

DNS Rebinding Attack Lab

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1 Introduction

The objective of this lab is two-fold: (1) demonstrate how the DNS rebinding attack works, and (2) help students gain the first-hand experience on how to use the DNS rebinding technique to attack IoT devices. In the setup, we have a simulated IoT device, which can be controlled through a web interface (this is typical for many IoT devices). Many IoT devices do not have a strong protection mechanism, if attackers can directly interact with them, they can easily compromise these devices.

The IoT device simulated in this lab is a thermostat, which controls the room temperature. To successfully set the temperature, the client needs to be able to interact with the IoT server. Since the IoT device is behind the firewall, outside machines cannot interact with the IoT device, and will therefore not be able to control the thermostat. To defeat the firewall protection, the attacking code must get into the internal network first. This is not difficult. Any time when a user from the internal network visits the attacker's website, the attacker's code (JavaScript code) actually runs from the user's browser, and therefore runs inside the protected internal network. However, due to the sandbox protection implemented by browsers, the attacker's code still cannot interact with the IoT device, even though it is now inside the internal network.

The objective of this lab is to use the DNS rebinding attack to circumvent the sandbox protection, so the JavaScript code from the attacker can successfully get the essential information from the IoT device and then use the information to set the temperature of the thermostat to a dangerously high value. This lab covers the following topics:

- DNS server setup
- DNS rebinding attack
- Attacks on IoT devices
- Same Origin Policy

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*, 3rd 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 Background: IoT

Our attack target is an IoT device behind the firewall. We cannot directly access this IoT device from outside. Our goal is to get an inside user to run our JavaScript code, so we can use the DNS rebinding attack to interact with the IoT device.

Many IoT devices have a simple built-in web server, so users can interact with these devices via web APIs. Typically, these IoT devices are protected by a firewall, they cannot be accessed directly from outside. Due to this type of protection, many IoT devices do not implement a strong authentication mechanism. If attackers can find ways to interact with them, they can easily compromise its security.

We emulate such a vulnerable IoT device using a simple web server, which serves two APIs: `password` and `temperature`. The IoT device can set the room temperature. To do that, we need to send out an HTTP request to the server's `temperature` API; the request should include two pieces of data: the target temperature value and a password. The password is a secret that changes periodically, but it can be fetched using the `password` API. Therefore, to successfully set the temperature, users need to first get the password, and then attach the password in the `temperature` API.

The password is not meant for the authentication purpose; it is used to defeat the Cross-Site Request Forgery (CSRF) attack. Without this protection, a simple CSRF attack is sufficient; there is no need to use the more sophisticated DNS rebinding attack. For the sake of simplicity, we hardcoded the password; in real systems, the password will be re-generated periodically.

3 Lab Environment Setup Using Container

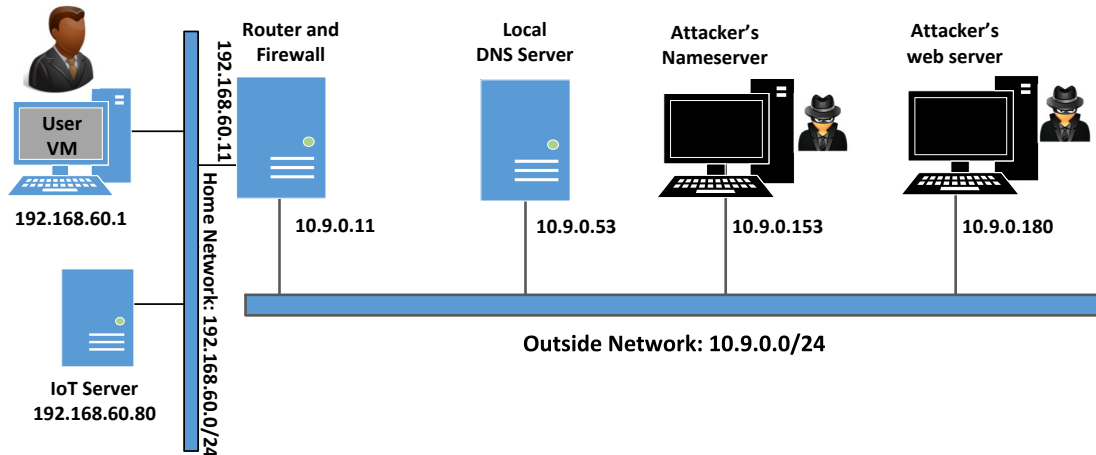


Figure 1: Lab environment setup

In this lab, we will use six machines. The lab environment setup is illustrated in Figure 1. Only the user machine will be using VM, and the others are all containers. In the setup, we have two networks, a home network and an outside network. The home network simulates a typical network at home. The user machine and the IoT services are connected to this network, which is protected by the firewall on the router container. The firewall blocks all traffic going to the `192.168.60.80`. This way, outside machines cannot access the IoT device. We also set up a NAT server on the router, so the machines on the home network can access outside (and the reply packets can come back).

