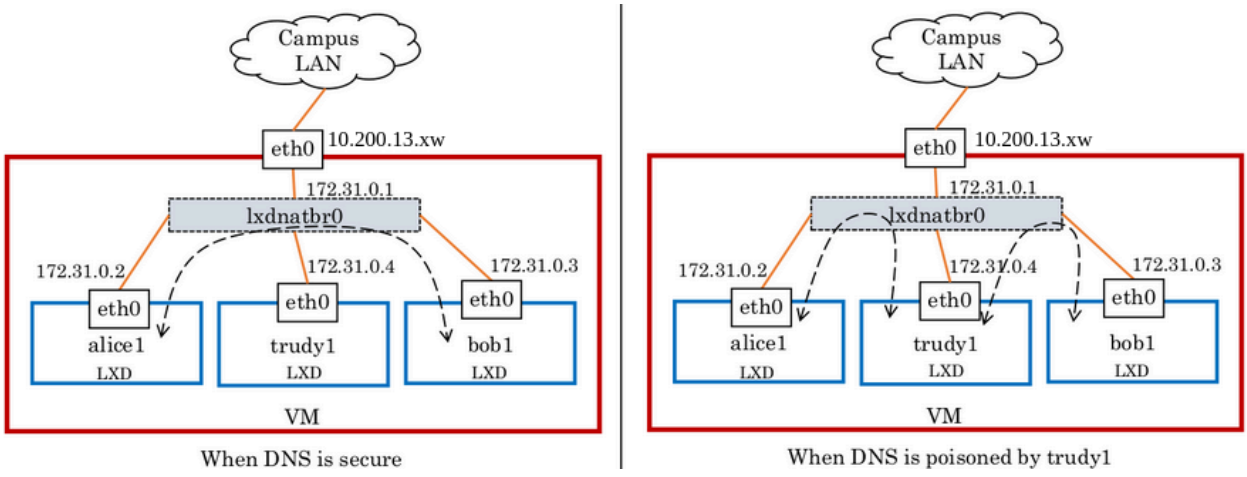
Assignment 7: Secure chat using openssl and MITM attacks

It's a group assignment with Max of 3 students per group playing the roles of Alice/Bob/Trudy! Select a different partner from the ones you paired up with for the other group assignments.

In this programming assignment, your group will implement a secure peer-to-peer chat application using openssl in C/C++ and demonstrate how Alice and Bob could chat with each other using it. Plus you will also implement evil Trudy who is trying to intercept the chat messages between Alice and Bob by launching various MITM attacks.

Setup:

Each group will be given a dedicated QEMU-KVM VM with the IP address (10.200.13.xw) in the CSE dept's over-cloud for completing this assignment. Refer Appendix B for some help on how to work with containers. The VM runs three LXD containers (one LXD container each for Alice, Trudy and Bob in the VM provided by the TAs) which are configured in a star topology i.e., with the switch at the center, Alice, Bob, Trudy are connected to the switch ports. **Make a note of hostnames assigned to Alice, Trudy and Bob from your VM.** DNS is already set up properly so ping using hostnames from Alice to Bob and vice-versa works. Under normal circumstances, Trudy does not come in the traffic forwarding path between Alice and Bob. But when DNS is poisoned by Trudy, all traffic between Alice and Bob is intercepted by Trudy as the MITM attacker. You can also launch a similar MITM attack using ARP cache poisoning.



Please upload ssh public key to your github profile and share your github user-id with TAs to get access to your group's VM through IITH's Wireguard VPN (if you are not on the campus). The three LXDs are reachable from inside the VM, and cannot be reached from the campus LAN.

Task 1: Generate keys and certificates (10M)

Use OpenSSL to create a root CA certificate (Subject name: iTS Root R1, V3 X.509 certificate, self-signed using 512-bit ECC Private Key of the root), an intermediate CA certificate (Subject Name: iTS CA 1R3, V3 X.509 certificate with 4096-bit RSA public key, signed by iTS Root R1), a certificate of Alice (Subject Name: Alice1.com with 1024-bit RSA public key, issued i.e., signed by the intermediate CA, iTS CA 1R3) and a certificate of Bob (Subject Name: Bob1.com with 256-bit ECC public key, issued i.e., signed by the intermediate CA, iTS CA 1R3). Ensure that you provide realistic meta-data while creating these X.509 V3 certificates like values for OU, L, Country, etc of your choice with appropriate key usage/constraints. Save these certificates as root.crt, int.crt, alice.crt and bob.crt, save their CSRs and key-pairs in .pem files and verify that they are valid using openssl. You can complete this task either on the VM provided (recommended) or on your personal machine.

