Computer Security
Coursework Exercise 2

January 20, 2020

In this coursework we will touch upon a number of topics related to both defense and attack of components that interact with security-critical parts of users' workflow. The deadline is 6 March 2020, 16:00.

1 Asymmetric Encryption with GPG

In this section you will learn to use GPG for day-to-day usage, most importantly including signing and verifying signatures. You will also have to prove your knowledge by solving a challenge. GPG (sometimes written as GnuPG) is the GNU Privacy Guard. GPG is an open source implementation of the OpenPGP standard for asymmetric encryption.

1.1 Introduction to GPG

The purpose of this part is to familiarise yourself with the GPG tool. You will see how to receive the public keys of other people and use them for encryption and signature verification. You will also learn how to generate private keys and use them for signing and decryption. The instructions that follow are specific for DICE machines, but should work on any Linux machine with slight variations. They should also work on MacOS machines with minimal adaptation. There exist some ports of GPG for Windows, but they are not supported in this coursework.

1.1.1 Verifying Signatures

Verifying the integrity of software you download is important to ensure that your software hasn't been tampered with. This section will show you how to verify signatures if they are available. Your task is to download the Alpine Linux mini root filesystem armv7[1] and the corresponding signature[2] and verify it. Save the contents of the second link to a file. You should place both files in the same directory. The names of the files are important: the signature must have the same name as the file it signs, with the added extension '`.asc`'.

Before you can verify the signature however, you need to import the public key which was used to make it. These are also available from the Alpine Linux download page[3]. The fingerprint of the signing public key is `0482 D840 22F5 2DF1 C4E7 CD43 293A CD09 07D9 495A`. More on what a fingerprint is later. To receive the public key, execute:

```
gpg --recv-key '0482 D840 22F5 2DF1 C4E7 CD43 293A CD09 07D9 495A'
```

This could take a while. You should see a report of the key which was imported. Next, to verify the file itself, go to the directory where you downloaded the files and run:

```
gpg --verify alpine-minirootfs-3.11.3-armv7.tar.gz.asc
```

[1]`http://dl-cdn.alpinelinux.org/alpine/v3.11/releases/armv7/alpine-minirootfs-3.11.3-armv7.tar.gz`

[2]`http://dl-cdn.alpinelinux.org/alpine/v3.11/releases/armv7/alpine-minirootfs-3.11.3-armv7.tar.gz.asc`

[3]`https://alpinelinux.org/downloads/`

You should see a line stating '`Good signature from <person>`'. This indicates that the signature is valid, and that you have the signer's public key. You will also see a rather scary-looking warning, which indicates that you haven't assigned the public key a trust level. Proper GPG usage recommends to verify your correspondents' keys by checking their fingerprint and subsequently signing their key and setting your trust level towards them, however we will not focus on it here.

Keep in mind that the aforementioned steps do not rule out completely the possibility of a Man in the Middle attack. An attacker could hijack the legitimate site, replace the original public keys with his own, put a backdoor in the provided source code and sign it with his key. GPG itself can only rule out such attacks if you have out-of-band reasons to trust the validity of the provided fingerprint. Such an out-of-band reason is the acknowledgement that the website itself is valid through TLS security.

1.1.2 Generating a Keypair

In order to sign or receive encrypted messages, you will need your own key pair. To generate one, run:

```
gpg --gen-key
```
[4]

Complete the command line dialogue, and wait for the key to be generated. The default option for key type (RSA both for encrypting and signing) is sufficient. Note that, after the key generation phase, the underlying algorithms are handled by gpg under the hood, so you should never run into problems because of the key type of others. A key length of 4096 and an expiration date after one year are recommended, and the comment field should be left empty. Note that it is **highly** recommended to secure the key with a strong passphrase. Your private key is your digital identity, do not treat it lightly.

1.1.3 Key IDs

Many commands in GPG need to identify the key to use. The public keys available can be listed with the command '`gpg -k`', and the private keys with '`gpg -K`'. Each key is associated with a long (160 bits) hexadecimal ID, which can be used to refer to it, known as the fingerprint of the key. Add the option '`--fingerprint`' to the previous commands to display it. More conveniently, keys can also be referred to by their email address.

1.1.4 Key Management

Once you've generated a key, there are a few maintenance operations you may need to do from time to time.

1. Upload your public key to the keyserver at '`hkp://keys.gnupg.net`'. You will have to set the '`keyserver`' option in '`~/.gnupg/gpg.conf`', and then run '`gpg --send-keys <Key ID>`'.

