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Design and Implementation of an Alternative to SSH

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Abstract

As Secure Shell (SSH) is an old application that has loads of features. Not all of those features are used in everyday business. In this thesis a simpler protocol prototype that can do the same as SSH was designed and implemented. The developed solution can replace SSH in its core feature: Connecting to a shell on a remote system.

This project developed an application called "oh-my-gosh" that is capable of the same core functionality that SSH provides. This includes a client application called "gosh" and a server counterpart with the name "goshd". The latter was designed to be run as a background process on a Linux system. This solution uses a secure connection as channel to provide more safety in the entire process. A user can authenticate itself on the remote system either via a password or using public key cryptography. All the usual work flows are possible on the shell such as:

- Navigating through the file system
- Running scripts and applications
- Using applications that use *ncurses(3X)* (2019)

The solution relies on a number of Unix specific technologies like pseudoterminals (ptys) and Pluggable Authentication Module (PAM), which is used in *login(1)* (2012) as well, to realize its use cases.

Preface

The SSH protocol (Moorer 1971, Bider & Baushke 2012, Baushke 2017, Bider 2018*a*,*b*) is a system that allows a user to log in on a remote machine and perform tasks on that remote machine via a Command Line Interface (CLI). SSH is widely known and used in everyday tasks. However: It is now over twelve years old in its current form. One of the problems with SSH is its complexity, both in the initial phase when key material is exchanged, but also later, for example because the server-side has to solve whether to return a character that has been sent to it or not (echo).

The goal of this work is a radically simplified protocol, which in its functions is similar to SSH (N.B. the similarity concerns the functions, not necessarily the protocol details). I develop the protocol, as well as a client and a server - all in the Go/Golang programming language (Go). I demonstrate that the software can replace SSH by showing that it can handle several common use cases, among them:

- Interactive session
- `Rsync` with my solution as transport protocol

This bachelor thesis was proposed by Dr. Stephan Neuhaus (Neuhaus 2018) and aroused my interest as it is a challenge in the domain of information security and will produce a palpable result.

On this note I would like to thank Dr. Stephan Neuhaus for helping me along the way of this Bachelors thesis.

As an additional remark, I would like to point out that the team for this Bachelors thesis originally consisted of two people, but after some months of uncertainty, Mr Schwarz decided to opt out of the project as he said he underestimated the workload from the modules he booked on top of the Bachelors thesis. This happened halfway through the project and had great impact on the project itself: The expected work from him had to be done by me, Raphael Emberger. This also meant less time for designing and implementing all the features described in the tasks (see 1.4). Fortunately Dr. Neuhaus adapted those to fit a one-man project.

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1. Introduction

There was no thesis done on this subject that could have been used as reference. There are however several software projects that deal with a similar problem.

1.1. OpenSSH

The most noteworthy work to mention is of course SSH itself. *OpenSSH* (1999) is the name of the open source project which provides millions of administrators and developers with the ability to securely connect to a remote host. It replaces the up until then widely used protocols like *telnet(1)* (1994) (see 1.2) and *rlogin(1)* (1999)/*rsh(1)* (1999) (see 1.3).

SSH uses an own protocol to secure the communication channel between two peers and has earned itself a spot on the low end of the port table: It occupies port 22.

SSH's features can be used very flexibly: After it builds up a secure connection between a client and a server, it can be used to remotely log in and use a terminal on that machine. It can also forward traffic on local ports to the remote host through the secure channel. This is also used by third party programs such as *rsync(1)* (2018).

When it comes to the log in procedure itself, SSH allows for standard user login using the Application Programming Interface (API) of PAM. Another feature is white listing of clients via their public keys, which stops intrusion attempts via hijacked user-password-credentials.

After a secure connection could be established, there are multiple possibilities to use the opened channel. One is to forward the Graphical User Interface (GUI) of a remote program to the client. Another one is to use this channel to tunnel more connections through it: For example can the traffic of an application which uses a specific port be forwarded to the remote host. This can obscure and secure this traffic between the host and the server.

1.2. Telnet

Telnet (C. Stephen 1969, Postel & Reynolds 1983) is an old (1969) and deprecated communication protocol which does not feature any security. However, in other implementations, Telnet Secure (TELNETS) was proposed, which features encryption over the communication channel. Telnet still has 23 as its very own port assigned to it.

It is also to mention that there is an application called Go-Telnet (Krempeaux 2016). This is a TELNETS supporting client-server-application which has been implemented in Go.

1.3. Berkeley r-Commands

The Berkley r-commands are a set of commands to do certain tasks on remote hosts. Those tasks are similar to their counterparts without a leading "`r`".

- *rlogin(1)* (1999)

  This command connects to the host and performs a *login(1)* (2012) command, which includes authentication and if successful, spawning a user shell.

- *rsh(1)* (1999)

  `rsh` executes a command on the remote host. If no command is specified, the user gets logged in on the host with *rlogin(1)* (1999).

- *rexec(1)* (1996)

  With this command, the user can log in to a remote machine and execute one command.

- *rcp(1)* (1999)

  Using this command gives the user the ability to copy from and to a remote host.

- *rwho(1)* (1996)

  This command tells the user what users are currently logged in on the remote machine.

- *rstat(1)* (1996)

  `rstat` displays file system information from remote hosts.

- *ruptime(1)* (1996)

  With this command, the user can see the uptime, number of logged in users and current work load of the remote machine.

It is to be noted that none of those commands support securing the communication channel in any way. This is also the reason why they got replaced by SSH, as the latter does secure it's tunnel between a client and a server.

1.4. Task

This project's objective is to design and implement a prototype for an alternative to SSH. It has to be able to provide the user with the ability to have an interactive session on a remote machine. The solution has to be able to connect to a remote server and use a shell there. Both client and server-side have to be designed and implemented.

The official formulation of the tasks can be found in the appendix A.1.1.

The chapter "Design" (see 2) is meant to give a detailed overview of how the solution initially was envisioned and designed. In the course of the project's development, many aspects and views changed, as can be read in the minutes (see A.1.3). To clarify these changes in detail is the "Implementation" chapter's objective. In there, another overview has been worded, which should give sufficient insight on the project's development.

This thesis has been worded with technically literate readers in mind. However: For core concepts and special terms, a glossary can be found at 6. Used acronyms are listed in 6.4.

2. Design

To create a client-server protocol for remote login and interactive sessions, a clear cut architecture is mandatory. The flow of a typical use case should look like this:

1. The server listens for incoming connection.
2. The client dials server.
3. The server spawns the users login shell and forwards all traffic between shell and Client.
4. The client uses the shell.
5. The client terminates the session.
6. The server listens for new incoming connections.

However, there are multiple security concerns to be satiated:

- The connection between the client and server has to be secured from exposure to or manipulation from third parties.
- The client must authenticate itself for a user of the remote system with the appropriate credentials.
- The server has to drop privilege after a successful login to prevent privilege escalation.
- The server has to spawn the login shell of the logged in user with the appropriate rights.

Furthermore, this design does not allow for multiple sessions to be run in parallel. Therefore it was decided to run a new kernel-level thread to handle everything after the connection has been established. This thread could also drop its privileges after the login succeeded.

Another action the server would have to take is to properly manage the session. That means the server has to make sure the login time stamp, who logged in, what device was used and other parameters are stored on the system. This is to act according to the Unix specification. This login accounting will allow for the logged in user to be displayed with commands like `w`.

This led to the following general flow of actions:

1. The server listens for incoming connections.
2. The client dials server.
3. The server handles the established connection.
4. The server sets up a secure connection (see 2.2).
5. The server requests necessary environment variables from the client.
6. The client responds with the values of said variables.
7. The server initiates a login procedure.
8. The client authenticates himself (see 2.3).
9. The server gathers essential data about the logged in user (see 2.4).
10. The server performs the necessary post-login actions that are expected in a Unix environment (see 2.6).

11. The server drops privilege to that of the logged in user (see 2.7).
12. The server spawns the user's login shell (see 2.5) with the same credentials and forwards all traffic between shell and client.
13. The client uses the shell on the remote machine.
14. The client terminates the session.
15. The server terminates.

The sequence diagram in figure 2.1 is an illustration of how the flow of actions was envisioned.