The second network simulates the outside world. In addition to the router, there are three containers

attached to this network, one serving as the local DNS server, and the other two serving as the attacker's nameserver and web server. The attacker owns the `attacker32.com` domain, which is hosted by the attacker's nameserver container. The web server hosts a malicious website used for the attack.

3.1 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
$ dcdown              # 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.

3.2 Configure the User VM

We need to provide further configuration on the user VM.

Step 0. Disable Firefox's DNS over HTTPS. Newer versions of Firefox enable the "DNS over HTTPS" by default. In this mode, the DNS resolution may not go through the local DNS server or the `/etc/hosts` file. This will create issues for this lab. We need to disable it. Go to `Setting`, click the "Privacy & Security" tab; find the "DNS over HTTPS" option, and select off.

Step 1. Reduce Firefox's DNS caching time. To reduce load on DNS servers and to speed up response time, Firefox browser caches DNS results. By default, the cache's expiration time is 60 seconds. That means that our DNS rebinding attack needs to wait for at least 60 seconds. To make our life easier, we reduce the time to 10 seconds or less. Type `about:config` in the URL field. After clicking through a warning page, we will see a list of preference names and their values. Search for `dnsCache`, find the following entry and change its value:

```
network.dnsCacheExpiration: change its value to 10 (default is 60)
```

After making the change, we should exit from the Firefox browser, and restart it; otherwise the change will not take effect.

Step 2. Change `/etc/hosts`. We need to add the following entry to the `/etc/hosts` file. We will use `www.seedIoT32.com` as the name for the IoT server. Its IP address is `192.168.60.80`. We need to use the superuser privilege to modify this file (using `sudo`):

```
192.168.60.80 www.seedIoT32.com
```

While we are in this file, check whether there is any entry that contains `attacker32.com`. Remove them if there is any. These entries may have been added when we worked on other SEED labs, and their existence will cause problems for this lab.

We can now test the IoT server. Point the browser to the following URL on the user VM. If everything is set up correctly, we should be able to see a thermostat. We can also change the temperature setting by dragging the sliding bar. Please provide a screenshot in your lab report.

```
http://www.seedIoT32.com
```

Step 3. Local DNS Server. We need to get the user VM to use a particular local DNS server. This is achieved by setting the local DNS server as the first `nameserver` entry in the resolver configuration file (`/etc/resolv.conf`). One challenge is that the provided VM uses the Dynamic Host Configuration Protocol (DHCP) to obtain network configuration parameters, such as IP address, local DNS server, etc. DHCP clients overwrite the `/etc/resolv.conf` file with the information provided by the DHCP server.

One way to get our information into `/etc/resolv.conf` without worrying about the DHCP is to add the following entry to the `/etc/resolvconf/resolv.conf.d/head` file (`10.9.0.53` is the IP address of the local DNS server in our setup):

```
nameserver 10.9.0.53
```

The content of the head file will be prepended to the dynamically generated resolver configuration file. Normally, this is just a comment line (the comment in `/etc/resolv.conf` comes from this head file). After making the change, we need to run the following command for the change to take effect:

```
$ sudo resolvconf -u
```

3.3 Testing the Lab Setup.

After configuring the user VM, use the `dig` command to get the IP address of `www.attacker32.com` and `ns.attacker32.com`. You should get `10.9.0.180` and `10.9.0.153`, respectively. If you do not get this, your lab environment is not set up correctly.

We can now test the attacker's website. Point the browser to the following URL on the user VM, and you should be able to see the attacker's website. Please provide a screenshot in your lab report.

```
http://www.attacker32.com
```

Note. We may have used the same hostname `www.attacker32.com` in other SEED labs, so it is likely that this name is already mapped to a different IP address. Therefore, if you do not see the expected attacker's website, you should check the `/etc/hosts` file, and remove any entry that contains `attacker32.com`.

4 Launch the Attack on the IoT Device

We are ready to launch the attack on the IoT device. To help students understand how the attack works, we break down the attack into several incremental steps.

4.1 Task 1. Understanding the Same-Origin Policy Protection

In this task, we will do some experiment to understand the same-origin policy protection implemented on browsers. On the user VM, we will browse the following three URLs. It is better to show these three pages on three different Firefox windows (instead of on three different tabs), so they are all visible.

```
URL 1: http://www.seedIoT32.com
URL 2: http://www.seedIoT32.com/change
URL 3: http://www.attacker32.com/change
```

The first page lets us see the current temperature setting of the thermostat (see Figure 2.a); it fetches the temperature value from the IoT server once every second. We should keep this page always visible, so we can see the temperature setting on the thermostat. The second and third pages are identical (see Figure 2.b), except that one comes from the IoT server, and the other comes from the attacker's server. When we click the button on both pages, a request will be sent out to the IoT server to set its temperature. We are supposed to raise the thermostat's temperature to 99 Celsius.