2. Make sure you can receive a coursemate's public key. After they have uploaded theirs, run '`gpg --recv-keys <Key ID>`'. You may have to wait a few minutes for their key to propagate before receiving it. Note that in this situation, the key ID *must* be the full fingerprint; an email address does not suffice.

3. Generate a revocation certificate for your key, using the command '`gpg --gen-revoke <Key ID>`'. A revocation certificate can be used to invalidate your key pair. This is not something you want to do right now, however it is helpful to know what to do. The revocation certificate can be imported with '`gpg --import`', similarly to keys. The (now revoked) public key can then be pushed to a keyserver. This may be useful if you want to stop using the particular email address or your private key has leaked.

4. You can export your keys with the command '`gpg --export > gpg.keys`'. This will create a binary file 'gpg.keys', containing all public keys in your database. It is also possible to export private keys, using the command '`gpg --export-secret-keys > gpg_private.keys`'. When exported in this way, the keys are still encrypted with your passphrase.

[4] On a DICE machine, you will first have to issue the command `gpg-agent --daemon --no-use-standard-socket` and then execute the command that is returned in order for the key generation to function properly.

1.1.5 Signing Messages

GPG signatures operate on files. The most basic way to sign a file is to execute '`gpg -b <file>`'. This will create a new file, called '`<file>.sig`', which contains the signature of the file with your private key. Adding the `-a` option will force the signature to be generated in an ASCII format, making it more convenient for embedding.

It is also possible to package the data together with the signature, by running '`gpg -s <file>`'. This is typically used in conjunction with encryption.

1.1.6 Encrypting and Decrypting Messages

To encrypt a message, double check that you have a coursemate's public key. Create a plain text file containing your message, and then encrypt it with '`gpg -e <file>`'. Send the newly created file to your coursemate. The same command can also be run with the `-s` option, to also sign the message, and the `-a` option to create an ascii-formatted message.

Hopefully you will have received an encrypted message from one of your coursemates. If not, ask someone to send you one. To decrypt the message, simply run '`gpg -d <file>`'.

1.2 Encrypted email exercise

In this exercise you will have to prove your ability to encrypt and decrypt messages correctly. This is the only marked exercise in the GPG section. The submission steps of this exercise should be completed while logged in on `lute`. Thus, before you start this exercise, ensure that you are logged in on `lute` or run "`ssh <uun>@lute.inf.ed.ac.uk`" and provide your passphrase if you are logged in on any other DICE machine.

1. Generate a private key if you don't already have one and upload it to the keyserver as explained above[5].
2. Submit a file named exactly '`fingerprint`' containing *only* your fingerprint to the Computer Security, Coursework 2 directory (`cs cw2`) using the `submit` DICE tool.
3. You will receive through email the challenge, encrypted with the public key corresponding to the fingerprint you uploaded. Decrypt it and solve the challenge.
4. Receive the key with fingerprint `55B6 5280 76FC 8B3A B21E 8FC7 FC43 FBAF BA4D 2929`[6].
5. Create a file containing *only* the answer and encrypt it using the public key that you just received. Use the GPG option '`-o solution`' when encrypting to create the encrypted file with the name '`solution`'.
6. Submit the encrypted answer as a file named exactly '`solution`'. If the answer is correct, you will receive a confirmation email.

2 Spoofing email sender

For this exercise, you will send us an email with a spoofed email sender field:

- The subject line of your email should be your student id
- The sender of your email should be `luke.skywalker@starwars.com`
- You will send your email to `cw-2@ed.ac.uk`.

One way of doing this is by using the `mailx` utility program. You are free to try this amongst yourselves before you actually send your email to us.

[5]The key does not necessarily have to be tied with your student email account, but you will have to have access to your student email account in order to complete the exercise.

[6]The corresponding email address is fake, therefore sending anything there is pointless.

3 Password Cracking

This question will involve (partially) cracking a list of hashed passwords. The password lists are based on the 2009 RockYou password leaks. The files `rockyou-samples.md5.txt`, `rockyou-samples.sha1-salt.txt`, and `rockyou-samples.bcrypt.txt` store 100,000 password hashes each. These files can be found on DICE in the `/afs/inf.ed.ac.uk/group/teaching/compsec/cw2/password-cracking/` directory. Each function is progressively more resistant to password cracking than the previous one.