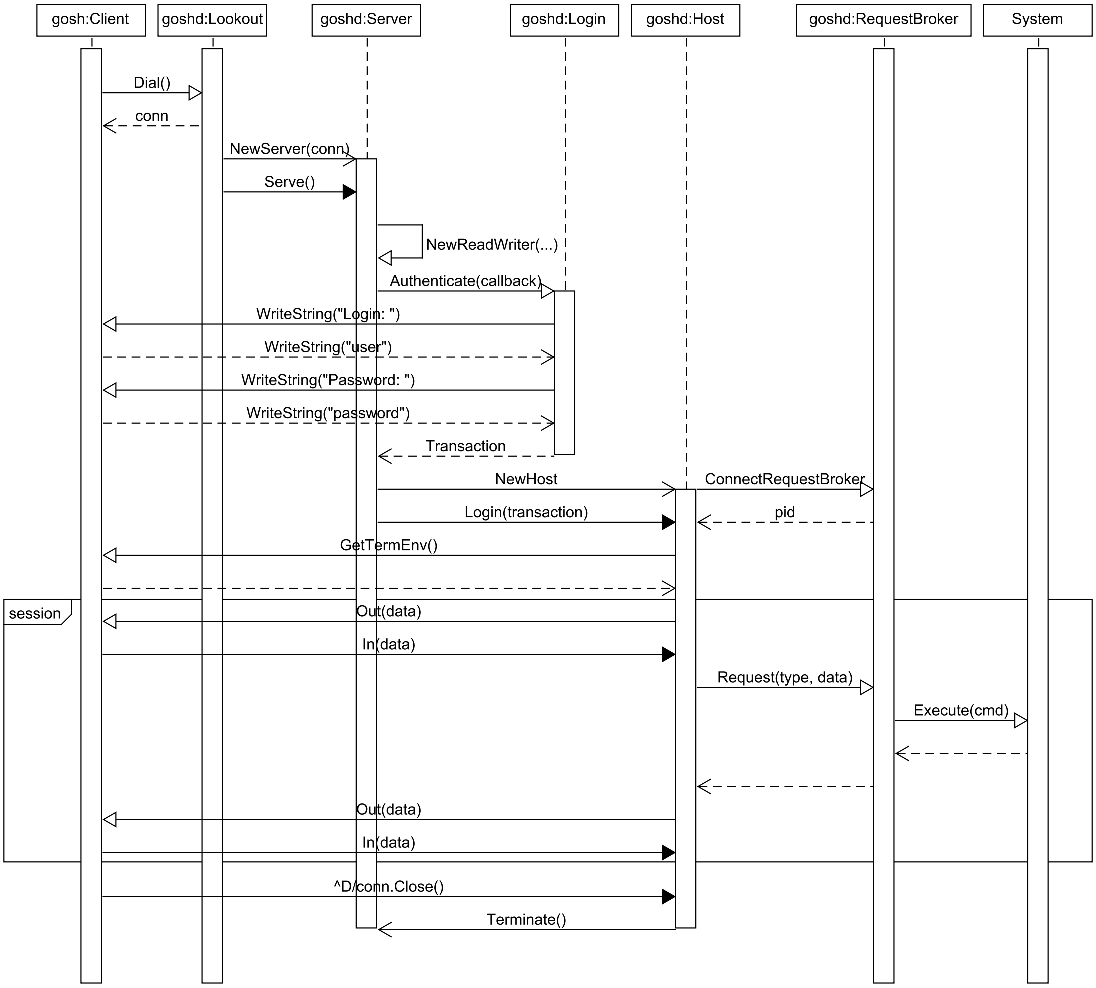

Figure 2.1.: Sequence diagram draft.

2.1. Implementation Language

In the beginning of the project, Dr Neuhaus suggested the use of Go as a modern low-level language over interpreted languages for considerations of security. He emphasized that the use of other low-level languages (like the C programming language (C) or the C++ programming language (C++)) was permissible. In the end the project was implemented in Go as suggested.

However, this led to a few problems in the implementation process (See 3.1).

2.2. Secure Connection

When building an application that communicates via the network, certain security measures are mandatory to ensure a secure communication. If such measures are not taken, the communication between the client and the server can be fully read and even altered by a third party. To prevent this, the communication can be encrypted with Transport Layer Security (TLS) (originally known as Secure Sockets Layer (SSL)). Today's state-of-the-art is TLS 1.3 (Rescorla 2018).

When connecting, the client checks the server's X.509-certificate to authenticate the peer. Optionally, the client can also authenticate himself to the server. After this, the two start an encrypted channel by for example using the Diffie-Hellman key exchange or letting the server decrypt a random secret that has been encrypted with the servers public key. After this, every message can be transferred between client and server in an encrypted way.

2.3. Authentication via Password

To let a user log in on the system, the user's authenticity has to be proven. To achieve that, Linux provides PAM. It provides a clean separation between a program and the sensitive part of the authentication. How the server solves this situation is up to the implementation. It is also possible to rely on the *login(1)* (2012) command, which also uses PAM in the background.

2.4. User Data Querying

To spawn the default shell of a user, the path to said shell is required. This and other information can be found inside the `/etc/passwd` file. The file holds information about a user's login-shell, password hash, groups, user information, User ID (UID), Group ID (GID) and home directory. To spawn a shell, the first and the last of these pieces of information are substantial to successfully log in a user. To query such data, Unix offers *getpwnam(3)/getpwuid(3)* (2019), which does not just read the `passwd` file, but also draws information about users from other sources like Network Information Service (NIS) or Lightweight Directory Access Protocol (LDAP).

2.5. Starting the Shell

A shell requires a multitude of information before it can function normally:

- The name of the user and the host.
- The `TERM` variable to allow for the use of *ncurses(3X)* (2019) dependent applications.
- The size of the teletype (tty) window (including updates to the window's size).
- It has to be the session leader.

The user information depends on the user that starts the shell or more precisely: The UID and GID, with which it has been started. Note that this is not the same as the display name of the user in the `USER` variable. The host name is the same as the `HOSTNAME` environment variable of the parent process.

There is also to note that for the usage of the correct terminal sequences, the `TERM` environment variable has to be known to the shell. This is needed to use the correct escape sequences for applications that use *ncurses(3X)* (2019).

A tty or terminal emulator sends a window change signal (`SIGWINCH`) to its child process to notify a change in its window size. If this is not forwarded, then the width and size the shell assumes, might collide with the actual values and lead to overflowing lines and unused space.

To take full control of the terminal, the shell has to be the session leader. This can be achieved by letting it set the Session ID (SID). If it is not set, the shell will print some errors regarding the `ioctl` device.

2.6. Login Accounting

When a user logs into a Unix machine, a session and a time stamp get created.

For this, the two files `/var/run/utmp` and `/var/log/wtmp` provide the appropriate storage. The `utmpx` API offers appropriate functions. The `utmpx` struct represents a single entry in those files:

```c
#define _GNU_SOURCE
/* Without _GNU_SOURCE the two field names below are prepended by "__" */
struct exit_status {
   short e_termination; /* Process termination status (signal) */
   short e_exit;   /* Process exit status */
};
#define __UT_LINESIZE 32
#define __UT_NAMESIZE 32
#define __UT_HOSTSIZE 256
struct utmpx {
   short ut_type;     /* Type of record */
   pid_t ut_pid;     /* PID of login process */
   char ut_line[__UT_LINESIZE]; /* Terminal device name */
   char ut_id[4];     /* Suffix from terminal name, or ID field from inittab(5) */
   char ut_user[__UT_NAMESIZE]; /* Username */
   char ut_host[__UT_HOSTSIZE]; /* Hostname for remote login, or kernel version for run-level messages */
   struct exit_status ut_exit; /* Exit status of process marked as DEAD_PROCESS (not filled in by init(8) on Linux) */
   long ut_session;    /* Session ID */
   struct timeval ut_tv;   /* Time when entry was made */
   int32_t ut_addr_v6[4];   /* IP address of remote host (IPv4 address uses just ut_addr_v6[0], with other elements set to 0) */
   char __unused[20];    /* Reserved for future use */
};
```

Listing 2.1: Definition of the utmpx structure (Kerrisk 2010, p.819)

On login, a record has to be written to the `utmp` file to indicate that the user logged in. If there is already a record for the active terminal, then the entry has to be updated, otherwise a new entry has to be appended. A call to *pututxline(3)* (2017) should suffice in performing these steps properly. The application has to set the `ut_type` field of the `utmpx` struct to `USER_PROCESS` to mark a user login.

Similarly to the `utmp` update after login, the application has to report to the `utmpx` API that the session ended. This procedure consists of almost the same actions as the one after logging in, with exception of `ut_user` being zeroed out and `ut_type` being set to `DEAD_PROCESS`(Kerrisk 2010, p.828).