How to communicate among LXDs and between VM and LXD?
You can use the Linux based commands like SCP for transferring the files like CSRs and certs. You have to be sure about the integrity and clearly show that the files transferred are indeed sent by the intended sender and received by the intended receiver. For example, if you send the CSR to the Signing Authority (the Intermediate CA), then the signing authority should be able to verify that it is sent by the intended sender and similarly when receiving the certificate back it should be verified that it is indeed signed and sent by the actual authority. You can use signing and verification concepts applied in the Openssl tutorial for this.

Task 2: Secure Chat App (30M)

Write a peer-to-peer application (`secure_chat_app`) for chatting which uses **DTLS 1.2** and **UDP** as the underlying protocols for secure communication. *Note that the* `secure_chat_app` *works somewhat like HTTPS except that here it's a peer-to-peer paradigm with no reliability where Alice plays the role of the client and Bob plays the role of the server and vice versa*. That means the same program should have different functions for server and client code which can be chosen using command line options "-s" and "-c <serverhostname>" respectively. Feel free to define your own chat headers (if necessary) and add them to the chat payload before giving it to DTLS/UDP. Make sure that your application uses only the hostnames for communication between Alice and Bob but not hard-coded IP addresses (refer `gethostbyname(3)`). The application should perform the following operations:

a) Bob starts the app using "`secure_chat_app -s`" and Alice starts the app using "`secure_chat_app -c bob1`"
b) Alice sends a *chat_hello* application layer control message to Bob and Bob replies with a *chat_ok_reply* message. It works like a handshake between peers at the application layer. Note that these control messages are sent in plain-text. Show that it is indeed the case by capturing Pcap traces at Alice-LXD and Bob-LXD.
c) Alice initiates a secure chat session by sending out a *chat_START_SSL* application layer control message and getting *chat_START_SSL_ACK* from Bob. Your program should then load the respective private keys and certificates for both Alice and Bob.

Furthermore, each of them should have pre-loaded the certificates of the root CA and the intermediate CA in their respective trust stores.

i) For example, if Alice sends a *chat_START_SSL* control message to Bob, upon parsing the message, Bob initiates replies with *chat_START_SSL_ACK.* Upon parsing this ACK from Bob, Alice initiates **DTLS 1.2** handshake by first sending a *client_hello* message as we discussed in the TLS lesson.

ii) Alice gets the certificate of Bob and verifies that. She also provides her certificate to Bob for verification. So, Alice and Bob use their certificates to perform mutual aka two-way authentication.

iii) DTLS 1.2 handshake between Alice and Bob should contain Alice specifying a list of one or more ciphersuites that offer perfect forward secrecy (PFS) as part of client_hello and Bob picking one of them if his application is pre-configured to support any of them. That means, client and server programs should be pre-configured to support PFS cipher suites using openssl API and then they can agree on some common ciphersuite. Make sure your program generates appropriate error messages if a secure connection could not be established due to mismatch in the supported ciphersuites at client and server.

d) Upon establishing a secure DTLS 1.2 pipe, it will be used by Alice and Bob to exchange their encrypted chat messages. Show that it is indeed the case by capturing Pcap traces at Alice-LXD/Bob-LXD.

e) Compare and contrast DTLS 1.2 handshake with that of TLS 1.2 handshake.

f) Your `secure_chat_app` should support session resumption using session tickets. Show that it is indeed the case by capturing Pcap traces at Alice-LXD/Bob-LXD.

g) Either of them sends a *chat_close* message which in turn triggers closure of TLS connection and finally TCP connection.

Since the underlying transport protocol is UDP, messages between Alice and Bob may not get delivered reliably. Use tc command to force some packet loss on the links. Make sure your secure chat application handles loss of the control messages specific to the secure chat application appropriately with timers and retries. Your application does not have to ensure reliable delivery of application DATA (i.e., chat) messages as only fast delivery of chat messages is important.