3.1 Brute-forcing MD5

The file `rockyou-samples.md5.txt` contains MD5 hashes of passwords, encoded in hexadecimal. Write a program in a programming language of your choice, which brute forces all five character passwords, using only numbers and lowercase ASCII letters (0-9 and a-z). The program should create an output file `md5-cracked.txt` which contains the passwords corresponding to the hashes in rockyou-samples.md5.txt and the number of occurrences for each of them. As the output format, keep one entry per line, with each entry being of the form *`n,password`* (E.g. `10,apples`). Submit the file `md5-cracked.txt`.

Be aware that the naive implementation of brute forcing will not be sufficient here. You will need to check each possible password against all hashes very quickly, it is therefore strongly advised to use hashmaps (or, even better, multisets).

3.2 Cracking Common Passwords with Salted SHA-1

The file `rockyou-samples.sha1-salt.txt` contains SHA-1 hashes of passwords with a salt. The format of each line is `$SHA1p$`salt`$`hash, where:

$$\mathsf{hash} = \mathsf{SHA\text{-}1}(\mathsf{salt} \mid\mid \mathsf{password})$$

The approach to brute-forcing from Part 1 can't be used in this case, as there is no fast way to check a given password against the entire list. Instead, write a program which tries the 25 most common passwords against the entire list, and reports how often each occurred (in the same format at in part 1). The 25 most common passwords are:

123456	12345	123456789	password	iloveyou
princess	1234567	rockyou	12345678	abc123
nicole	daniel	babygirl	monkey	lovely
jessica	654321	michael	ashley	qwerty
111111	iloveu	000000	michelle	tigger

Save your results in the same format as in Part 1, as the file `salt-cracked.txt`. Submit this file.

3.3 Cracking bcrypt?

The file `rockyou-samples.bcrypt.txt` contains bcrypt hashes of passwords. Bcrypt is a more modern hash function designed for use with passwords. Its primary feature is that a bcrypt hash is (comparatively) slower to compute, making brute force attacks far less effective than with the extremely efficient SHA-1 and MD5 hashes. The bcrypt hashes are stored in a standard format for bcrypt, and should be recognized by a bcrypt library of your choice. The hashes further automatically include a salt.

Write a program that finds the first five occurrences of the password `123456` by line number (counting from 1). Write each line number, in order, on a single line of the file `bcrypt-lines.txt`. Submit this file.

4 (wo)Man in the Middle Attack

You are asked to mount a (wo)Man-in-the-Middle (MitM) attack against the toy implementation of an encrypted chat between terminals provided in `/afs/inf.ed.ac.uk/group/teaching/compsec/cw2/mitm/`.

4.1 High-level overview

When Alice and Bob hear about encryption, they immediately set out to implement an encrypted chat client so that they are sure no one eavesdrops their intimate discussions. They decide to use AES[7] to encrypt their messages, since everyone says it's the best. They also hear of the Diffie-Hellman key exchange[8] (DHKE) and figure it would be cool to use a new secret key for AES every time they connect.

4.1.1 AES

Just like every symmetric encryption scheme, AES consists of two algorithms:

- The encryption algorithm takes a key K_1 and a message M_1 as input and returns a ciphertext C_1 as output: $C_1 = Enc(K_1, M_1)$
- The decryption algorithm takes a key K_2 and a ciphertext C_2 as input and returns a message M_2 as output: $M_2 = Dec(K_2, M_2)$

If a message M is encrypted with key K and the resulting ciphertext C is decrypted with the same key K, the result of the decryption will be the original message M: $\forall K \forall M, M = Dec(K, Enc(K, M))$

A simple library for encrypting and decrypting using `pyaes` is provided in `symmetric.py`.

4.1.2 Diffie-Hellman Key Exchange

This is a protocol between two parties (say Alice and Bob) that want to obtain a common key that is unknown to anybody else. Their communication takes place over an insecure channel that anyone can eavesdrop.

A physical-world equivalent is the following: A group of people sit around a table and two of them want to speak in private. They can have a brief exchange (of very long numbers) *which everybody hears*. After that they will possess a common secret *that no one else knows*. They can use this secret as the key for encrypting, sending and decrypting private messages in plain sight.

We assume that both parties have agreed beforehand on a finite cyclic group G and a generator g of G. For production software, these parameters are standardised by cryptographers and hardcoded in the implementation by the developers.