A program can also query the `utmp` file with the according `get*` methods:

```c
#include <utmp.h>

struct utmp *getutent(void);
struct utmp *getutid(const struct utmp *ut);
struct utmp *getutline(const struct utmp *ut);

struct utmp *pututline(const struct utmp *ut);
```

Listing 2.2: `utmpx` API functions

It is worth mentioning that the Linux command *login(1)* (2012) also uses PAM to authenticate a user.

2.6.1. Login Accounting with PAM

PAM supports binding login accounting to its own session functions *pam_open_session(3)* (2016) and *pam_close_session(3)* (2016):

```
#include <security/pam_appl.h>

int pam_open_session(pam_handle_t *pamh, int flags);
int pam_close_session(pam_handle_t *pamh, int flags);
```

Listing 2.3: PAM session management

2.7. Privilege Separation

Allowing a user to log in as any user requires the authenticating process to have `root` rights. However: After performing the authentication procedure and after successfully finishing the latter, a shell will be spawned for the user to interact with. This implies that without dropping the privilege of the process down to the appropriate privileges of the logged in user, the shell would run with `root` rights, which is a privilege escalation and not permissible.

Linux provides *setuid(2)* (2019) and *setgid(2)* (2019) to set the owning user/group of a process and therefore also changing it's permissions. Unless the user is `root`, the process' owner cannot be changed.

In comparison: SSH chains the authentication of a user between an unprivileged child process that forwards the information between the two processes (see figure 2.2) - thereby putting a privilege separation in place.

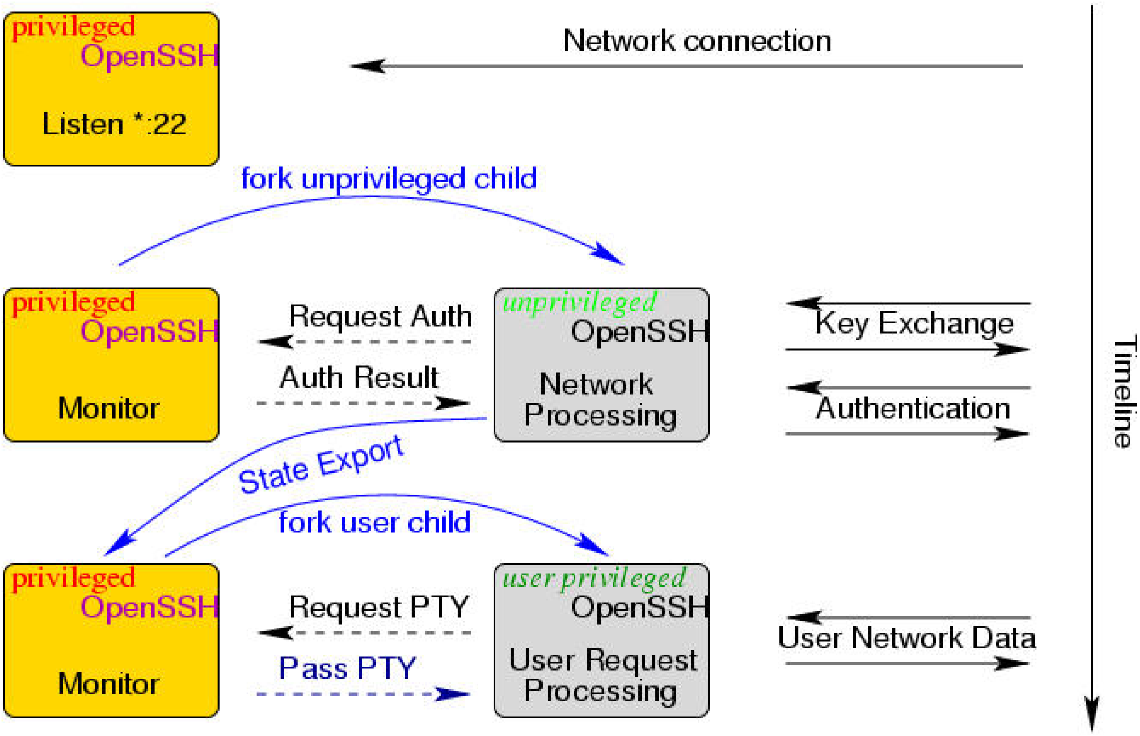

Figure 2.2.: Privilege separation in SSH (Provos 2003)

3. Implementation

The implementation of the project differs from the envisioned design. This new version of the server has three executables:

- The first is the client-side application, that is used to connect to a server.
- One is `goshd`, a daemon (also refer to 3.10), which only has one function: To listen for incoming connections and then to start a child process of the second executable.
- This last executable is the host (`goshh`) and it is responsible for handling the new connection.

Now, the work flow of the solution looks as follows (note that unchanged entries are gray):

1. The server listens for incoming connections.
2. The client dials server.
3. The server executes `goshh` as a child process (referred to as "host" in subsequent steps).
4. The host handles the established connection.
5. The host sets up a secure connection (see 3.2).
6. The host requests necessary environment variables from the client.
7. The client responds with the values of said variables.
8. The host notifies the client to prepare itself for the session.
9. the client sets the appropriate tty mode (see 3.8).
10. The host initiates a login procedure
    - The host finds a public key that belongs to the client and is authorized for login on the specific user account. The host now initiates authentication via keys (see 3.4):
        a) The host encrypts a random secret with it and then sends that to the client.
        b) The client decrypts the secret and sends the answer back.
        c) The host checks whether the received answer matches the original secret:
            – If it matches, the authentication has succeeded.
                i. The host gathers essential data about the logged in user (see 3.5).
                ii. The host spawns the users login shell (see 2.5 and 3.6) with the credentials of the logged in user and forwards all traffic between shell and client.
            – If it fails, the authentication via keys has failed and instead, the authentication via password gets initiated.
    - The host does not find a public key that matches the client or the authentication with keys did not succeed.
        a) The host starts an instance of *login(1)* (2012), which asks the client to authenticate itself (see 3.3).
        b) After successful login, *login(1)* (2012) drops privileges, takes post-login actions and starts a user login shell.
11. The client uses the shell on remote machine.

12. The session ends in particular ways:
    - The client terminates session.
        a) The child process of the host terminates.
        b) The host terminates.
    - The client dies.
        a) The connection dies.
        b) The shell receives `EOF` and terminates.
        c) The host terminates.
    - The host dies or receives a interrupt signal (`SIGINT`).
        a) The connection dies.
        b) The client receives `EOF` and terminates.
    - The server dies or receives a `SIGINT`.
        a) The server sends a `SIGINT` to all the active hosts.
        b) The host terminates.
        c) The connection dies.
        d) The client receives `EOF` and terminates.

A new sequence diagram was created after the rough finishing of the project to display it's new work flow (see figure 3.1).

In the process of implementing this project, several problems arose that had to be addressed. The reason being that some envisioned features or mechanisms could not be implemented as originally thought. This is also the reason why the work flow described in the beginning of this chapter differs from that of the design in chapter 2.

3.1. Problems

3.1.1. Forking

To handle new established connections, it was deemed important to *fork(2)* (2017) the process, as this duplicated the current process' memory and returns the Process ID (PID): 0 for the child process and a number greater than 0 for the parent to have the PID of the child.

In theory, this should have enabled the program to use Go's standard library capabilities to handle connections. However, there were several problems with this approach, which break the privilege separation design discussed in section 2.7:

Forking not supported

The Go standard library does not support the classical C-like forking. According to Google, Go does not have such mechanics, as Go was designed with Go-routines in mind instead. Go-routines however do not support privilege dropping. Instead, it only has a `syscall.ForkExec` method, which is documented as:

> Combination of *fork(2)* (2017) and *exec(3)* (2019), careful to be thread safe.

But since it uses *exec(3)* (2019) as well, it is the same as calling arbitrary binaries/scripts with the `exec.Cmd` function.

However: Go has a feature called CGo, which allows programs to call and interact with native C-routines. This opens up the possibility of using *fork(2)* (2017).

Forking breaks Go objects

Forking with the functionality of CGo does not solve the problem either. The reason is that after forking there are two programs with a `net.Conn` object. This led to both connection objects being corrupted and turning unusable. Therefore, it was necessary to abandon the clean solution of forking and instead creating a new executable that can handle new connections by its own.

Sharing Data with Child

The question then was: How can a process instantiate a child process and hand over all resources to it necessary for handling the new connection?

Since they are two separate processes now, they do not share any memory anymore. Hence the parent has to give the child the information about the connection via arguments. The most direct way to deal with this is to use file descriptors (fds), which can be passed as integer arguments to the child.