Task 3: START_SSL downgrade attack for eavesdropping (20M)

Downgrade attack by Trudy by intercepting the chat_START_SSL control message from Alice (Bob) to Bob (Alice).

a) If Alice receives a chat_START_SSL_NOT_SUPPORTED message after sending *chat_START_SSL* to Bob, it assumes that Bob does not have capability to set up secure chat communication.

b) In this attack, Trudy blocks *chat_START_SSL* from reaching Bob and sends a forged reply message *chat_START_SSL_NOT_SUPPORTED* to Alice and thereby forcing Alice and Bob to have unsecure chat communication for successfully intercepting their

communication. Show that it is indeed the case by capturing Pcap traces at Trudy/Alice/Bob LXDs.

c) You need to write a program (`secure_chat_interceptor`) to launch this downgrade attack (`-d` command line option) from Trudy-LXD. For this task, you can assume that Trudy poisoned the /etc/hosts file of Alice (Bob) and replaced the IP address of Bob (Alice) with that of her. It's a kind of DNS spoofing for launching MITM attacks. In this attack, Trudy only plays with *chat_START_SSL* message(s) and forwards the rest of the traffic as it is i.e., eavesdropper.
   To poison /etc/hosts file of Alice and Bob containers, use the following command from inside the VM
   `bash ~/poison-dns-alice1-bob1.sh`
   To revert back the /etc/hosts file of Alice, Bob containers, use the following command from inside the VM.
   `bash ~/unpoison-dns-alice1-bob1.sh`
   To start a downgrade attack, start the secure chat interceptor program using the following command from inside the Trudy LXD.
   `./secure_chat_interceptor -d alice1 bob1`

Task 4: Active MITM attack for tampering chat messages and dropping DTLS handshake messages (40M)

Active MITM attack by Trudy to tamper the chat communication between Alice and Bob. For this task also, you can assume that Trudy poisoned the /etc/hosts file of Alice (Bob) and replaced the IP address of Bob (Alice) with that of her.

a) Also assume that Trudy hacks into the server of the intermediate CA and issues fake/shadow certificates for Alice and Bob. Save these fake certificates as fakealice.crt and fakebob.crt, save their CSRs and key-pairs in .pem files and verify that they are indeed valid using openssl!
b) Rather than launching the START_SSL downgrade attack, in this attack Trudy sends the fake certificate of Bob when Alice sends a client_hello message and vice versa. This certificate is indeed signed by the trusted intermediate CA, so its verification succeeds at Alice. So, two DTLS 1.2 pipes are set up: one between Alice and Trudy; the other between Trudy and Bob. Trudy is now like a malicious intercepting proxy who can decrypt messages from Alice to Bob (and from Bob to Alice) and re-encrypt them as-it-is or by altering message contents as she desires! Show that it is indeed the case by capturing Pcaps at Trudy/Alice/Bob LXDs.
c) Modify the secure_chat_interceptor program to launch this active MITM attack from Trudy-LXD, name it as secure_chat_active_interceptor
   To start the MITM attack, start the secure chat interceptor program using the following command from inside the Trudy LXD.
   `./secure_chat_active_interceptor -m alice1 bob1`

Since the underlying transport protocol is UDP, DTLS handshake messages between Alice and

Bob may get lost sometime. Does your secure application have to implement any reliable data transfer mechanism for exchanging DTLS handshake messages in a reliable manner? Explain by obtaining a Pcap trace (screenshot of wireshark) in the presence of packet loss for DTLS messages using tc command on the links.

Task V: Optional

Bonus Marks (25 M): In this assignment, you emulated DNS poisoning by running `poison-dns-alice1-bob1.sh script` written by TAs to manipulate the entries in the /etc/hosts file. **Instead you need to implement one of the following to get the bonus marks:**

1. You need to first ensure that Alice/Bob sends DNS queries (over UDP) to a local resolver which in turn contacts an emulated DNS infra (root servers and Authoritative Name servers) and gets DNS response. Trudy tampers these responses so that the DNS cache of the resolver is poisoned.
2. ARP cache poisoning where Trudy sends gratuitous fake ARP messages to Alice/Bob. Refer this assignment https://seedsecuritylabs.org/Labs_20.04/Networking/ARP_Attack/ for launching this real MITM attack in your set up.