These are the steps of the protocol:

- Alice chooses a random number x and calculates $a = g^x$.
- Alice sends a to Bob.
- Bob chooses a random number y and calculates $b = g^y$.
- Bob sends b to Alice.
  - Now all eavesdroppers know a and b, but not x and y.
- Alice derives the common secret b^x.
- Bob derives the common secret a^y.

Given that $(g^x)^y = (g^y)^x$, both Alice and Bob have derived the same common secret. Assuming that an eavesdropper cannot find x from a or y from b, we conclude that no one else can derive the common secret.

A simple library for doing the necessary steps of DHKE is provided in `diffie_hellman.py`. You can see how to use it in the `do_Diffie_Hellman()` function in `util.py`.

[7]`https://en.wikipedia.org/wiki/Advanced_Encryption_Standard`
[8]`https://en.wikipedia.org/wiki/Diffie%E2%80%93Hellman_key_exchange`

4.1.3 Putting it all together

The entire process of chatting is then as follows:

1. Alice and Bob establish a communication socket
2. They do DHKE over this socket
3. Bob encrypts his message under the derived key (with AES)
4. Bob sends the resulting ciphertext through the socket
5. Alice decrypts the ciphertext using the derived key
6. Alice reads the message

Steps 3–6 can be repeated as many times as desired, possibly with changed roles. (In our implementation, the process is repeated only twice, so Bob sends first, then Alice, then both parties terminate.)

4.1.4 MitM attack

The described approach sounds very reasonable. Unfortunately Alice and Bob overlooked a fatal flaw: When communicating over the internet (or even locally), one cannot know with certainty that they are speaking to the intended party, at least not without using some form of cryptographic *authentication*[9].

Going back to our round-table example, consider the case where every member of the group wears a different mask, uses a voice jammer and sits at random seats. Alice would be unable to recognize Bob. In an even worse scenario, if Bob happens to be missing from the table, someone with a good disguise could impersonate him and fool Alice into performing DHKE with him. This is why Alice and Bob should have agreed to only speak to each other after authenticating themselves.

Given that no authentication takes place, Eve the attacker is now able to do the following: After Bob opens his end of the socket and before Alice connects, Eve connects and performs a DHKE with Bob. Eve then opens a new socket and waits for Alice to connect. When Alice and Eve connect, they perform another DHKE. Now Eve can decrypt messages from one party, read them and reencrypt them for the other party. If she so wishes she can even send arbitrary messages, completely unrelated to the original ones. In short, she has complete control of the channel while Alice and Bob think they communicate with each other privately.

4.2 Implementation details

4.2.1 How to use the provided code

Open two terminals and navigate to the directory with the scripts. First run `python3 bob.py` in one and then `python3 alice.py` in the other (the order is important). You should see secure channel establishment, a couple of messages being exchanged and finally the channel closing.

4.3 Code overview

Open both aforementioned scripts with your favourite editor. Each of the two scripts calls `setup()` with its name and the name of the pre-agreed buffer file over which communication happens. This name is set in `const.py`. Then Bob waits for a message, while Alice sends it. Bob then prints the message and the roles are reversed. Finally both parties close their sockets.

Familiarise yourself with the scripts and understand which lines correspond to each of the steps above. You can optionally dive in the code of the various supporting sources as well.