Go Connection Cannot Be Transferred

Getting a `net.Conn` interface from a fd is supported in Go via:

```go
fd := uintptr(0) // Dummy fd
conn, err := net.FileConn(os.NewFile(fd, "conn"))
if err != nil {
   panic(err.String())
}
```

Listing 3.1: Getting a `net.Conn` interface from a fd

Getting the fd from a connection is also possible:

```go
file, err := conn.(*net.TCPConn).File()
if err != nil {
   panic(err.String())
}
fd := file.Fd()
```

Listing 3.2: Getting the fd from a `net.Conn` object

However: Creating a connection with the high-level API of Go and handing over the fd to the child to derive a `net.Conn` object from, fails.

This had some implications for the project: The listener on the server could not be created with the high-level like:

```go
ln, err := net.Listen("tcp", ":8080")
if err != nil {
   // handle error
}
for {
   conn, err := ln.Accept()
   if err != nil {
      // handle error
   }
   go handleConnection(conn)
}
```

Listing 3.3: Go's high level API for listener

Instead the project had to rely on the low-level socket. The x-package `Unix` provides the necessary wrapper functions, which can be used instead.

The obvious drawback being having to rely on a x-package which is subject to change and not being able to use the higher-level methods which **are** part of the standard library.

3.1.2. Privilege Dropping

To have a sensible privilege separation, the host process should drop the `root` privileges to the privileges of the logged in user. But after performing the login procedure, setting the UID or GID both resulted in an error about insufficient permissions. This problem could not be solved in the course of this project. Instead, it was relied upon spawning the shell already with set UID and GID values to ensure appropriate permissions. This worked out well, as looking at the process in a process monitor like `htop` showed that the spawned shell does have the right UID and GID.

3.1.3. Terminal Process Group

A login shell such as `bash` expects a properly set up the fd with *ioctl(2)* (2017) properly. This can be done by letting the process set `ctty`. However: Setting the corresponding flag when starting the process via Go fails with an error. The solution omits this step, which shows in `bash` printing the following:

```
bash: cannot set terminal process group (-1): Inappropriate ioctl for device
bash: no job control for this shell
```

Listing 3.4: `bash` error when starting shell without the `setctty` flag

3.2. Secure Connection

As described in 2.2, TLS was used to secure the connection between the client and the server. For this, the Go-package `crypto/tls` has been used. This package requires both client and server to extend the `GODEBUG` variable with a flag to activate support for TLS 1.3:

```
func init() {
    os.Setenv("GODEBUG", os.Getenv("GODEBUG")+",tls13=1")
}
```

Listing 3.5: Activating TLS 1.3 in Go

The server-side of the solution has to have a certificate, which has to be generated newly when actually installing the solution on a machine. For testing purposes, a self-signed certificate was created using *openssl(1)* (n.d.):

```
openssl req -newkey rsa:2048 -nodes -keyout key.pem -x509 -days 365 -out
    certificate.pem
```

Listing 3.6: Generating a self-signed certificate and private key

The files `key.pem` and `certificate.pem` can be found inside the `test` folder in the project's root folder.

The current implementation is set to skip verification of insecure certificates. Handling such a case has been decided to be handled in future improvements. The security aspects of this implementation are discussed in subsection 5.3.1.

3.3. Authentication via Password

There are no official packages in Go that provide a wrapper to PAM (refer to 2.3). In earlier stages of the project, a wrapper from Steinert (2015) has been used. However, login using PAM failed on one of the test environments (namely Arch Linux). After some trial and error, switching to *login(1)* (2012) solved said issue, even though this command also uses PAM. This came with additional desired features like the login-accounting and other post-login actions (see 2.6 and 2.6.1), which the command already covers. After roughly a month of switching to *login(1)* (2012), the login procedure failed again on said environment. This occurred in a later stage of the project and it was deemed to time consuming, returning to the old implementation, which still lacked login accounting. Fortunately this only affected one of the environments: The other environments (i.e. Windows Subsystem for Linux (WSL)) were still functioning.

3.4. Authentication via Keys

A user can also authenticate himself without a password but instead using public key cryptography. For this, a user has to create a key pair consisting of a private and a public key. Before the actual authentication, a hashed version of the public key has to be stored on the server.

When starting an authentication, the user sends his public key to the server, which compares its hash with the stored keys that are deemed permissible for authentication. If it matches, the server encrypts a random secret (with high entropy) with the public key to the user. The user decrypts the message with his private key and sends it back to the server. If the returned secret matches the original secret, the user proved that he is the legitimate owner of the public key.

This authentication is sufficiently secure from third parties which do not have access to the private key of the user, as it can prove the authenticity of a user.

This mechanism has been implemented but with some alterations.

The first change was to store the public key in a plain text format, which was done out of convenience and can be changed in the future. Not storing the hashed public key does not pose any security threat, so fixing this deviation was deemed of low priority.

The second and last alteration was to have the structure of authorized keys on the server be stored exclusively in the `root` user's home directory. This is a sub-optimal approach, as his requires users to store their public keys in the super user's directory, which can lead to mistakes. This will be fixed in the future.

To test the application, a test user was created and given a key pair which was created as follows using *openssl(1)* (n.d.):

```
openssl genpkey -out client.pem -algorithm rsa -pkeyopt rsa_keygen_bits:2048
openssl rsa -in client.pem -out client.pub -pubout
```

Listing 3.7: Generating a key pair for the client

3.5. User Data Querying

Querying user data (see 2.4) is *partially* supported by the Go standard library. It can give all the information about a user on the system but its login shell. Therefore it was necessary to obtain said information in a different manner. One way to get the login shell of a user is to read in the `passwd` file of the system. This originally has been implemented by using a private Go package that parsed the `passwd` file. This was deemed incomplete, as a system can acknowledge users that are not listed in said file. An example of this is NIS or LDAP, which would not be covered by solely relying on the `passwd` file.

In later stages, this has been corrected by switching to using CGo and calling the Unix API routines *getpwnam(3)/getpwuid(3)* (2019) as described in section 2.4.

```c
#include <sys/types.h>
#include <pwd.h>

struct passwd {
   char *pw_name; /* username */
   char *pw_passwd; /* user password */
   uid_t pw_uid; /* user ID */
   gid_t pw_gid; /* group ID */
   char *pw_gecos; /* user information */
   char *pw_dir; /* home directory */
   char *pw_shell; /* shell program */
};

```

```c
struct passwd *getpwnam(const char *name);
struct passwd *getpwuid(uid_t uid);
```

Listing 3.8: Definition of passwd and *getpwnam(3)/getpwuid(3)* (2019)

3.6. Starting the Shell

In Go, a process can be started with special settings. These allow for setting the UID, GID and even letting the process set itself as the session leader.

```go
cmd := exec.Command("/bin/bash", "--login")
cmd.SysProcAttr = &syscall.SysProcAttr{
   Setsid: true,
   Credential: &syscall.Credential{
      Uid: pwd.Uid,
      Gid: pwd.Gid,
   },
}
cmd.Env = []string{"TERM=xterm-256color"}
```

Listing 3.9: Starting a process in Go

The transfer of the `SIGWINCH` has not been realized in this project however.

3.7. Login Accounting

The current implementation either outsources the post-login actions described in 2.6 to *login(1)* (2012)(see 3.3) or omits them completely, as is the case in 3.4. The implementation of this feature is not part of the current project.

3.8. Terminal Mode

The client expects to send all its input directly to the shell without prior interpretation. To achieve this, the client-side terminal has to be set from the default `cooked`- into the `raw`-mode(Kerrisk 2010, p.1309). This sends each key stroke to the server-side shell as is. After the termination of the session, the original `cooked`-mode has to be restored to ensure operation as per usual.

Setting the terminal mode as described above in Go can be achieved with the functionality of the x-package “`golang.org/x/crypto/ssh/terminal`”:

```go
import "golang.org/x/crypto/ssh/terminal"
//...
oldState, err := terminal.MakeRaw(0)
if err != nil {
   panic(err)
}
defer terminal.Restore(0, oldState)
```

Listing 3.10: Setting the terminal mode in Go

3.9. Pseudoterminal

ptys are an Inter-Process-Communication (IPC) mechanism that help solving the problem of how two remote programs can communicate as if they were directly connected via a terminal (see figure 3.2).

A shell expects to be connected to a full fledged tty(or a tty emulator). To check whether it is inside such an environment, it uses *isatty(3)* (2019) on the fd it is connected to. Therefore the fd it is connected to should behave like a real terminal. This is where ptys come into play.