When you build the tar file with filename as <RollNoX|RollNoY|RollNoZ>.tgz, have separate subfolders for Alice, Bob, Trudy and the data (i.e., the certificates, keys, pcaps, etc). Each of Alice/Bob/Trudy folders should have their own Makefiles with the targets described in README instructions file.

The assignment will be evaluated by the TAs on a scheduled date and time. Make sure your demo works without any glitches and be prepared for viva.

1st Due Date for Tasks 1&2: March 17th

2nd Due Date for Tasks 3&4: April 10th

Late Submission Policy: 20% penalty for each late day.

Deliverables in GC as a tar ball:

- **Readable Report cum Design Document enumerating steps followed with screenshots for each of the important steps for tasks 1-4. (10M)**
    - **Details of your chat protocol like its headers and typical message flow. For example, HTTP uses GET/POST/OK methods for message flow between client and server.**
    - **Details on how various MITM attacks are realized by Trudy, tc is used to inject packet loss and how packet loss is tackled for application layer chat messages and DTLS handshake messages.**

- **Credit Statement (1-pager): share an accurate and detailed description of each of the group member's contributions to the assignment in terms of coding, report writing, documentation, bug fixes, etc.**

The report should be self sufficient to understand what your group has done. You can add screenshots to show the working of the system. All the tools and softwares used should be mentioned with references. Reports should also list the important code snippets with explanations. Simply attaching code without any explanation will not fetch any credits.

- **Video clip(s) (e.g., screen recording with voice over of all of the teammates) demonstrating how your application works in various scenarios. Submit these finally after completing all the tasks. (10M)**
- **README file, Pcap traces collected with appropriate names and all Source code (well documented like in GitHub - openssl/openssl: TLS/SSL and crypto library), keys, certificates, etc in appropriate folders. Submit this for both 1st and 2nd deadlines. (10M)**

ANTI-PLAGIARISM STATEMENT <Include it in your report>

We certify that this assignment/report is our own work, based on our personal study and/or research and that we have acknowledged all material and sources used in its preparation, whether they be books, articles, packages, datasets, reports, lecture notes, and any other kind of document, electronic or personal communication. We also certify that this assignment/report has not previously been submitted for assessment/project in any other course lab, except where specific permission has been granted from all course instructors involved, or at any other time in this course, and that we have not copied in part or whole or otherwise plagiarized the work of other students and/or persons. We pledge to uphold the principles of honesty and responsibility at CSE@IITH. In addition, We understand my responsibility to report honor violations by other students if we become aware of it.

Names:
Date:
Signature: <keep your initials here>

References:

1. OpenSSL Cookbook: Chapter 1. OpenSSL Command Line (feistyduck.com)
2. /docs/man1.1.1/man3/index.html (openssl.org)
3. OpenSSL client and server from scratch, part 1 – Arthur O'Dwyer – Stuff mostly about C++ (quuxplusone.github.io)
4. ssl — TLS/SSL wrapper for socket objects — Python 3.9.2 documentation
5. Secure programming with the OpenSSL API – IBM Developer
6. Simple TLS Server - OpenSSLWiki
7. The /etc/hosts file (tldp.org)
8. PowerPoint Presentation (owasp.org)

9. [SEED Project (seedsecuritylabs.org)]

Appendix: Some help regarding the setup

- To login to the VM allocated, type **`ssh ns@10.200.13.xw`** command.
- To list out the containers inside the VM, use **`lxc ls`** command from inside the VM.
- To login to a container, use **`lxc exec <containername> bash`** command from inside the VM.
- To logout from the respective container use **`exit`** command.
- To capture packet traces inside a container (eg. trudy1), use **`lxc exec trudy1 -- sudo tcpdump -i eth1 -nn not tcp port 22`**
- Root file-system of a container (eg alice1) is located as a subtree under its storage pool **`/var/snap/lxd/common/lxd/storage-pools/default/containers/alice1/rootfs`**
- To copy files from local system to remote system:
  `scp <filename> root@<destination-ip>:~/`
  To copy files from remote system to local system
  `scp root@<source-ip>:~/<filename> .`

- **To create a new container:**
  lxc init -p default-profile ubuntu:20.04 <CONTAINER_NAME>
- **To start container:**
  lxc start <CONTAINER_NAME>

  Note: You can configure it to autostart using this command:
  lxc config set <CONTAINER_NAME> boot.autostart true