instance[link_watch_0]:
        name: ethtool
        link: up
        down count: 0
  ens37
    link watches:
      link summary: up
      instance[link_watch_0]:
        name: ethtool
        link: up
        down count: 0
```

6.7.6 Creating a bridge based on Network Teams

When creating bridges based on network teams, it becomes important to switch off NetworkManager since they're incompatible. The team configuration file `ifcfg-team0` needs to be edited to add the line `BRIDGE=brteam0` has to be added to it to ask it to connect to the bridge device.

Since the team interfaces will be slaves to the connection provided by the team, it's important to ensure that there are no IP configurations in the `ifcfg-team0-port` files anymore. Basically, we need to disable the team driver since the bridge will now control the team interface. For this we do:

```
# nmcli dev dis team0
# systemctl stop NetworkManager; systemctl disable NetworkManager
```

Now we can manually create a configuration file for the bridge connection that has the contents:

```
DEVICE=brteam0
TYPE=Bridge
IPADDR0=192.168.122.100
PREFIX0=24
```

Finally, since we're not using the `NetworkManager` service, we directly restart the networking with: `systemctl restart network`. Now, the bridge on top of the team interface should be active and operational. Again, examples for these congigurations are present in the nmcli-examples man page, accessible with `man 5 nmcli-settings`.

6.8 Configuring IPv6

Since there is a shortage of unique IPv4 addresses when compared to the number of devices that are connected to the internet, IPv6 is the new standard for the IP addresses. Just like IPv4 addresses, it can be divided into two parts: the network ID and the host ID. However, in the case of the IPv6 addresses, the host ID contains the MAC address of the interface itself! A typical IPv6 address looks like:

```
fe80::2af4:9908:7092:34cb/64
```

In this, the network ID is `fe80` while the node part is the `2af4:9908:7092:34cb` with the prefix of `64` defining how long the network ID is. Thus, the computer listens for the Network ID, and then appends it's own MAC address to obtain a truly unique IPv6 address! For configuring connections with both IPv6 and IPv4 addresses, nmcli can be used as:

```
# nmcli con add con-name testCon type ethernet ip6 2001:db8:0:10::d000:310/64 gw6
↪   2001:db8:0:10::1 ip4 192.168.0.10/24 gw4 192.168.0.1
```

Again, for new connection just like for IPv4 connections where `nmcli con add` takes as argument the term **ip4** instead of *ipv4* (unlike the `con mod` command, which accepts *ipv4*), the `nmcli con add` needs an argument of **ip6** and not *ipv6*. Now to add a DNS server for it:

```
# nmcli con mod testCon +ipv6.dns 2001:4680:4680::8888
```

Chapter 7

Managing Linux Based Firewalls

7.1 Understanding Firewalld Operation

Firewalld provides primarily two interfaces to manage it: `firewall-cmd`, a command line utility to manage its functions, and `firewall-config` a graphical user interface to do the same. However, since most servers don't provide a GUI or even have a window manager installed, this second options isn't always available.

`firewall-cmd` has a list of pre-defined zones and services that can be accessed with `--get-<parameter>` options. To list the parameter that are actually active at the moment, we use `--list-parameter` option instead. For exmaple, we use `--list-services` to get the list of currently active services:

```
# firewall-cmd --get-zones
block dmz drop external home internal public trusted work
# firewall-cmd --get-services
RH-Satellite-6 amanda-client amanda-k5-client bacula bacula-client bitcoin bitcoin-rpc
 ↪  bitcoin-testnet bitcoin-testnet-rpc ceph ceph-mon cfengine condor-collector ctdb
 ↪  dhcp dhcpv6 dhcpv6-client dns docker-registry dropbox-lansync elasticsearch
 ↪  freeipa-ldap freeipa-ldaps freeipa-replication freeipa-trust ftp ganglia-client
 ↪  ganglia-master high-availability http https imap imaps ipp ipp-client ipsec
 ↪  iscsi-target kadmin kerberos kibana klogin kpasswd kshell ldap ldaps libvirt
 ↪  libvirt-tls managesieve mdns mosh mountd ms-wbt mssql mysql nfs nrpe ntp openvpn
 ↪  ovirt-imageio ovirt-storageconsole ovirt-vmconsole pmcd pmproxy pmwebapi pmwebapis
 ↪  pop3 pop3s postgresql privoxy proxy-dhcp ptp pulseaudio puppetmaster quassel radius
 ↪  rpc-bind rsh rsyncd samba samba-client sane sip sips smtp smtp-submission smtps snmp
 ↪  snmptrap spideroak-lansync squid ssh synergy syslog syslog-tls telnet tftp
 ↪  tftp-client tinc tor-socks transmission-client vdsm vnc-server wbem-https xmpp-bosh
 ↪  xmpp-client xmpp-local xmpp-server
# firewall-cmd --list-services
ssh dhcpv6-client
```

These predefined services are stored in the folder `/usr/lib/firewalld/services` as *XML* files, listing the service name and the associated ports and protocol:

```xml
<?xml version="1.0" encoding="utf-8"?>
<service>
    <short>LDAP</short>
    <description>Lightweight Directory Access Protocol (LDAP) server</description>
    <port protocol="tcp" port="389"/>
</service>
```

For certain services, certian kernel modules may also be loaded, such as in the case of *FTP*, for which the `/usr/lib/firewalld/services/ftp.xml` has:

```
<service>
    <short>FTP</short>
    <description>FTP is a protocol used for remote file transfer. If you plan to make
    ↪  your FTP server publicly available, enable this option. You need the vsftpd
    ↪  package installed for this option to be useful.</description>
    <port protocol="tcp" port="21"/>
    <module name="nf_conntrack_ftp"/>
</service>
```

The kernel module `nf_conntrack_ftp` is loaded for the service by firewalld. The services in the `/usr/lib/firewalld/services` folder are system defined and any changes made to them are overwritten with every system update. So, the user defined services go in the folder `/etc/firewalld/services` with the added advantage of overwriting the settings of the system defined services in `/usr/lib/firewalld/services`.

Every change made using firewall-cmd is not permanent, unless explicitly made permanent using the `--permanent` option. Even then, the firewall has to be reloaded using the `--reload` option for the changes to take effect. Finally, the state of the firewall can be guaged with:

```
# firewall-cmd --state
running
```

The firewalld configurations are stored in `/etc/firewalld/firewalld.conf`:

```
# firewalld config file

# default zone
# The default zone used if an empty zone string is used.
# Default: public
DefaultZone=public

# Minimal mark
# Marks up to this minimum are free for use for example in the direct
# interface. If more free marks are needed, increase the minimum
# Default: 100
MinimalMark=100

# Clean up on exit
# If set to no or false the firewall configuration will not get cleaned up
# on exit or stop of firewalld
# Default: yes
CleanupOnExit=yes

# Lockdown
# If set to enabled, firewall changes with the D-Bus interface will be limited
# to applications that are listed in the lockdown whitelist.
# The lockdown whitelist file is lockdown-whitelist.xml
# Default: no
Lockdown=no

# IPv6_rpfilter
# Performs a reverse path filter test on a packet for IPv6. If a reply to the
# packet would be sent via the same interface that the packet arrived on, the
# packet will match and be accepted, otherwise dropped.
# The rp_filter for IPv4 is controlled using sysctl.
# Default: yes
IPv6_rpfilter=yes

# IndividualCalls
# Do not use combined -restore calls, but individual calls. This increases the
# time that is needed to apply changes and to start the daemon, but is good for
# debugging.
# Default: no
IndividualCalls=no

# LogDenied
# Add logging rules right before reject and drop rules in the INPUT, FORWARD
# and OUTPUT chains for the default rules and also final reject and drop rules
# in zones. Possible values are: all, unicast, broadcast, multicast and off.
# Default: off
LogDenied=off

# AutomaticHelpers
# For the secure use of iptables and connection tracking helpers it is
# recommended to turn AutomaticHelpers off. But this might have side effects on
# other services using the netfilter helpers as the sysctl setting in
# /proc/sys/net/netfilter/nf_conntrack_helper will be changed.
# With the system setting, the default value set in the kernel or with sysctl
# will be used. Possible values are: yes, no and system.
# Default: system
AutomaticHelpers=system
```

The value of the default zone can be directly obtained with:

```
# firewall-cmd --get-default-zone
public
```

7.2 Configuring Firewalld Services and Zones

The very first thing to remember while working with **firewalld** is to stop and disable the **iptables** service, which used to be the old firewalling solution and is still available as a service in certain versions of RHEL 7, but is incompatible with firewalld. For this, we use:

```
# systemctl disable iptables
# systemctl stop iptables
# systemctl mask iptables
```

The very last command is masking of a service, which is creating a link to `/dev/null` from the service unit file in `/etc/systemd/system/iptables.service`, so that it may never even accidentally be started. Any service masked in this manner can be reactivated using `systemctl unmask <serviceName>`.

Firewalld can have multiple active zones. An overview of all the active zones can be obtained by:

```
# firewall-cmd --get-active-zones
public
interfaces: ens33 ens37 br0 team0
```

This is particularly useful in cases of configurations of private subnets on one zone, assigned to an interface and the internet on another zone, assigned to another interface.

Every single configuration detail for the default zone can be obtained with the command:

```
# firewall-cmd --list-all
public (active)
  target: default
  icmp-block-inversion: no
  interfaces: ens33 ens37 br0 team0
  sources:
  services: ssh dhcpv6-client
  ports:
  protocols:
  masquerade: no
  forward-ports:
  source-ports:
  icmp-blocks:
  rich rules:
```

The config details for another, specific zone can be obtained by filtering with:

```
# firewall-cmd --list-all --zone=dmz
dmz
  target: default
  icmp-block-inversion: no
  interfaces:
  sources:
  services: ssh
  ports:
  protocols:
  masquerade: no
  forward-ports:
  source-ports:
  icmp-blocks:
  rich rules:
```

7.2.1 Adding and removing services

To add a service to a particular zone, the `--zone=<zoneName>` option has to be used. Without it, the currently active zone will have the service added to it. The command to add the `ftp` service for example, is:

```
# firewall-cmd --list-services
ssh dhcpv6-client
# firewall-cmd --add-service=ftp
success
# firewall-cmd --list-services
ssh dhcpv6-client ftp
# firewall-cmd --reload
success
# firewall-cmd --list-services
ssh dhcpv6-client
# firewall-cmd --add-service=ftp --permanent
success
# firewall-cmd --list-services
ssh dhcpv6-client
```

```
# firewall-cmd --reload
success
# firewall-cmd --list-services
ssh dhcpv6-client ftp
```

At first we only add the service to runtime by excluding the `--permanent` tag. Then upon reload of the firewall, the service disappears. When the service is made permanent, the changes are written to a configuration file, and not the runtime, and thus the firewall needs to be reloaded for the changes to take effect. The removal of a service also takes this form, and can be done by the command:

```
# firewall-cmd --remove-service=ftp --permanent
success
# firewall-cmd --reload
success
# firewall-cmd --list-services
ssh dhcpv6-client
```

7.2.2 Letting an IP address through

To only allow traffic from a particular IP (or a subnet) via the firewall, we use the command:

```
# firewall-cmd --permanent --add-source=10.0.0.0/24
success
# firewall-cmd --reload
success
# firewall-cmd --list-all
public (active)
  target: default
  icmp-block-inversion: no
  interfaces: ens33 ens37 br0 team0
  sources: 10.0.0.0/24
  services: ssh dhcpv6-client
  ports:
  protocols:
  masquerade: no
  forward-ports:
  source-ports:
  icmp-blocks:
  rich rules:
```

7.2.3 Unblocking a specific port

In the case of unblocking a port, we need to specify the protocol associated with the port as well, in the format `<port#>/<protocol>`. Thus, the command to unblock the port 53 (DNS) becomes:

```
# firewall-cmd --permanent --add-port=53/tcp
success
# firewall-cmd --reload
success
# firewall-cmd --list-all
public (active)
```

```
  target: default
  icmp-block-inversion: no
  interfaces: ens33 ens37 br0 team0
  sources: 10.0.0.0/24
  services: ssh dhcpv6-client
  ports: 53/tcp
  protocols:
  masquerade: no
  forward-ports:
  source-ports:
  icmp-blocks:
  rich rules:
```

7.3 Creating Services Files

To create our own service file for firewalld, we need to copy an existing service file into the `/etc/firewalld/services/` directory, to prevent errors stemming from creating the service file from scratch. So, to create a service file we do:

```
# cp /usr/lib/firewalld/services/ldap.xml /etc/firewalld/services/custom.xml
```

Now, if our application requires the port 8888 unblocked for the TCP protocol, we edit the file's contents to:

```
<?xml version="1.0" encoding="utf-8"?>
<service>
    <short>Custom</short>
    <description>Service for custom application</description>
    <port protocol="tcp" port="8888"/>
</service>
```

Now, if we were to use the `--get-services` option, we wouldn't see our custom service till we reloaded the firewall:

```
# firewall-cmd --get-services | grep -Eo " c(\S)*"
ceph
ceph-mon
cfengine
condor-collector
ctdb
# firewall-cmd --reload
success
# firewall-cmd --get-services | grep -Eo " c(\S)*"
ceph
ceph-mon
cfengine
condor-collector
ctdb
custom
```

The `grep -E` enables extended RegEx while the `-o` flag only prints the matching part. The expression `c(\S)*` prints anything starting with a c till a whitespace character is encountered. Using a service file can be advantageous because we can add/remove multiple ports and protocols simultaneously from the firewall configuration using just a single command.

7.4 Configuring Rich Firewall Rules

There are two types of firewall rules: *direct rules* and **rich rules**. Direct rules are hand-coded rules inserted by administrators that are processed before anything else in the zones. However, it isn't recommended to use them since they're a last resort when rules cannot be added via rich rules.

Rich rules are used to create custom rules via an expressive language that can accomplish tasks that basic syntax can't, thus allowing us to create complex rules in an easy to understand manner. The documentation for this *rich language* can be found using `man 5 firewalld.richlanguage`. To work with rich rules, we must understand the order in which firewalld handles rules. The order is:

1. Port Forward and Masquerading rules.
2. Login rules
3. Allow rules
4. Deny rules

Thus any packet that the firewall encounters is first checked against the port forwarding and masquerading rules, then the login rules, then the allow rules and finally the deny rules. Note that there are no longer *chains* as found while using **iptables**. To manage rich rules, the `firewall-cmd` command has 4 subcommands:

- `--add-rich-rule=<rule>`
- `--remove-rich-rule=<rule>`
- `--query-rich-rule=<rule>`
- `--list-rich-rules`

7.4.1 Basic Syntax for Rich Rules

The basic syntax of the rich language is:

```
rule [family="ipv4|ipv6"]
  [source [not] address="address[/mask]"|mac="mac-address"|ipset="ipset"]
  [destination [not] address="address[/mask]"]
  service|port|protocol|icmp-block|icmp-type|masquerade|forward-port|source-port
  [log [prefix="prefix text"] [level="log level"] [limit value="rate/duration"]]
  [audit [limit value="rate/duration"]]
  [accept|reject|drop|mark] [limit value="rate/duration"]
```

Each of the criteria can have the values:

Terms	Usage	Example
service	service name="service name"	`service name="ftp"`
port	port port="portid[-portid]" protocol="tcp|udp"	`port port="53" protocol="udp"` **OR** `port port="8100-8115"`
protocol	protocol value="protocol value"	`protocol value="cbt"`
icmp-block	icmp-block name="icmptype name"	`icmp-block name="echo-reply"`

masquerade	masquerade	`masquerade`
icmp-type	icmp-type name="icmptype name"	`icmp-type name="destination-unreachable"`
forward port	forward-port port="port value" protocol="tcp|udp" to-port="port value" to-addr="address"	`forward-port port="69" protocol="tcp" to-port="1058" to-addr="10.0.0.69"`
source port	source-port port="port value" protocol="tcp|udp"	`source-port port="2022" protocol="tcp"`

For both icmp-block and icmp-type, the argument is of type *icmptype* which can be listed using: `firewall-cmd --get-icmptypes`. The log and audit options are a way to include logging. Also, it is only possible to limit the log/audit functionality or the action itself.

Actions

There are three types of actions that we need to be concerned with for any packet that meets the criteria set in the firewall: **accept**, **reject** or **drop**. With *accept*, all matching packets will be accepted. With *reject*, all matching packets will be rejected and the source will receive an ICMP error message (default ICMPv6). In the case of *drop*, the packets are rejected silently, and the source gets no error messages.

7.4.2 Creating Rich Rules

Allowing/Denying packets from an IP address

The rich rule to deny all traffic from `10.0.0.100` will be:

```
# firewall-cmd --permanent --zone=public --add-rich-rule='rule family=ipv4 source address=10.0.0.100/32 reject'
success
# firewall-cmd --reload
success
# firewall-cmd --list-rich-rules
rule family="ipv4" source address="10.0.0.100/32" reject
```

Allowing/Denying a service based on Rate Limitation

To limit the number of http packets flowing through the firewall that are allowed into the network up to 3 per minute, we use:

```
# firewall-cmd --permanent --add-rich-rule='rule service name=http limit value=3/m accept'
success
# firewall-cmd --reload
success
# firewall-cmd --list-rich-rules
rule family="ipv4" source address="10.0.0.100/32" reject
rule service name="http" accept limit value="3/m"
```

Allowing/Denying a Protocol

There are several protocols listed in the `/etc/protocols` file, from which the firewall can look up a particular protocol being used. The file describes several protocols from the TCP/IP subsystem in the format: `<protocol name> <number> <alias> <comments>` The first few lines of `/etc/protocols` are:

```
ip      0       IP              # internet protocol, pseudo protocol number
hopopt  0       HOPOPT          # hop-by-hop options for ipv6
icmp    1       ICMP            # internet control message protocol
igmp    2       IGMP            # internet group management protocol
ggp     3       GGP             # gateway-gateway protocol
ipv4    4       IPv4            # IPv4 encapsulation
st      5       ST              # ST datagram mode
tcp     6       TCP             # transmission control protocol
cbt     7       CBT             # CBT, Tony Ballardie <A.Ballardie@cs.ucl.ac.uk>
egp     8       EGP             # exterior gateway protocol
...
```

Now, if we want all packets using the *CBT* protocol to pass through the firewall, we use the command:

```
# firewall-cmd --permanent --add-rich-rule='rule protocol value=cbt accept'
success
# firewall-cmd --reload
success
# firewall-cmd --list-rich-rules
rule family="ipv4" source address="10.0.0.100/32" reject
rule service name="http" accept limit value="3/m"
rule protocol value="cbt" accept
```

More complicated rules

A rule to allow TCP requests from the network 10.0.0.0/24 from ports 7900-7905 will be:

```
# firewall-cmd --permanent --add-rich-rule='rule family=ipv4 source address="10.0.0.0/24"
 ↪   port port="7900-7905" protocol=tcp accept'
success
# firewall-cmd --reload
success
# firewall-cmd --list-rich-rules
rule family="ipv4" source address="10.0.0.100/32" reject
rule service name="http" accept limit value="3/m"
rule protocol value="cbt" accept
rule family="ipv4" source address="10.0.0.0/24" port port="7900-7905" protocol="tcp"
 ↪   accept
```

Logging

The rule to log SSH packets passing through the firewall at a limit of 2 per min in the syslog with a prefix of "ssh", a level of "notice":

```
# firewall-cmd --permanent --add-rich-rule='rule service name=ssh log prefix="ssh"
 ↪   level="notice" limit value="2/m" accept'
success
```

```
# firewall-cmd --reload
success
# firewall-cmd --list-rich-rules
rule family="ipv4" source address="10.0.0.100/32" reject
rule service name="http" accept limit value="3/m"
rule protocol value="cbt" accept
rule family="ipv4" source address="10.0.0.0/24" port port="7900-7905" protocol="tcp" accept
rule service name="ssh" log prefix="ssh" level="notice" limit value="2/m" accept
```

Now, to see the final configuration at the end we use:

```
# firewall-cmd --list-all
public (active)
  target: default
  icmp-block-inversion: no
  interfaces: ens33 ens37 br0 team0
  sources: 10.0.0.0/24
  services: ssh dhcpv6-client
  ports: 53/tcp
  protocols:
  masquerade: no
  forward-ports:
  source-ports:
  icmp-blocks:
  rich rules:
        rule family="ipv4" source address="10.0.0.100/32" reject
        rule service name="http" accept limit value="3/m"
        rule protocol value="cbt" accept
        rule family="ipv4" source address="10.0.0.0/24" port port="7900-7905" protocol="tcp" accept
        rule service name="ssh" log prefix="ssh" level="notice" limit value="2/m" accept
```

7.5 Understanding NAT and Port Forwarding

Let us consider we have a web server running on the IP `10.0.0.10:80`. Let us consider a host on the internet with IP `2.1.1.1` wants to communicate with us. Then, the host needs to reach our web-server which has been assigned a **RFC 1918** private IPv4 range. The problem with private IPs is that there's several of them - in each subnet of every organization. Thus, the host won't be able to find the correct server! So, it needs to go through the router with the public IP `4.5.6.7`. On the router, the port `80` is open, and any packet that it receives on this port is forwarded to the webserver at port `80`. This is called port forwarding.

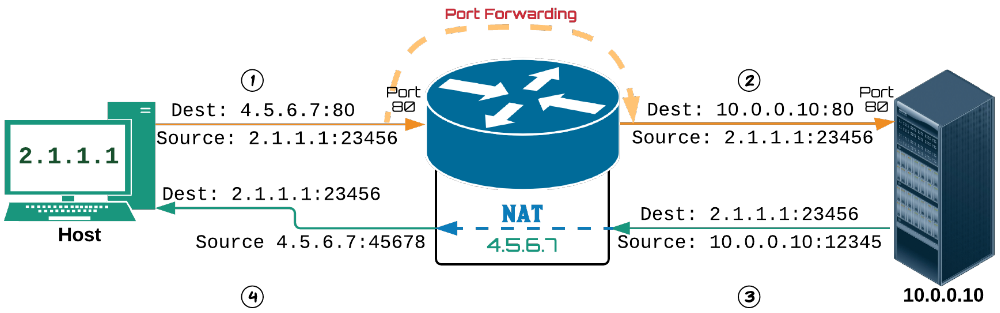


Figure 7.1: Port Forwarding and Network Address Translation (NAT)

Thus, when the IP packet originates from the host it has a source IP of `2.1.1.1:23456` (assuming an application uses the port 23456 to send the request). The destination IP is set to the public IP `4.5.6.7:80`, which is port 80 on the router. According to the port forwarding rules, the packet is sent to the web-server at `10.0.0.10:80`, where the web-server handles the request.

Next, the response is sent from the web-server to the host. However, since the web-server has the private IP of `10.0.0.10:12345` (port number is a random one based upon the application generating the request), the packet can't be allowed on the internet with a RFC 1918 address, since IP dictates that every node on the internet must have a unique public IP address. Thus, enroute to the host at `2.1.1.1`, the router has to translate the private IP to a public IP (`4.5.6.7`). This is called NAT.

So, after NATting has been performed by the router, when the reply finally reaches the host, the header of the IP packet contains a source address of `4.5.6.7:45678` (The port number is now a random one decided upon by the NAT device/mechanism in the router) and a destination address of `2.1.1.1:23456`. In Port forwarding the Destination address (of the web-server) is changed (and not the source, since otherwise the web-server won't know who to reply to!) while in NAT, the source address (again, of the web-server) is changed.

7.6 Configuring NAT

Another name for the operation in which the router changes the IP address of the host on the private network to it's own public IP address is called **masquerading**. To configure NAT using this method is very easy:

```
# firewall-cmd --permanent --add-masquerade
success
# firewall-cmd --reload
success
# firewall-cmd --list-all
public (active)
  target: default
  icmp-block-inversion: no
  interfaces: ens33 ens37 br0 team0
  sources: 10.0.0.0/24
  services: ssh dhcpv6-client
  ports: 53/tcp
  protocols:
  masquerade: yes
  forward-ports:
  source-ports:
  icmp-blocks:
  rich rules:
```

Now, the hosts on the internet will only see the public IP of the router for packets that originate behind the router on the private network.

7.7 Configuring Port Forwarding

Similar to the command to implement NATting, the command for port forwarding is also of a single line, but a bit complex. It is:

```
# firewall-cmd --permanent
 ↪  --add-forward-port=port=888:proto=tcp:toport=80:toaddr=10.0.99.12
success
# firewall-cmd --reload
success
# firewall-cmd --list-all
public (active)
  target: default
  icmp-block-inversion: no
  interfaces: ens33 ens37 br0 team0
  sources: 10.0.0.0/24
  services: ssh dhcpv6-client
  ports: 53/tcp
  protocols:
  masquerade: yes
  forward-ports: port=888:proto=tcp:toport=80:toaddr=10.0.0.10
  source-ports:
  icmp-blocks:
  rich rules:
```

In this command, the **port** of `888` is the port on the router that's going to be listening for incoming connections from the internet. On receiving packets sent via *proto* (protocol) of TCP on port `888`, it'll forward the packet to the value specified in *toport* `80` on the *toaddr* `10.0.0.10` address.

Chapter 8

Configuring Apache Virtual Hosts

8.1 Understanding Apache Configuration Files

The main configuration file for the apache web server is `/etc/httpd/conf/httpd.conf`. Within this file, is a config called the `ServerRoot`. All the file names defined within this file are relative to the *ServerRoot*.