To do this, two files are created: The pseudoterminal master (ptm) and the corresponding pseudoterminal slave (pts)(see figure 3.3). Linux provides a pty generator at `/dev/ptmx`, which creates a ptm and a pts. This works by simply opening the `/dev/ptmx` file using *posix_openpt(3)* (2017). After this, a program has to grant the pts file ownership and permissions with *grantpt(3)* (2017), unlock it with *unlockpt(3)* (2017) and retrieve its file name with *ptsname(3)* (2017):

```c
#define _XOPEN_SOURCE 500
#include <stdlib.h>

int posix_openpt(int flags);
int grantpt(int fd);
int unlockpt(int fd);
char *ptsname(int fd);
```

Listing 3.11: pty related Linux API functions

With the pty properly set up, a child bound to the pts side will assume it is connected to a terminal and also behave as such. This mechanism is key to running a shell and forwarding all traffic between a remote client and the shell. In case of SSH and the objective of this thesis, the layout looks like in figure 3.4.

Go does have a wrapper for ptys in an official package, but the code is inside an internal package, called `os/signal/internal/pty`, which uses CGo to call the required API routines described in 3.9:

```go
// Open returns a master pty and the name of the linked slave tty.
func Open() (master *os.File, slave string, err error) {
   m, err := C.posix_openpt(C.O_RDWR)
   if err != nil {
      return nil, "", ptyError("posix_openpt", err)
   }
   if _, err := C.grantpt(m); err != nil {
      C.close(m)
      return nil, "", ptyError("grantpt", err)
   }
   if _, err := C.unlockpt(m); err != nil {
      C.close(m)
      return nil, "", ptyError("unlockpt", err)
   }
   slave = C.GoString(C.ptsname(m))
   return os.NewFile(uintptr(m), "pty-master"), slave, nil
}
```

Listing 3.12: Go's pty wrapper

For the project, this code has been altered to better fit the flow of the application.

3.10. Service Hosting

The `goshd` program has to run on a server to accept incoming requests. For ease of use, the program should be able to be run as a daemon. On Linux, this can be achieved using the service manager *systemd(1)* (n.d.), for which a unit file has been created, which is located inside the `init` directory of the project. After deployment of the software, the service can be controlled using *systemd(1)* (n.d.) commands:

```
# Setup of goshd
sudo systemctl enable goshd.service
sudo systemctl start goshd.service
sudo systemctl info goshd.service
```

```

# Breakdown of goshd
sudo systemctl stop goshd.service
sudo systemctl disable goshd.service
```

Listing 3.13: `goshd` service control

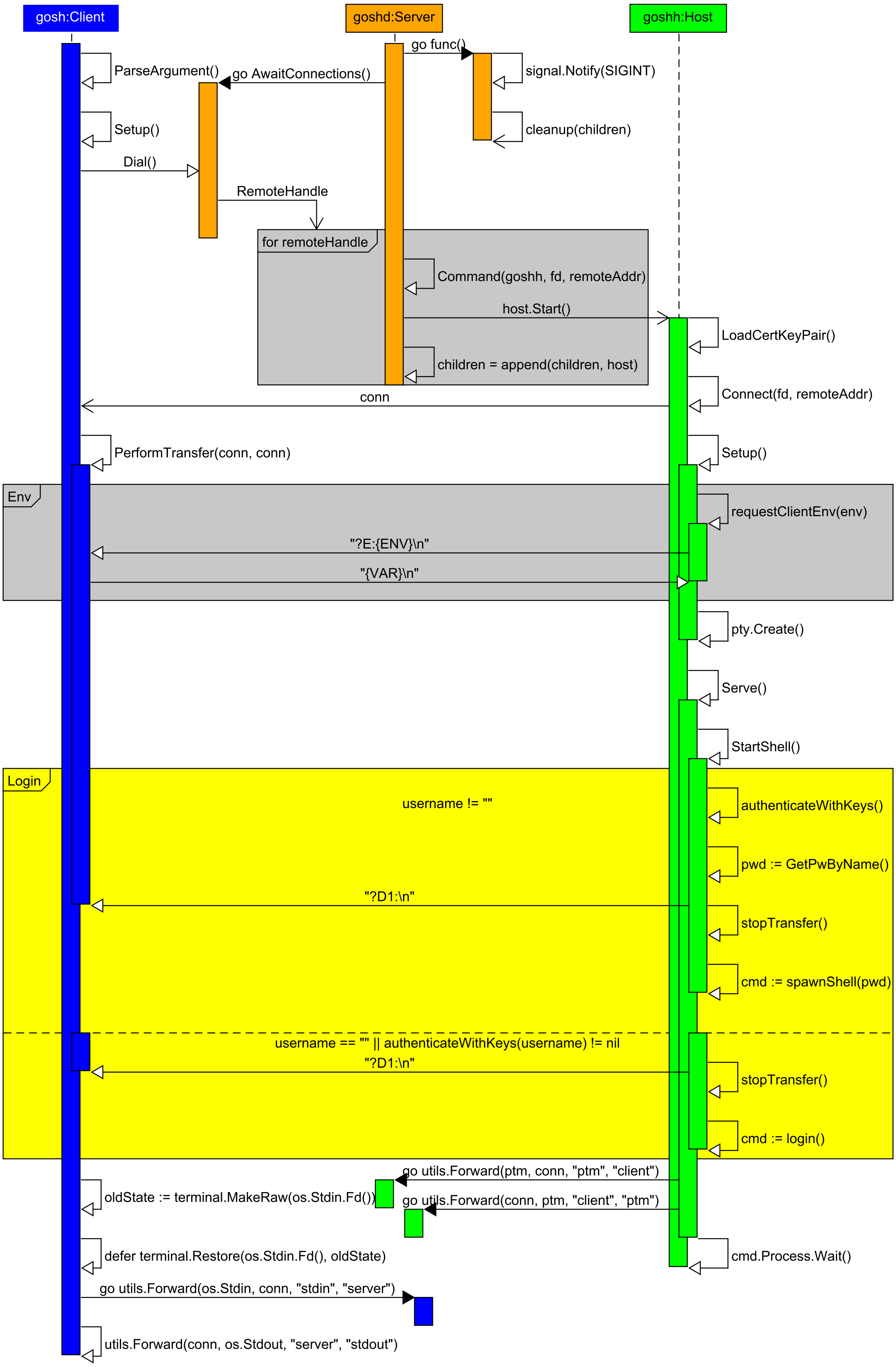

Figure 3.1.: Sequence diagram of current implementation.

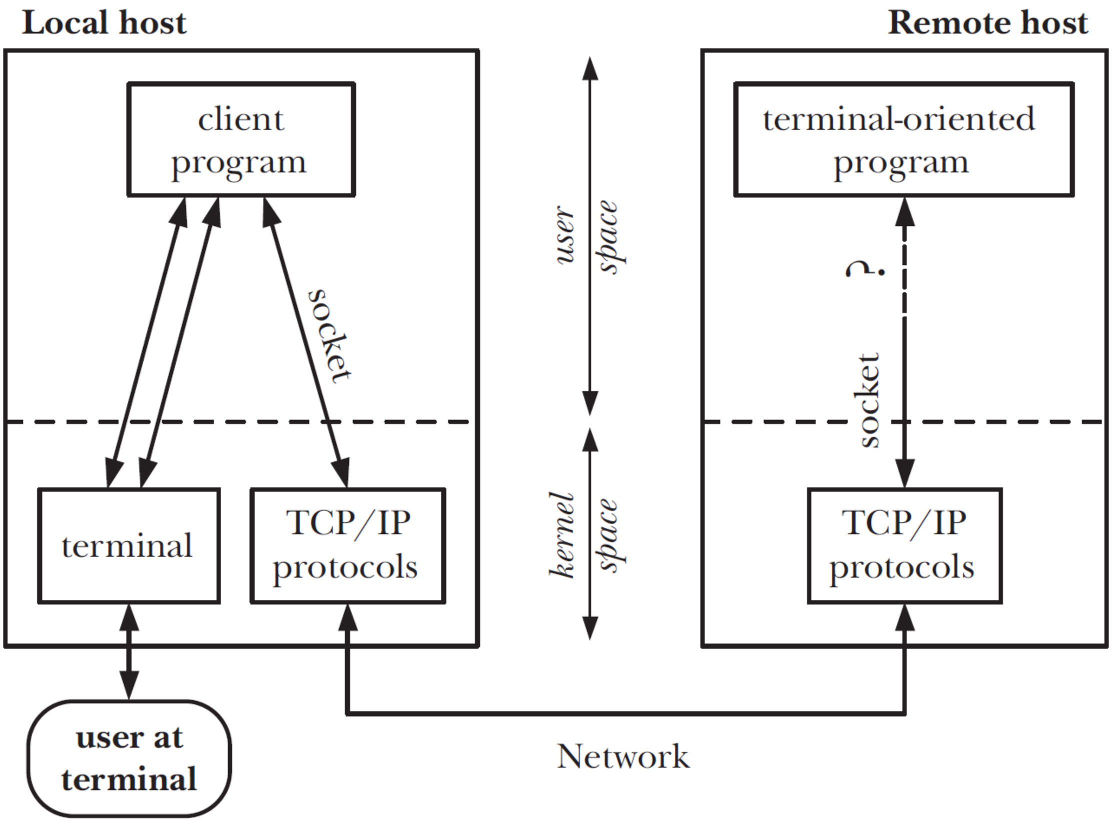

Figure 3.2.: How to operate a tty-oriented program over a network? (Kerrisk 2010, p.1376)