Click the button on the second and third pages, and describe your observation. Which page can successfully set the thermostat's temperature? Please explain why. To find the reason, click the following menu sequence from Firefox. A console window will appear, which displays error messages if any. Hint: the reason is related to the same-origin policy enforced by browsers. Please explain why this policy causes one of the pages to fail.

```
Web Developer -> Web Console
```

4.2 Task 2. Defeat the Same-Origin Policy Protection

From the previous task, it seems impossible to set the thermostat's temperature from the attacker's page, due to the browser's same-origin policy protection. The objective of this task is to defeat such a protection, so we can set the temperature from this page.



Figure 2: The web pages from the three URLs

The main idea for defeating the same origin protection comes from the fact that the policy enforcement is based on the host name, not on the IP address, so as long as we use `www.attacker32.com` in the URL, we are complying with the SOP policy, but that does not mean we are restricted to communicate with the `www.attacker32.com` web server.

Before the user's browser sends out requests to `www.attacker32.com`, it first needs to know the IP address of `www.attacker32.com`. A DNS request will be sent out from the user's machine. If the IP address is not cached at the local DNS server, a DNS request will eventually be sent to `attacker32.com`'s nameserver, which is controlled by the attacker. Therefore, the attacker can decide what to put in the response.

Step 1: Modify the JavaScript code. On the attacker's web server, the JavaScript code running inside the `www.attacker32.com/change` page is stored in the following file: `/app/rebind_server/templates/js/change.js`. Since this page comes from the `www.attacker32.com` server, according to the same-origin policy, it can only interact with the same server. Therefore, we need to change the first line of the code from `http://www.seediot32.com` to the following (we have installed a simple editor called `nano` in the container):

```
let url_prefix = 'http://www.attacker32.com'
```

After making the change, restart the attacker's web server container (see the command below). Then go to the user VM, refresh the page, and click the button again. Do you still see the error message in the web console? Please explain your observation.

```
$ docker ps
...
78359039627a  attacker-www-10.9.0.180

$ docker container restart 7835
```

Step 2: Conduct the DNS rebinding. Our JavaScript code sends requests to `www.attacker32.com`, i.e., the requests will come back to the Attacker's web server. That is not what we want; we want the requests to go to the IoT server. This can be achieved using the DNS rebinding technique. We first map `www.attacker32.com` to the IP address of the attacker's web server, so the user can get the actual page from `http://www.attacker32.com/change`. Before we click on the button on the page, we remap the `www.attacker32.com` hostname to the IP address of the IoT server, so the request triggered by the button will go to the IoT server. That is exactly what we want.

To change the DNS mapping, students can modify the `zone_attacker32.com` file inside attacker's nameserver container. The zone file can be found in the `/etc/bind` folder. The following shows the content of the zone file. The first entry is the default Time-To-Live (TTL) value (seconds) for the response, specifying how long the response can stay in the DNS cache. This value may need to be modified. The following is the content of the zone file:

```
$TTL 1000
@      IN      SOA    ns.attacker32.com. admin.attacker32.com. (
                        2008111001
                        8H
                        2H
                        4W
                        1D)

@      IN      NS     ns.attacker32.com.

@      IN      A      10.9.0.22
www    IN      A      10.9.0.22
ns     IN      A      10.9.0.21
*      IN      A      10.9.0.22
```

After making the changes to the zone file, run the following command to ask the nameserver to reload the revised zone data.

```
# rndc reload attacker32.com
```

Because of the tasks conducted previously, the DNS mapping for the `www.attacker32.com` has already been cached by the local DNS server, it will not expire until 1000 seconds later. To shorten the waiting, students are allowed to clean out the cache using the following command (on the local DNS server). However, this can only be conducted before the attack starts. Once the attack starts, students are not allowed to touch the local DNS server.

```
// Do it on the local DNS server container
# rndc flush
```

If both steps in this task are done correctly, clicking the button on the `change` page from `www.attacker32.com` should be able to change the thermostat's temperature successfully. Please provide evidence in your report to demonstrate your success.

4.3 Task 3. Launch the Attack

In the previous task, the user has to click the button to set the temperature to the dangerously high value. Obviously, it is unlikely that users will do that. In this task, we need to do that automatically. We have already created a web page for that purpose. It can be accessed using the following URL:

```
http://www.attacker32.com
```

Once you have loaded this page into the user VM, you should be able to see a page with a timer, which goes down from 10 to 0. Once it reaches 0, the JavaScript code on this page will send the set-temperature request to `http://www.attacker32.com`, and then reset the timer value to 10. Students need to use the DNS rebinding technique, so once the timer reaches 0, the thermostat's temperature is set to 88 Celsius.

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.