```
ServerRoot "/etc/httpd"
```

Apache is modular in nature, which means different functionalities can be added as modules, instead of just one monolithic program. This means that each of these modules may need their own configuration specific to their functionality. The configuration files for the different modules are stored in `/etc/httpd/conf.modules.d`. Further, with every new module that's included in the apache server running on a host, the folder might get a new config file for that module.

The contents of the module config directory (`/etc/httpd/conf.modules.d`) are added to the configuration of the web server by the include instruction in `httpd.conf`:

```
Include conf.modules.d/*.conf
```

This folder contains files that aid primarily in the loading of appropriate modules from the `/usr/lib/httpd/modules` directory, which has a softlink in `/etc/httpd/modules`. The directory structure of the httpd directory is:

```
# ls -l /etc/httpd
total 0
drwxr-xr-x. 2 root root  37 Mar  7 22:48 conf
drwxr-xr-x. 2 root root  82 Mar  7 22:37 conf.d
drwxr-xr-x. 2 root root 146 Mar  7 22:37 conf.modules.d
lrwxrwxrwx. 1 root root  19 Mar  7 22:37 logs -> ../../var/log/httpd
lrwxrwxrwx. 1 root root  29 Mar  7 22:37 modules -> ../../usr/lib64/httpd/modules
lrwxrwxrwx. 1 root root  10 Mar  7 22:37 run -> /run/httpd
```

In addition to all the above, files in the `/etc/httpd/conf.d` directory that end with a `.conf` extension will also automatically be included in the apache configuration. The files in this directory are included optionally in `httpd.conf` using:

```
IncludeOptional conf.d/*.conf
```

This directory is primarily used by the plugin files from RPMs. (eg. httpd-manual). Apache is also configured to use a default document root at /var/www/html. This is the directory that serves as the base directory of the website being hosted on the web server. The default *DocumentRoot* is configured in httpd.conf using:

```
DocumentRoot "/var/www/html"
```

8.2 Exploring the httpd.conf file

The listen directive tells the Apache web server which IP address and port to listen on for incoming connections. This can take two forms:

```
# Listen 12.34.56.78:80
Listen 80
```

In the first example we are instructing the Apache web server's http daemon to listen for incoming connections only on port 80 of the IP address 12.34.56.78. In case of multiple network interfaces connected to the host running the web server, only the host with the IP address 12.34.56.78 will be able to provide incoming connections. However, if we were to omit the IP address, then the httpd process will listen on port 80 for every IP address associated with the network interfaces on the server. For obvious reasons, one of these directives need to stay commented out while the other is active.

Further down, there's the *user* and *group* parameter, which determines the user and group as which the Apache web server is run with.

```
User apache
Group apache
```

The apache process runs under the apache user and apache group, and thus if any security in the website is exploited and someone gains unauthorized access, they can gain a minimal amount of power since the apache user is given minimal privileges. Next, the location of the error logs is set in the parameter:

```
ErrorLog "logs/error_log"
...
LogLevel warn
```

Since the location is relative, the absolute location for a *ServerRoot* of /etc/httpd is: /etc/httpd/logs/error_log.

8.2.1 Directory access rules

The httpd.conf file contains several <Directory> tags that determine the kind of access the web server has over certain directories. For example, the /var/www directory, i.e., the parent directory of the **DocumentRoot** has the following rules associated to it:

```
<Directory "/var/www">
    AllowOverride None
    # Allow open access:
    Require all granted
</Directory>
```

The AllowOverride directive decides what kind of information may be contained within .htaccess files which are used to customize the kind of permission each directory has on a granular level. When a .htaccess file is encountered, based on the values in the <Directory> tags for that folder, certains settings from the .htaccess files will override the original settings in the config files.

The Require directive is used to determine who has access to visit the directory using HTTP/HTTPS through the website. For example, the Require all granted statement means that anyone from any IP can visit the contents of this directory. Require all denied mean the directory is inaccessible via the web server. Additionally, the Require ip 10.0.50.99 would only allow the mentioned IP to access the contents of that directory. Similarly, the Require host example.org statement would allow hosts on the *example.org* domain to access the directory contents, while denying all other hosts, and so on.

```
Options Indexes FollowSymLinks
```

The Options directive controls which features of the Apache server are available in a particular directory. For example, Options FollowSymLinks would let the httpd process follow symlinks in the concerned directory. Similarly, the Options Indexes makes the server present a formatted list of directory content when an index.html page is not found in the folder corresponding to the URL.

8.3 Configuring a simple Web Server

Configuring a basic web server is simple, but it does take a bit of prep work. First, we must install the Apache web server which provides the http daemon, and comes in the package httpd. Now, by default the service httpd isn't started. So, we need to enable and start it. Then, we need to open the appropriate firewall ports (80 for HTTP, 443 for HTTPS). Then, we can ensure that the web server is operational by visiting the http://localhost site, where we should see a distro specific welcome page for the web server.

```
# yum -y install httpd
# systemctl enable httpd; systemctl start httpd
# firewall-cmd --add-service=http --add-service=https --permanent
# firewall-cmd --reload
# yum -y install elinks
# elinks http://localhost
```

Now, we can go to the *DocumentRoot* (/var/www/html by default) and create a file called index.html and see if we can access it from our browser by going to the localhost site (http://localhost). The contents of the index.html file should contain valid html like:

```
<html>
    <head>
        <title>Test Page!</title>
    </head>
    <body>
        <h1>Success!</h1>
        <p>The Web Server at vmPrime is now operational!</p>
    </body>
</html>
```

8.3.1 Changing DocumentRoot

Let's now create an index.html file within a `/var/www/html/web` directory:

```
# mkdir /web
# cd /web
# vim index.html
```

Inside the index.html, we put the contents:

```
<html>
    <head>
        <title>Subdirectory Test Page!</title>
    </head>
    <body>
        <h1>Success!</h1>
        <p>You're now visiting a subdirectory in the DocumentRoot</p>
    </body>
</html>
```

To make this the new homepage within our site, we need to change the *DocumentRoot* in httpd.conf and then adjust the SELinux contexts. The `/etc/httpd/conf/httpd.conf` file will need to have the original DocumentRoot specification deleted/commented out, and have the new lines added:

```
# DocumentRoot "/var/www/html"
DocumentRoot "/web"
<Directory "/web">
    Options Indexes FollowSymLinks
    AllowOverride None
    Require all granted
</Directory>
```

8.3.2 Dealing with SELinux Security Context

Now, we need to deal with the SELinux contexts. Since the new DocumentRoot is in `/web` and not a child of `/var/www/hmtl`, it'll have a different SELinux security context. This needs to be fixed for the httpd process to be able to access it. The default security context can be seen with:

```
# ls -ldZ /web
drwxr-xr-x. root root unconfined_u:object_r:default_t:s0 /web
# ls -ldZ /var/www/html
drwxr-xr-x. root root system_u:object_r:httpd_sys_content_t:s0 /var/www/html
```

We can see that the security context for the folders are different, which will trigger SELinux to block the httpd process. In case the correct context is not know, we use the command `semanage fcontext -l` grep <processName|originalPath>| to determine the right context: AllowOverride None Require all granted AllowOverride None Require all granted

```
# semanage fcontext -l | grep /var/www
/var/www(/.*)?        all files        system_u:object_r:httpd_sys_content_t:s0
```

We have now confirmed the security context should be `httpd_sys_content_t`. Now, to apply it to the `/web` directory, we again use `semanage fcontext`:

```
# semanage fcontext -a -t httpd_sys_content_t "/web(/.*)?"
# restorecon -Rv /web
restorecon reset /web context
 ↪  unconfined_u:object_r:default_t:s0->unconfined_u:object_r:httpd_sys_content_t:s0
```

The `restorecon` command recursively rectifies the contexts according to the security context of the `/web` directory. Since our original RegEx for the file selection in the `semanage` command was `/web(/.*?)`, i.e., `/web` and all it's children, the `restorecon` commands applies the `httpd_sys_content_t` context to everything under the `/web` directory. Now we just restart the `httpd` service for the changes in `/etc/httpd/conf/httpd.conf` to take effect:

```
# sysmtectl restart httpd
# elinks http://localhost
```

8.3.3 Giving Web Developers access to the new DocumentRoot

The developers need read-write access on the `/web` directory for it to be of any use. However, since it's a directory directly inside the / directory, and due to a host of other security reasons, it's a bad idea to make them owners of the directory. We could create a *webdev* group and make them the group owner, but this approach is limited since only one group can be the group owner of a directory. If some other group also needs access, then this method fails. So, the best way to deal with this is to use Access Control Lists (ACLs). We can get the default ACL by:

```
# getfacl /web
getfacl: Removing leading '/' from absolute path names
# file: web
# owner: root
# group: root
user::rwx
group::r-x
other::r-x
```

First of all, we need to create a group for the web developers. Then, since we have to create an ACL for a directory, we need two sets: one for the existing files in the directory (and the directory itself) as well as a default ACL for any files that are created in the future. So, we use:

```
# groupadd webdev
# chmod -R u=rwX,go=rX /web
[root@vmPrime web]# ls -l /web; ls -ld /web
total 4
-rw-r--r--. 1 root root 165 Mar  8 12:29 index.html
drwxr-xr-x. 2 root root 24 Mar  8 12:34 /web
[root@vmPrime web]# setfacl -R -m g:webdev:rwX /web
[root@vmPrime web]# setfacl -R -m d:g:webdev:rwX /web
[root@vmPrime web]# getfacl /web
getfacl: Removing leading '/' from absolute path names
# file: web
# owner: root
# group: root
```

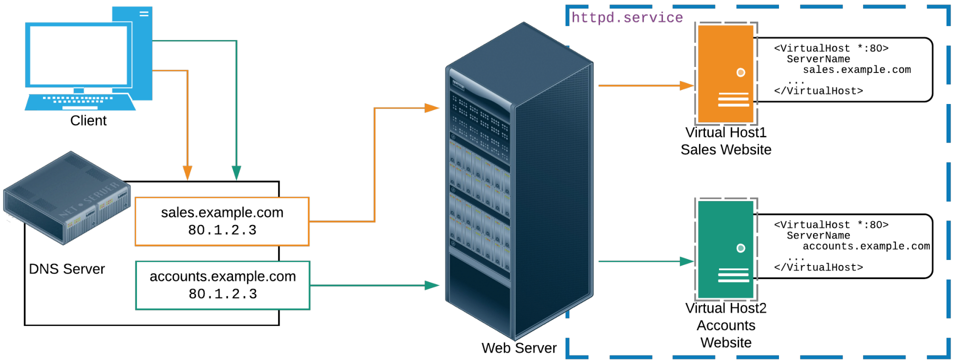
```
user::rwx
group::r-x
group:webdev:rwx
mask::rwx
other::r-x
default:user::rwx
default:group::r-x
default:group:webdev:rwx
default:mask::rwx
default:other::r-x
```

Note the use of capital **X** in the permissions (**rwX**)- which means only the directories should be given execute permissions, (i.e., the user/group/others) can visit it. The execution permissions of the files are not touched, thus they remain executable if they already were, but if they weren't, they still aren't made executable.

Now, each new file and directory within `/web` as well as the existing ones are accessible with read-write permissions to the members of the group *webdev*. In case any errors were made while setting the ACLs, the command `setfacl -Rb /web` would remove any extended ACL so that we can try again!

8.4 Introducing Virtual Hosts

When looking for a particular website, a client requires name resolution either through a DNS query or domain name to IP mapping in `/etc/hosts`. In either case, when a web server hosts multiple websites, they each are configured with a virtual host. Thus, a single httpd process may be managing many virtual hosts, each representing a website.



```
<VirtualHost *:80>
  ServerName
     sales.example.com
  ...
</VirtualHost>
```

```
<VirtualHost *:80>
  ServerName
     accounts.example.com
  ...
</VirtualHost>
```

Figure 8.1: Virtual Hosts

Each of the virtual hosts are configured to run on the same IP address - in this particular process of virtual hosting, called **Name Based Virtual Hosting**. An alternative approach is called *IP based Virtual Hosting*, where each virtual host is configured to use a different IP. However, in our case, all the virtual hosts use the same IP as assigned to the web server. The httpd process on the web server keeps listening on port 80 and the incoming packets are evaluated to determine which host the packet is addressed to, and then forwards it to that host.

8.5 Configuring Virtual Hosts

To add a virtual host, we only need to add a couple of lines to the Apache configuration, and we can do that directly in the main config file `httpd.conf`. While this approach works for a smaller number of virtual hosts, a better option is to create a `.conf` file within the `/etc/httpd/conf.d` directory and add our specifications for the virtual hosts in that file. Let us create two virtual hosts: *sales* and *accounts*, by creating `sales.conf` and `accounts.conf` in the aforementioned directory. The contents of `sales.conf` will be:

```
<Directory /srv/web/sales>
    AllowOverride None
    Require all granted
</Directory>

# Virtual Host settings:
<VirtualHost *:80>
    DocumentRoot /srv/web/sales
    ServerName sales.somuVMnet.local
    ServerAlias salesSite.somuvmnet.local
    ServerAdmin root@sales.somuvmnet.local
    ErrorLog "logs/sales_error_log"
    CustomLog "logs/sales_access_log" combined
</VirtualHost>
```

The first line of the virtual host configuration, `<VirtualHost *:80>` asks the httpd process to listen for incoming connections for this virtual host on **all IPs(*)** instead of any specific IP on the port 80. The ServerAlias provides an alternate name for the server. The ServerAdmin is an email id that the webserver can send automated mail to. The ErrorLog is the location of the error log for this particular virtual host, since we wouldn't want to combine the error logs of several servers! Now, we set up name resolution by either a DNS server or by adding the line `127.0.0.1   sales.somuVMnet.local` to the `/etc/hosts` file. We also add a test web page in the `/srv/web/sales` directory:

```
<html>
    <head>
        <title>Virtual Host Test Page!</title>
    </head>
    <body>
        <h1>Success!</h1>
        <p>Welcome to the sales dept homepage!!</p>
    </body>
</html>
```

Now, finally, we check the syntax of the config files using `httpd -t`. This command is extremely useful because in a live production environment a bad config can bring down the web server as long as httpd refuses to restart. If the syntax is OK, we restart the webserver:

```
# httpd -t
Syntax OK
# systemctl restart httpd
```

Once the above is done (assuming the SELinux context for `/srv/web/sales` has been sorted out), the server should be reachable at *sales.somuVMnet.local*. We confirm using `elinks http://sales.somuVMnet.local`. If anything were to go wrong with the httpd, we could find the error logs for the server at `/var/log/httpd/sales_error_log`.

8.5.1 Warnings

Note that due to the use of the virtual host, the default HTTP configuration that we created for localhost is now non-operational, since the httpd process assumes any and all servers will now be presented as a virtual host.

Another side effect is that if a host can't be found, the httpd process presents the first virtual host that was configured irrespective of what the original query was. This can lead to massive confusion since one bad config can present enormous problems here! Now, httpd loads virtual hosts in an alphabetical order, and thus we can name a file `00-errorHost.conf` and configure it to be a virtual host that shows an error message in perpetuity.

8.5.2 Creating a second virtual host on the same server

Now, for the accounts department virtual host, we may choose to put it in the original DocumentRoot of our server at `/web`. This means the config file for this virtual host won't need a `<Directory>` tag. Thus, the config file for `/etc/httpd/conf.d/accounts.conf` becomes:

```
# Virtual Host settings:
<VirtualHost *:80>
    ServerName accounts.somuVMnet.local
    ServerAlias acc.somuvmnet.local
    ServerAdmin root@accounts.somuvmnet.local
    ErrorLog "logs/acc_error_log"
    CustomLog "logs/acc_access_log" combined
</VirtualHost>
```

We now need to create a web page in `/web/index.html` that contains:

```
<html>
    <head>
        <title>Subdirectory Test Page!</title>
    </head>
    <body>
        <h1>Account Dept</h1>
        <p>You're now visiting accounts dept homepage!</p>
    </body>
</html>
```

We need to configure hostname resolution for the accounts website. So, we add to the `/etc/hosts` files the line: `127.0.0.1 accounts.somuVMnet.local`. Now we recheck the configuration using `httpd -t` and if all is okay, we do `systemctl restart httpd`. At this point, both virtual hosts should be working on the same IP.

8.5.3 IP Based Virtual Hosts

The configuration of IP based virtual hosts isn't much different. The basic criterion is that the web-server must have multiple IPs assigned to it via one/more interfaces. Then, we need only change the host name resolution to the appropriate IPs and change the Virtual Host definition to (assuming a virtual host has an IP of `10.0.0.5`, and we want the server to listen on port `80`):

```
<VirtualHost 10.0.0.5:80>
    ServerName t1.testSite.local
    ServerAdmin webmaster@testSite.local
    ErrorLog "logs/ts_error_log"
    CustomLog "logs/ts_access_log" combined
</VirtualHost>
```

In fact, the virtual hosts may be configured to run on the same IP but listening on different ports.

8.6 Common errors working with Virtual Hosts

Some of the most common errors while working with virtual hosts are:

- No **DocumentRoot** specified for a host (and the host isn't in the *default DocumentRoot* setup in `httpd.conf`).
- Non-default DocumentRoot with a faulty SELinux Security Context label.
- No/Improper name resolution or an error in naming (like trying *example.com* instead of *www.example.com*).

8.6.1 Troubleshooting

The most potent ways to troubleshoot httpd problems are:

- Check the error log (default `/etc/httpd/logs/error_log`).
- Check journald with the command: `journalctl UNIT=httpd.service` [requires that httpd forwards reports to journald].

Chapter 9

Managing Advanced Apache Features

9.1 Setting up Authenticated Web Servers

9.1.1 The HTTPD Manual

The first thing that we're going to do is use `yum -y install httpd-manual` to install the httpd-manual. This package installs a set of local web-pages that serve as a manual for all Apache configurations. Thus, it provides an easy way to look up information and/or commands offline when needed. Once installed, the manual can be browsed from `http://localhost/manual`.

9.1.2 Apache Users for basic Authentication

Let us consider a website with 3 sections: a public space, a private space and an exclusive space for a certain user '*lisa*'. For authentication we need users - and rather than use Linux users, Apache has it's own system to create users. The users and their passwords are stored in password-files, which are created using the `htpasswd` utility that comes bundled with Apache. To create a password and show it on screen, we use `htpasswd -n <username>` and enter the password when prompted:

```
# htpasswd -n somu
New password:
Re-type new password:
somu:$apr1$ejEfs5E7$wzlrLgYWYNKSrG7BQVLIa1
```

However, this is of no use for authentication, since the information isn't stored and Apache can't use it to verify users. Thus, to securely store the password in some passwordfile (that is inaccessible from the internet, so that people can't just *download* it), we choose to store it in `/etc/httpd/htpasswd` with:

```
# htpasswd -c /etc/httpd/htpasswd lisa
New password:
Re-type new password:
Adding password for user lisa
# cat /etc/httpd/htpasswd
lisa:$apr1$pUh9Uxin$zCRJuoWcbkkpDBw04ZaxS0
```

The `-c` option enables the creating of a new password file, or replace (overwrite) an existing one if present. It's very important to only use the -c option for a brand new password file. Every subsequent use should be without any option:

```
# htpasswd /etc/httpd/htpasswd lori
New password:
Re-type new password:
Adding password for user lori
# cat /etc/httpd/htpasswd
lisa:$apr1$r6Xj/zbR$MTFl/9Oq/vcm01.PLue5W0
lori:$apr1$gZ8ZnGGD$q3GL3wpB0T.JTCa2pw/jD0
```

9.1.3 Directory rules in httpd.conf

Now that we have users, we need to add the specifications for the protected directory in the Apache configs, and dictate when the server should ask for a password and which users should be allowed access. The next part of the required config can either be added in `/etc/httpd/conf/httpd.conf` (preferably at the very bottom to maintain organization) or in a seperate `.htaccess` file within the directory whose access it'll control (For this, the `AllowOverride` directive for the directory can't be set to `none`). In either case, the `<Directory>` directives must be defined in the `httpd.conf` file, or any `.conf` file in the `conf.d` directory. Let us assume we've set up a virtual host called *authtest.somuvmnet.local* which will house the files we need. So, the file `/etc/httpd/conf.d/authtest.conf` will contain:

```
# Rules for the directory private and all its subdirs (which have .htaccess files)
<Directory "/var/www/html/authtest/private">
    AllowOverride all
</Directory>
# Virtual host config
<VirtualHost *:80>
    DocumentRoot /var/www/html/authtest
    ServerName     authtest.somuvmnet.local
    ServerAlias      aut.somuvmnet.local
    ServerAlias      aut.svmn.loc
    ServerAdmin    root@aut.somuvmnet.local
    ErrorLog     "logs/aut_error_log"
    CustomLog    "logs/aut_access_log" combined
</VirtualHost>
```

In the next step, either the steps in Section 9.1.4 or 9.1.5 should be followed:

9.1.4 Controlling access via .htaccess files

The final directory structure of our site will look like:

```
# tree -a /var/www/html/authtest
/var/www/html/authtest
├── index.html
└── private
        ├── .htaccess
        ├── index.html
        └── lisaZone
                ├── .htaccess
                └── index.html
```

For example, if we're trying to restrict access to /var/www/html/authtest/private we'll add a new .htaccess file in it, with the contents:

```
AuthType Basic
AuthName "Private Space"
AuthUserFile /etc/httpd/htpasswd
Require valid-user
```

Now, we create a directory /var/www/html/authtest/private/lisaZone and create a .htaccess file within it with the contents:

```
# Only one user (lisa) allowed in lisaZone
AuthType Basic
AuthName "lisaZone"
AuthUserFile /etc/httpd/htpasswd
Require user lisa
```

The above .htaccess files sets up the permissions for two folders: *private* and *private/lisaZone*. While any valid Apache user is allowed in the private directory, only user lisa can enter private/lisaZone, due to the Require user directive.

9.1.5 Controlling access via httpd.conf

If we were to put these settings in httpd.conf instead of .htaccess files in the proper directories, we'd need <Directory> directives to define the location where these'd be applied. The following lines would then need to be added to httpd.conf:

```
<Directory /var/www/html/authtest/private>
    AllowOverride none
    AuthType Basic
    AuthName "Private Space"
    AuthUserFile /etc/httpd/htpasswd
    Require valid-user
</Directory>

<Directory /var/www/html/authtest/private/lisaZone>
    AllowOverride none
    AuthType Basic
    AuthName "lisaZone"
    AuthUserFile /etc/httpd/htpasswd
    Require user lisa
</Directory>
```

Finally, we add the html content for the site.

9.1.6 Adding HTML Content

The /var/www/html/authtest/index.html should contain:

```
<html>
    <head>
        <title>Public Space</title>
    </head>
    <body>
        <h1>Welcome to the public space!</h1>
        <p>This portion of the website should be accessible by all!</p>
        <p>The only reason this page exists is to act as a control page to test the
         ↪   reactions of the private page to the new configs. Regardless, try to click
         ↪   the link below and see if you can actually access it...</p>
        <a href="private/">Click me to Enter the Restricted Area!</a>
    </body>
</html>
```

The /var/www/html/authtest/private/index.html should contain:

```
<html>he \verb|/var/www/html/authtest/private/index.html| should contain:
    <head>
        <title>Private Space</title>
    </head>
    <body>
        <h1>Welcome to the PRIVATE Space</h1>
        <p>This portion of the website should be accessible to only authenticated
         ↪   users</p>
        <p>If you can see this page without authenticating something is wrong with the
         ↪   configs!!!</p>
        <a href="../">Go Back</a>
        <a href="lisaZone/">Go to lisaZone!</a>
    </body>
</html>
```

Finally, the /var/www/html/authtest/private/lisaZone/index.html should contain:

```
<html>
    <head>
        <title>LisaZone -- the ultimate protected space</title>
    </head>
    <body>
        <h1>Welcome to the lisaZone</h1>
        <p>This portion of the website should be accessible to user lisa</p>
        <p>If you can see this page and aren't user LISA, something is wrong with the
         ↪   configs!!!</p>
        <p><a href="../">Go Back to Private Zone</a></p>
        <p><a href="../../">Go Back to Public Zone</a></p>
    </body>
</html>
```

Now our site is ready. So, we need to check the httpd config syntax using `httpd -t`. If the syntax is correct, we restart httpd using `systemctl restart httpd`. Then we visit the website by `elinks http://authtest.somuvmnet.local`. Based on authentication, we should be allowed to access the different parts of the sites.

9.2 Configuring Apache for LDAP Authentication

Manual user creation via `htpasswd` gets cumbersome and inefficient when large sites are concerned. In those cases, we can choose LDAP authentication instead. This, however, doesn't mean that local users and groups have to be omitted from the config.

Let us consider an organization `myorg`. Let it contain a group `mygroup`. We want to restrict access to directory `/www/docs/private` to either Apache or LDAP users and groups. Then, configuration in `/etc/httpd/conf/httpd.conf` will look like:

```
<Directory /www/docs/private>
    AuthType Basic
    AuthName "Private"
    AuthBasicProvider file
    AuthUserFile /usr/local/apache/passwd/passwords
    AuthLDAPURL ldap://ldaphost/o=myorg
    AuthGroupFile /usr/local/apache/passwd/groups
    Requrie group GroupName
    Require ldap-group cn=mygroup,o=myorg
</Directory>
```

Here, we have an order of checking for the users/groups, just like in the case of the Pluggable Authentication Module (PAM). First Apache tries to find the user in the password file. If it can't *then* it checks LDAP.

9.3 Enabling CGI Scripts

On any web server, there might be a requirement for dynamic content. This kind of content is generated by a script using a server side scripting language such as CGI, PHP or even python. Scripts becomes crucial when databases are involved since the scripts often fetch information from a database.

9.3.1 CGI

CGI is an abbreviation for **Common Gateway Interface**. It is a specification for information transfer between a web server (such as Apache) and a CGI program/script. CGI is the oldest standard, and even though it can be used by both PHP and python, it's not optimal. To use CGI, we need to use:

```
ScriptAlias    /cgi-bin/    "/var/www/cgi-bin"
```

The CGI scripts must be executable by the `apache` user and group. There are also a certain file context (`httpd_sys_script_exec_t`) on the directory `/var/www/cgi-bin` which is needed by SELinux to permit the execution of such scripts.

9.3.2 PHP

PHP has been much more common than CGI for quite some time now. For PHP scripting to be enabled, the **mod_php** Apache module must be installed and loaded. This simple act itself adds all the necessary configuration to the http configuration, such as setting:

```
SetHandler    application/x-httpd-php
```

This line ensures that PHP can be run from the Apache web server, and other than the installation of *mod_php* Apache module, no manual intervention is needed by default.

9.3.3 Python

In case of python, the name of the required module is **mod_wsgi**. Then we'd need to define a `WSGIScriptAlias` to redirect to the correct application:

```
WSGIScriptAlias     /myapp/     /srv/myapp/www/myapp.py
```

To connect to a local database, no additional configuration besides that in the script is necessary. However, if the database is a remote database, then certain SELinux booleans need to be set to true. These are: `httpd_can_network_connect_db` and depending on the database we're using, perhaps `httpd_can_network_connect` as well.

9.4 Understanding TLS protected Web Sites

TLS stands for **Transport Layer Security** and it performs data encryption and identity verification to enhance security. For example, if we visit the website of our bank, we would want to ensure that it's indeed the website of the bank that we're visiting and not some other site that some nefarious agent may have copied to steal data.

Further, we'd also want to ensure that the login credentials, or our personal data that the bank holds (such as account numbers or balances) are not being leaked during transit. Both of these features are provided by TLS. The entire basis of TLS are certificates that act as public keys for websites.

9.4.1 Certificate Authorities

The validity of the certificates are guaranteed by a Certificate Authority (CA), who are 3rd party agents who verify that the organization handing out the certificate are the true owner of the server you're about to access. If so, they sign a digital certificate and provide it to them which they can then give to people who're interested in visiting their site. Now, when we communicate with the site, we can by ourselves check whether their credentials match the one on the certificate to determine if we're communicating with the right server.

9.4.2 Self-Signed Certificates

Certificates can be self-signed too. There are mechanisms via which any server can generate it's own certificate and provide/install it on a client's computer. However, we can't be sure if the organization who just provided us the certificate is really who they claim to be. For example, a site impersonating our bank's website may also hand out a TLS Certificate that matches it's signature. Now, unless we involve CAs, there's no way for us to determine which certificate is the genuine one belonging to our bank.

However, for testing environments, a self-signed certificate is good enough, since no actual valuable data is being passed around, and in case of internal networks, attacks such as *man-in-the-middle* attack (which TLS Certs actively protect against) are useless/impractical. However, signed certificates are essential for production due to the concerns noted above.

9.4.3 Asymmetrical Encryption

NOTE: This particular section is **optional** since it deals with a bit of complicated mathematics, and is irrelevant to the RHCE course, and should only be interesting to those who want a glimpse at the inner mechanisms of public-private key encryption.

Cryptography is a branch of mathematics that deals in creating algorithms of functions that can scramble information. Much like a padlock that needs a key, a number (or a set of them) is required to scramble and unscramble this message. Thus, we refer to such a number as a key. The entire basis of cryptography is contingent upon creating messages that are hard to decode without a certain key. As such, there are two possible methods: Symmetric encryption and Asymmetric encryption.

Method of Symmetric Encryption

In the case of symmetric encryption, there is a function *Encrypt* $E_k(m) = f(m, k)$ that takes a message m and encrypts it with a key k. Let this output be a *cypher-text* denote by $E_k(m) = f(m, k) = c$. Now, if this same key can be used to decrypt the message with a function Decrypt $(D_k(c) = f^{-1}(c, k))$ that does the opposite actions of function f, i.e. $D_k(c) = f^{-1}(c, k) = m$, then we've got symmetric cryptography. So, it the rules for symmetric crypto are:

$$E_k(m) = f(m, k) = c \tag{9.1}$$

$$D_k(c) = f^{-1}(c, k) = m \tag{9.2}$$

So, the initiator of the communication simply performs $E_k(m)$ to get the encrypted message e and sends it to the recipient. The recipient, who is also in possession of the key, then performs $D_k(c)$ to obtain the original message m.

The drawback of this form of crypto is that the key must be known to both parties. However, this means that the key itself has to be shared over some means of encryption or risk some 3rd party intercepting the key and gaining access to privileged communication. This problem is so serious that spies in the cold war used to meet up in secret and share encryption/decryption keys in envelopes. Thankfully, we now have a better way.

Method of Asymmetric Encryption

In the case of asymmetric encryption we need two keys, instead of just one: we'll called them a public key (k_p) and private (secret) key (k_s). The encryption function $E_{k_p}(m) = f_1(m, k_p) = c$ now uses the public key (k_p) to encrypt the message, and the decryption function $D_{k_s}(c) = f_2(c, k_s) = m$ uses the private (secret) key (k_s) to decrypt it. So, we have:

$$E_{k_p}(m) = f_1(m, k_p) = c \tag{9.3}$$

$$D_{k_s}(c) = f_2(c, k_s) = m \tag{9.4}$$

The functions E_{k_p} and D_{k_s} are often *one-way* functions which are a special category of functions that produce an output so complex, that the computational power and/or time required to reverse engineer the functions from the given input and output without the key is near zero. Contrastingly, a one-way function is easy to solve: for function $s(i) = i^2$, we get $s(2) = 2^2 = 4$ and we can reverse engineer it to find $s^{-1}(4) = \sqrt{4} = 2$, if we know the input and output, i.e., 2 and 4.

9.4.4 Mathematics of Asymmetrical Encryption

Encryption step

Practically in RSA encryption, the keys are the product of two **gargantuan** prime numbers, while the cypher-text is based on modular arithmetic. Thus, it becomes computationally intensive enough to be declared *practically* impossible to factor the key to generate the original set of prime numbers. An example would be where the encryption (private/secret) key N is the product of two primes p_1 and p_2. We'd also choose another number e such that the result of $((p_1 - 1) \times (p_2 - 1))$ and e are relatively prime, i.e., they don't share a common factor. Then, the encryption function for a message m is:

$$\begin{aligned} E_{k_s}(m) &= m^e(\mod N) && (9.5)\\ &= m^e(\mod (p_1 \times p_2)), \text{ where:} && (9.6)\\ N &= (p_1 \times p_2) && (9.7)\\ 1 &= \text{GCD}(e, (p_1 - 1) \times (p_2 - 1)) && (9.8) \end{aligned}$$

i.e., p_1 and p_2 are relatively prime (when greatest common divisor=1)

Decryption step

In this step, we need yet another number which is the decryption key d such that:

$$\begin{aligned} e \times d &\cong 1 \mod ((p_1 - 1) \times (p_2 - 1)), \text{ i.e.,} && (9.9)\\ 1 &= ed \mod (p_1 - 1)(p_2 - 1) && (9.10) \end{aligned}$$

Due to the above relation, it's so important that N and e be relatively prime! (otherwise, due to the nature of congruity, and due to the many-to-1 mapping of the modulus function's input and output, weird things happen). And the decrypted text, i.e., the original message m is given by:

$$\begin{aligned} D_{k_p}(c) &= c^d(\mod N) && (9.11)\\ &= c^d(\mod (p_1 \times p_2)) && (9.12)\\ &= m && (9.13) \end{aligned}$$

So, the only way to know the decryption number d is to know the numbers p_1 and p_2. Then our **private key** is the set of numbers p_1 and p_2 while the public keys are the set of the numbers N and e:

$$\begin{aligned} \text{Private Key}: k_s &= \{p_1, p_2\} && (9.14)\\ \text{Public Key}: k_p &= \{N, e\} && (9.15) \end{aligned}$$

Since alphanumeric characters can be mapped to their decimal equivalent via ASCII/UTF-8/etc conversion standards, they can be encrypted and decrypted via asymmetrical encryption called public key encryption.

9.4.5 Implications of the Encryption

Due to the nature of these keys, only a message encrypted by a private key can only be decrypted by the proper public key. Thus, utilities like the `ssh-keygen` and `genkey` always generate key-pairs, i.e, both private and public key together. These keys can be used in two ways:

- Encryption for transmission
- Authentication

Since only the message encrypted with the private key can be transformed to form the original message when decrypted with the public key, a person or an organization could convert a pre-determined message (that is expected by the recipient) to cypher-text using their private key. Now, recipient simply decrypts the message with the public key of sender. If the message is as expected, then we know that only the sender could've encrypted it with the private key, since no one else has it, thus verifying his/her/their identity. Both of these properties are used by TLS certificates.

9.5 Setting up TLS protected Web Sites

9.5.1 Generating the TLS Certificate

To generate a TLS certificate, we need the **crypto-utils** package and the **mod_ssl** Apache plugin. So, we execute:

```
# yum -y install crypto-utils mod_ssl
```

Within the crypto-utils package an utility called `genkey` is capable of generating TLS certificates. We launch the TUI for it using:

```
# genkey vmPrime.somuvmnet.local
```

The utility then notifies us that a **key** will be stored in `/etc/pki/tls/private/` location with the file name `vmPrime.somuVMnet.local.key`. This is our private key. The public key is the certificate that we give everyone, and is stored in `/etc/pki/tls/certs/` with the name `vmPrime.somuVMnet.local.crt`. Thus the important things to remember are:

Key type	Location	Name
Private Key	`/etc/pki/tls/private/`	vmPrime.somuVMnet.local.key
Public Key	`/etc/pki/tls/certs/`	vmPrime.somuVMnet.local.crt
Common Path	`/etc/pki/tls/`	
Naming Convention	`<FQDN>.key` **OR** `<FQDN>.crt`	

Next, we're asked about the security level used in the certificates, and the *2048 bits* used are good enough for most purposes. The shorter the key, the faster the response time for the server, but the key is also easier to crack.

Once the key generation is completed, it asks us if we'd like the certificate to be sent to a CA for it to be a signed. Since this is going to be a self-signed certificate, we choose No. Next, we're asked if we'd like to encrypt the private key using a pass-phrase. If we choose to encrypt it, we'll have to enter the pass-phrase (that should be the same for all keys installed on a server installation) every time the web server boots. If left unencrypted, anyone who steals the file from the server can decrypt the communication. Encrypting the private key makes this significantly harder. This should be followed for any real installation. However, for our test, we'll choose not to encrypt.

Next, we're asked for information about the server needed to form its *Distinguished Name (DN)*. While the rest of the information is used for non-technical purposes, the common name is the most important part. The common name must match the server name! Upon choosing "next" the certificate will be generated:

```
# genkey vmPrime.somuVMnet.local
/usr/bin/keyutil -c makecert -g 2048 -s "CN=vmPrime.somuVMnet.local, O=SomuVMnet,
 ↪  L=Bangalore, ST=Karnataka, C=IN" -v 1 -a -z /etc/pki/tls/.rand.2953 -o
 ↪  /etc/pki/tls/certs/vmPrime.somuVMnet.local.crt -k
 ↪  /etc/pki/tls/private/vmPrime.somuVMnet.local.key
cmdstr: makecert

cmd_CreateNewCert
command:  makecert
keysize = 2048 bits
subject = CN=vmPrime.somuVMnet.local, O=SomuVMnet, L=Bangalore, ST=Karnataka, C=IN
valid for 1 months
random seed from /etc/pki/tls/.rand.2953
output will be written to /etc/pki/tls/certs/vmPrime.somuVMnet.local.crt
output key written to /etc/pki/tls/private/vmPrime.somuVMnet.local.key


Generating key. This may take a few moments...

Made a key
Opened tmprequest for writing
/usr/bin/keyutil Copying the cert pointer
Created a certificate
Wrote 1682 bytes of encoded data to /etc/pki/tls/private/vmPrime.somuVMnet.local.key
Wrote the key to:
/etc/pki/tls/private/vmPrime.somuVMnet.local.key
```

We can see that the certificates have been generated with the correct SELinux context label of `cert_t`:

```
# ls -Z /etc/pki/tls/private/vmPrime.somuVMnet.local.key; ls -Z
 ↪  /etc/pki/tls/certs/vmPrime.somuVMnet.local.crt
-r--------. root root unconfined_u:object_r:cert_t:s0
 ↪  /etc/pki/tls/private/vmPrime.somuVMnet.local.key
-rw-r-----. root root unconfined_u:object_r:cert_t:s0
 ↪  /etc/pki/tls/certs/vmPrime.somuVMnet.local.crt
```

9.5.2 Setting up Apache to use the TLS Certificates

The installation of `mod_ssl` creates a configuration file called `/etc/httpd/conf.d/ssl.conf`. The important parameters in this file are:

```
Listen 443 https
```

This instructs the httpd process to listen for incoming https connections on port 443, which is the designated port for HTTPS by default. In this default configuration, the server listens to both port 80 (HTTP) and 443 (HTTPS), but if we really want our server to be secure, we only want to accept incoming HTTPS connections, and thus we should ask the httpd process to refrain from listening on port 80 and the port 80 should be closed. We could setup a virtual host and have it listen only on port 443.

By default this configuration is set to use a file called `localhost.crt` and `localhost.key`. However, we must use our self-signed certificates here, by changing the paths to the correct file paths:

```
SSLCertificateFile /etc/pki/tls/certs/vmPrime.somuVMnet.local.crt
SSLCertificateKeyFile /etc/pki/tls/private/vmPrime.somuVMnet.local.key
```

Now, we can close the file, check the syntax with `httpd -t` and if all is ok, we restart the server using:

```
# systemctl restart httpd
```

Now when we try to visit the site using firefox with the command: `firefox https://localhost`, firefox is going to warn about the fact that the certificate is self-signed, and the fact that localhost doesn't match the CN of the certificate (vmPrime.somuVMnet.local). We can add an exception and move on.

9.5.3 Configuring TLS Certs for Virtual Hosts

While everything else remains the same, the `genkey` utility will need to be invoked with the name of the virtual host itself. Then, on the configuration for the virtual host, the following lines should be added:

```
<VirtualHost *:443>
    ServerName    sales.example.com
    DocumentRoot    /web/sales
    SSLEngine    on
    SSLCertificateFile    /etc/pki/tls/certs/sales.example.com.crt
    SSLCertificateKeyFile    /etc/pki/tls/private/sales.example.com.key
</VirtualHost>
```

Part III

DNS and File Sharing

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Configuring a Cache-only DNS Server

Chapter 11

Configuring NFS File Sharing

Chapter 12

Managing SMB File Sharing

Part IV

Essential Back-end Services

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Setting up an SMTP Server

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