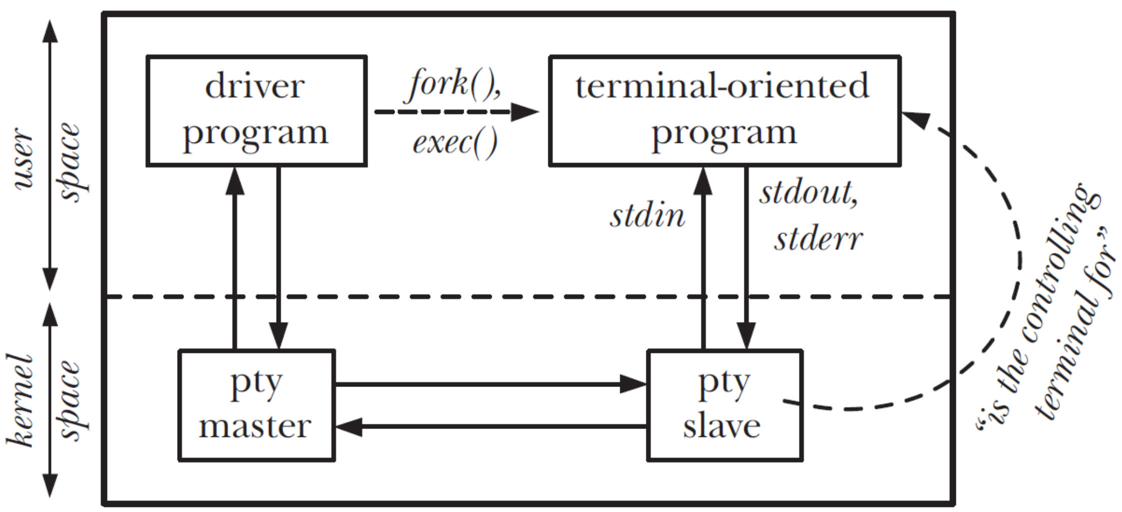

Figure 3.3.: Two programs communicating via a pty (Kerrisk 2010, p.1377)

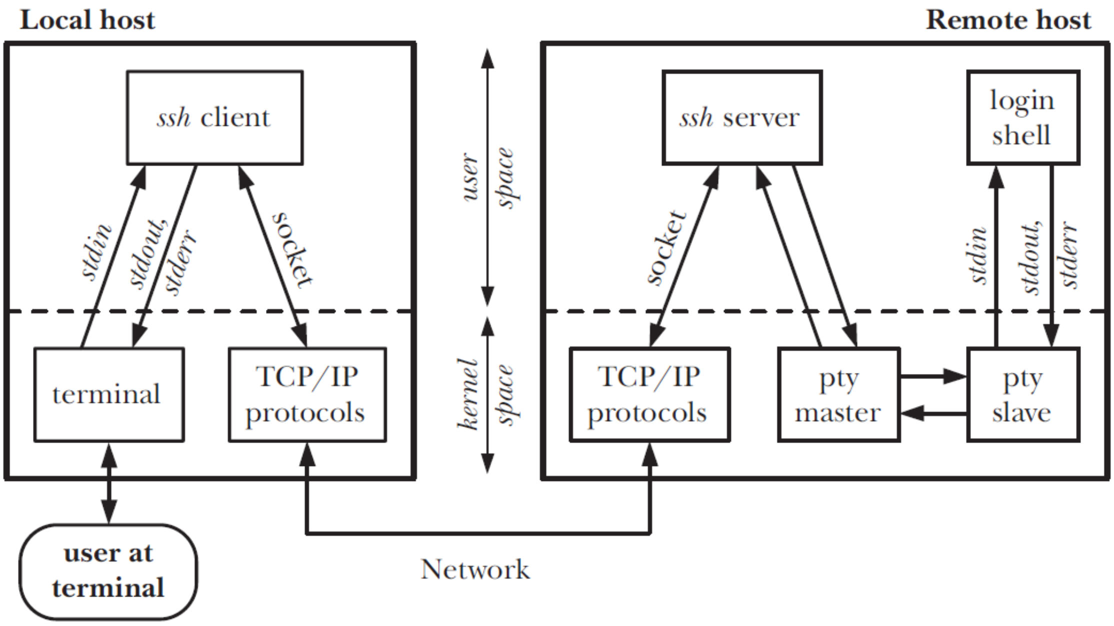

Figure 3.4.: How `ssh` uses a pty (Kerrisk 2010, p.1378)

4. Results

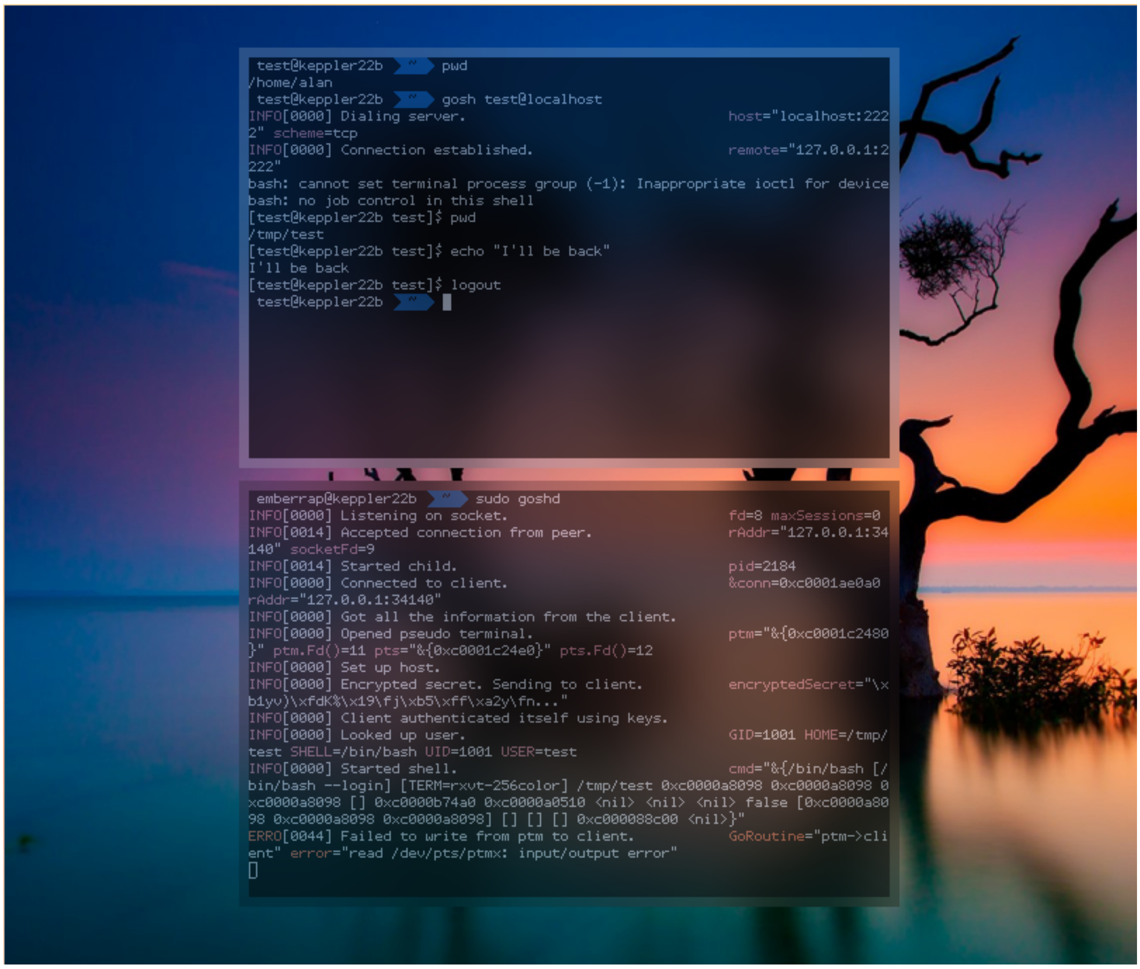

Figure 4.1.: Screenshot of `gosh` (right) connecting to the local `goshd` (left) server.