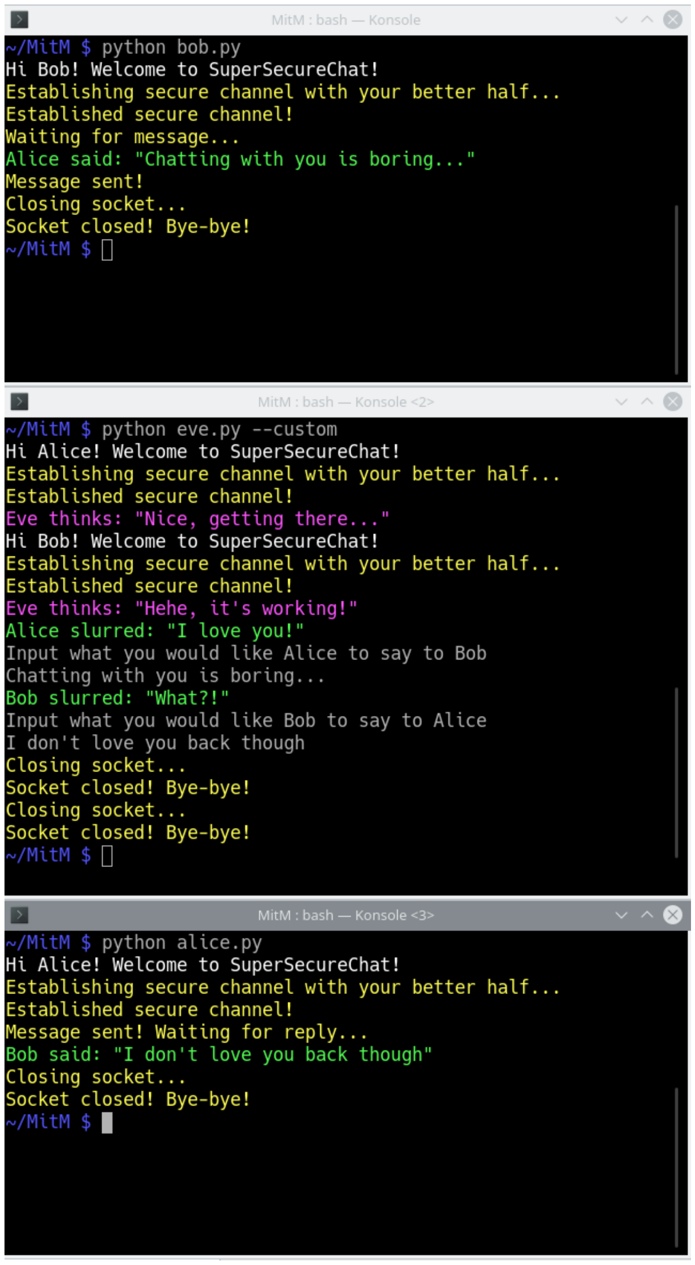
[9] `https://en.wikipedia.org/wiki/Message_authentication_code`

4.4 Exercise

You will have to implement and submit `eve.py` (`submit cs mitm eve.py`). The attack should execute correctly when first `bob.py` is started in one terminal, then `eve.py` in a second and last `alice.py` in a third. `eve.py` should be followed by exactly one of the following three flags: `--relay`, `--break-heart` or `--custom`.

- If the flag is `--relay`, Eve should just relay the two messages from Bob to Alice and from Alice to Bob. In this case, the outputs of both `alice.py` and `bob.py` in the terminals should be identical to the case when the MitM attack isn't executed.
- With the `--break-heart` flag, Eve should change the messages so that Bob receives the message "`I hate you!`" and Alice receives "`You broke my heart...`". Remember, Eve still has to encrypt both messages correctly.
- As for the `--custom` flag, after receiving Alice's messsage, Eve must prompt the user to input a message to the terminal and then must send this message to Bob instead. The same should happen for Bob's message; Eve must prompt the user for a second message and this time send it to Alice.

Hint: Your solution will have to use the buffer file somehow. The function `os.rename()` will prove helpful.
Note: It may happen that a script dies without closing its socket gracefully. In that case, you should manually remove the remaining buffer file (by default called `buffer`) before restarting the scripts.



```
~/MitM $ python bob.py
Hi Bob! Welcome to SuperSecureChat!
Establishing secure channel with your better half...
Established secure channel!
Waiting for message...
Alice said: "Chatting with you is boring..."
Message sent!
Closing socket...
Socket closed! Bye-bye!
~/MitM $
```

```
~/MitM $ python eve.py --custom
Hi Alice! Welcome to SuperSecureChat!
Establishing secure channel with your better half...
Established secure channel!
Eve thinks: "Nice, getting there..."
Hi Bob! Welcome to SuperSecureChat!
Establishing secure channel with your better half...
Established secure channel!
Eve thinks: "Hehe, it's working!"
Alice slurred: "I love you!"
Input what you would like Alice to say to Bob
Chatting with you is boring...
Bob slurred: "What?!"
Input what you would like Bob to say to Alice
I don't love you back though
Closing socket...
Socket closed! Bye-bye!
Closing socket...
Socket closed! Bye-bye!
~/MitM $
```

```
~/MitM $ python alice.py
Hi Alice! Welcome to SuperSecureChat!
Establishing secure channel with your better half...
Established secure channel!
Message sent! Waiting for reply...
Bob said: "I don't love you back though"
Closing socket...
Socket closed! Bye-bye!
~/MitM $
```

Figure 1: The output of your `eve.py` does not have to match the example, but that of `alice.py` and `bob.py` have to.