The project provides 3 applications:

- `gosh` is the application for the client side use case. It takes the following arguments:
  - `--help`: Displays the help text.
  - `--conf`: Sets the path where the configuration file is stored (defaults to “`/etc/gosh`”).
  - `--auth`: Sets the path where the key pair is stored (defaults to “ `/.gosh`”).
  - *string*: An optional address with optional credentials (defaults to `localhost`).
- `goshd` is the daemon on the server side that awaits incoming requests. It takes the following arguments:
  - `--help`: Displays the help text.
  - `--conf`: Sets the path where the configuration file is stored (defaults to “`/etc/gosh`”).
  - `--auth`: Sets the path where the key pair is stored (defaults to “ `/.gosh`”).

  - `--cert`: Sets the path of the server certificate (defaults to “`/etc/gosh/certificate.pem`”).
  - `--key`: Sets the path of the server key file (defaults to “`/etc/gosh/key.pem`”).

- `goshh` is a host that handles a new connection. This binary is only executed by the server and takes the following arguments:
  - `--help`: Displays the help text.
  - `--conf`: Sets the path where the configuration file is stored (defaults to “`/etc/gosh`”).
  - `--auth`: Sets the path where the key pair is stored (defaults to “ `/.gosh`”).
  - `--cert`: Sets the path of the server certificate (defaults to “`/etc/gosh/certificate.pem`”).
  - `--key`: Sets the path of the server key file (defaults to “`/etc/gosh/key.pem`”).
  - `--remote`: Sets the address of the peer (defaults to “`localhost:2222`”).
  - `--fd`: Provides the fd of the connection the host has to handle.

To configure the applications, the client side has a configuration file called `gosh_config.toml`. The server's configuration file is called `goshd_config.toml` respectively, where both `goshd` and `goshh` refer to the same file. In it, the user can specify the following parameters and a few more:

- The default port to communicate over.
- The default log level.
- The location of the authorized keys.
- The maximum amount of allowed sessions (server-side only).

The project allows a user to connect to a server and enter an interactive session with a remote user's login shell (see 3.8, 3.3, 3.4, 3.9 and 3.7). On the server side an appropriate privilege separation is performed upon user login (see 2.7 and 3.1). The communication is secured in the beginning of the transaction using TLS (see 3.2).

To test the applications, the user can execute the binaries from within the root folder of the project on both the client and the server (they can be the same machine, if so desired). To do this, the user can make use of the CLI flags described above to redirect the dependencies to the test files in the project:

```
# Setup environment: Create test user, its home directory and the login shell.
./scripts/setup.sh

# Start the server
sudo goshd --conf configs --auth test --cert test/certificate.pem --key
    test/key.pem

# Start the client
gosh --conf configs --auth test
# Or
gosh --conf configs --auth test 192.168.0.100
# Or
gosh --conf configs --auth test test@localhost
```

Listing 4.1: Running the applications for test purposes

To change the log level, giving the application the environment variable `LOG_LEVEL` set to the desired log level (i.e. “trace”, “debug”, etc.) should suffice.

5. Discussion And Prospects

As described in chapter 4, the developed solution is capable of providing a TLS secured channel to an interactive session of a remote user's shell, of which the privilege has been dropped to the appropriate level for said user. It can be said that with this, the main goal of this thesis could be achieved. In the following list, an overview of the solutions to the official tasks are given and explained:

- **Design and implement a client-server protocol that can manage interactive sessions**

  This has been completed in chapters 2 and 3 respectively. Both chapters give an overview and then list certain points of interest to be highlighted.

- **Design and implement a privilege-separation architecture on the server side that allows safe dropping of privileges once a client establishes a connection**

  The design has been discussed in section 2.7 and the implementation and problems encountered displayed in subsection 3.1.2 respectively. Despite the encountered problems, a privilege separation was still realized.

As described in section 1.4, the following tasks are required for a passing grade:

- **An introduction to the problem and why the envisaged solution will solve it**

  This has been discussed in chapter 1.

- **A survey of related work in the area**

  Related works are listed and discussed in chapter 1 as well (specifically in the sections 1.1, 1.2 and 1.3).

- **A detailed design of the solution**

  The entire design can be found in chapter 2. The implementation differs from the original design however, which is also discussed in chapter 3.

- **An evaluation of the performance of the implemented solution**

  An explanation to this task can be found at subsection 5.1.

- **A privilege-separation architecture**

  This is the same as the first task and can be considered solved as of section 2.7 with remark to subsection 3.1.2.

In the following lists, there are additional tasks described in section 1.4:

- **A comparison of all the related work with the envisaged solution, outlining why the envisaged solution is better**

  A small comparison to the surveyed solutions can be found in section 5.2.

- **A detailed analysis of the security of the solution, including possible attacks and defenses**

  This task will be cleared later in this chapter: The section 5.3 clears this task.

- **Use of TLS as the transport layer**

  This topic can also be considered solved as of sections 2.2 and 3.2.

- **A proof-of-concept client that can handle interactive sessions**

  A usable client has been developed and can be used after compilation of the source code. An overview of the developed applications can be found in chapter 4.

- **A proof-of-concept client that works as a transport for rsync**

  This is a task that has not been solved in this thesis but its addition is discussed in subsection 5.4.2.

5.1. Performance

The pty is an interface that needs data to be forwarded to and received from. This holds true for both sides (ptm and the pts) and therefore needs a mechanism to transfer said data. On the slave side, the shell itself already seamlessly communicates with the device via its standard pipes. A similar concept is applied for the client and its connection to the server, where the application communicates via the connection with the server. There, the client uses a Go-routine to asynchronously forward the standard input of the program to the connection.

The master side has to transfer the input from the remote client to the ptm and the output from the latter to the former as well. For this, the server uses two Go-routines that asynchronously forward the data from each stream to the other and waits until the shell process terminates.

Both these transfers are performed using Go's `WriteTo` method:

```go
// WriteTo implements io.WriterTo.
// This may make multiple calls to the Read method of the underlying Reader.
// If the underlying reader supports the WriteTo method,
// this calls the underlying WriteTo without buffering.
func (b *Reader) WriteTo(w io.Writer) (n int64, err error)
```

Listing 5.1: `WriteTo` method of Go

This mechanism helps keeping the memory usage low.

As for speed, the application has been tested on speed of the connection. For this, the client was changed to sending a stream of zeroes from `/dev/zero` to the connection once the latter has been established. The server-side on the other hand still spawns a *host*, but that forwards the entire data received from the connection to its `stdout`. To measure the throughput, the server's output gets piped into pipeviewer (`pv`), with the following arguments:

- `-t`: show elapsed time
- `-r`: show data transfer rate counter
- `-a`: show data transfer average rate counter
- `-b`: show number of bytes transferred
- `-W`: display nothing until first byte transferred

The data stream gets then redirected to `/dev/null`.

```bash
# Set the log level to error to prevent sending bytes to pv before the client
    sends the stream
sudo LOG_LEVEL=error goshd | pv -rabtW > /dev/null
```

Listing 5.2: Throughput measurement

Two variations of the test were performed: One using the blank Go connection `net.Conn` and the other one having a TLS layer in between.

Using this as a basic setup, several tests were performed:

- On a native Arch Linux laptop, the whole solution was tested over loopback.

- Connected via a switch, a WSL hosted the server. The same Arch Linux laptop as in the former test connected to the former as the client.

Once it was tested with the raw connection and once when traveling using TLS. Achieved was this by simply sending data from `/dev/zero` through the connection and printing the received data into the standard output. This was then piped into `pv` and then into `cat`, which redirected its output to `/dev/null`:

```
sudo goshd | pv -a | cat > /dev/null
```

Listing 5.3: Throughput measurement

- Raw connection: 1020MiB/s
- TLS connection: 354MiB/s

This demonstrates that the application is sufficiently fast to be used in most use cases. Therefore later implementation of a feature of this solution to be used as a transport protocol (i.e. for *rsync(1)* (2018) - see 5.4.2) is deemed viable.

5.2. Comparison

5.2.1. OpenSSH

As described in section 1.1, SSH uses an own protocol to secure the connection between client and server. This project differs in this point, as it uses TLS to create a secure channel (see 2.2 and 3.2).

Both SSH and the developed solution provide means to login with a user/password combination or via keys. This feature behaves the same in both cases.

SSH has a plethora of features that are not supported by the solution, but also were not required. The reason for that is simply because the task was to create a simple alternative.

Both have privilege separation mechanisms implemented, but the developed solution was not able to drop the privilege of the host process after login. This is another point where the two differ. That the solution does not drop privileges after login is also listed as a security issue in section 5.3.

Authentication in SSH are per default solved using PAM, which can be changed in the configuration files. Although the project in earlier stages used PAM as well, it outsourced the login functionality to *login(1)* (2012), which in turn uses PAM as well.

SSH also performs login accounting in each case, whereas the solution again outsources this mechanism to *login(1)* (2012) or omits it completely (in the case of authentication via keys). This is a feature that is missing from the project (see 5.4.5).

5.2.2. Telnet

In comparison to *telnet(1)* (1994), the solution has several differences, that distinguishes it from the old protocol. For one, the communication channel of *telnet(1)* (1994) is not secured. The developed solution however provides a TLS secured communication tunnel. This is the main difference between these two.

Furthermore, *telnet(1)* (1994) does not support authentication via keys, which is a feature that has been implemented in the project. Authentication via keys is also performed using PAM.

Just as in the case of SSH, it also does proper login accounting, which as mentioned before is missing in the solution when authenticating via keys.

5.2.3. Berkeley r-Commands

From the list of Berkeley r-commands, only *rlogin(1)* (1999) is of interest, as the other ones are used with slightly different use cases in mind. The only other one that could be compared to as well is *rsh(1)* (1999), which without a command to execute on the remote server behaves the same as *rlogin(1)* (1999).

As mentioned in section 1.2, the communication channel of *rlogin(1)* (1999) is not secured. Just as with *telnet(1)* (1994), user-password combinations are sent over a network in plain text and can be read without much difficulty. This gets prevented in the developed solution by relying on TLS.

The r-commands also do not support authentication via keys, which has been implemented in the solution. The authentication via password on the other hand is virtually the same, as both use *login(1)* (2012) to accomplish this task. This also goes for using PAM for authentication, login accounting and the post-login actions the server performs.

5.3. Security

Although the solution uses TLS as a security measure, the current state of the project still has several weaknesses. Some of them seem to be of a lower magnitude, whereas others have a higher priority to be resolved. This section lists some security issues that have been solved and others that are still unsolved.

5.3.1. Secure Connection

A secure channel is mandatory in an architecture like this. As described in sections 2.2 and 3.2, the connection has been secured using TLS (specifically TLS 1.3). This means an attacker has to deal with the security measures that TLS brings with itself.

Apart from that, the current solution only uses a server-side certificate; The client's certificate is never checked as it does not exist in the current solution. This means an attacker that knows the login credentials of a user on the remote system can log in in the system and deal harm to it without the server being able to distinguish the attacker machine from the expected client. Using client-side certificates could help to increase the level of difficulty of an attacker to perform this attack.

Furthermore, in the current solution, insecure server certificate errors simply get ignored. An attacker can use this to take on the role of a "man in the middle". This attack vector allows the attacker to appear to the client like it is the server the client wants to log in to and at the same time appear to the server as if it is the client trying to connect to it. This leads to two TLS connections: One from the client to the attacker and one from the attacker to the server. This means the attacker can read the entire data stream in an unencrypted way and manipulate as desired. This also leads to possible password exposure to the attacker if the client authenticates itself via password to the server. Therefore this weakness is considered a severe security issue that can easily be exploited by an attacker by simply sitting between the two connecting parties. To prevent such attacks, the certificate verification cannot be skipped.

5.3.2. Authentication

As described in sections 2.3, 3.3 and 3.4, two possible paths of authentication were realized.

Authentication via Password

Relying on *login(1)* (2012) simplified the task, as time was pressing. Using this standardized command also helps removing possible security issues in the authentication process and afterwards. However, this comes with a cost: The *login(1)* (2012) command allows a user to directly log in as `root` user. This cannot be prevented by the server. Ideally the server would have a default option of allowing root login set to false. There is no reason to allow any client to try to log in as `root` user. Especially since a logged in user can simply use `su` or `sudo` to gain `root` privileges. "`root`" however is the only user name that can be logged in and an attacker knows exists and only needs the knowledge of one password (which *could* be a default password) to gain full system control.

Another way to prevent `root` user login despite the usage of *login(1)* (2012) could be to pre-fetch the user credentials from the client (see 5.4.3).

Authentication via Keys

When authenticating a user via public key cryptography, the server looks up which users can be logged in. It does so by looking into the `root` user's home directory `/root/.gosh`. There, the directory structure defines what public key can log in as which user. In this case, Each directory has the name of a user and inside are the public keys stored in plain text with the file name of the `USER` value of the connecting client. This for one means that to allow a remote user to log in as this very user, the remote user's public key has to be named after that user's name and placed into the `root` user's home directory. Storing such files in the `root` user's home directory is a bad idea as this means that every change to this file structure needs `root` privileges. The public keys are also stored in plain text, which is not needed and can be replaced with their hashes instead as described in section 3.4.

5.3.3. Privilege Separation

To have a proper privilege separation (see section 2.7), the host process should also drop its privileges once the login succeeded. This is desired as the forwarding of the data is still in the host's hands and as the host still runs with `root` privileges, an attacker could potentially gain `root` access if the attacker manages to gain access to that process. Such privilege escalation should be prevented but was not entirely achieved in the current solution, as described in subsection 3.1.2.

5.4. Prospects

Although the project created a working alternative to SSH, there are several points that have to be improved, which couldn't be completed in the course of this thesis. These points are listed here:

5.4.1. Security Issues

Of course the primary task to solve in further works would be to solve the security issues with this project. As this project should be able to replace SSH in its core functions, the security aspects have to be comparable as well. Suggestions on how to solve the above mentioned security issues can be found in the respective subsections 5.3.1, 5.3.2 and 5.3.3.

5.4.2. Rsync

One of the proposed extensions was to use this project's solution as a transport layer for *rsync(1)* (2018). This could not be achieved in the course of this project, but could be done in subsequent works.

5.4.3. Prefetching of Credentials

Instead of forwarding the client's inputs to the login mechanism, the client could ask the user for user name and password beforehand and send them to the server. The server can then check for the user name to be sane (for example for preventing `root` login) and only then forward it to *login(1)* (2012). This could solve the security issue discussed in subsection 5.3.2.

5.4.4. Using PAM

In earlier stages of the project the authentication via password was already partially solved by using PAM. For other reasons (see 3.3) this was dropped in favor of *login(1)* (2012). It is suggested to return to using PAM directly and also handle login accounting (see 2.6) as well.

5.4.5. Using Utmpx

Part of post-login actions are login accounting, which would be realized using Linux' `utmpx`-API. This does happen in the case of relying on *login(1)* (2012), but not in the case of authentication via keys. The session is therefore not properly set up and should be added in future works.

5.4.6. Add Transfer of SIGWINCH

As mentioned in section 3.6, the `SIGWINCH` is not being transferred to the shell. This means that the shell assumes default values for window width and height, which leads to faulty formatting. This feature should be implemented to make the interactive session more seamless.

5.4.7. Forwarding of Data Flow

As of now, the solution simply calls forwarding routines to transfer the data flow between the shell (of more specifically, the ptm) and the connection to the client. This sometimes leads to an unclean session breakdown when terminating. It is therefore desirable to implement the data forwarding with other means. Possible Linux support could be drawn from the functions *select(2)* (2019) or *poll(2)* (2019).

6. Index

6.1. Bibliography

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6.2. Glossary

Application Programming Interface
Accessible interface for developers to use external code. 7

CGo C support for Go. 15, 16, 18, 20

Command Line Interface
A text based interface centered around commands to perform specific tasks. 3

daemon A (possibly latent) background process on a Unix machine that handles certain events when said events occur. 14, 20, 25

Diffie-Hellman key exchange A key exchange algorithm that prevents exposure to eavesdropping third parties. 11

file descriptor
A file descriptor is an integer that represents the handle to a file. 16

Graphical User Interface
Graphical interface for the user to visually interact with a program. 7

Group ID
The unique identifier of a group represented as an integer. 11

Inter-Process-Communication
Communication between processes. 19

interrupt signal
A signal supported by Unix based Operating Systems(OSes) which signals to a process to interrupt it's work. 15

Lightweight Directory Access Protocol
A protocol for querying and managing information of distributed directory information services. 11

Linux A Unix based OS which uses Linus Torvalds kernel and was inspired by Minix. 2, 11–13, 17, 20, 31, 32, 37, 40

login The action of logging in. plural 7, 9–14, 17–19, 26, 29–31

loopback A channel with only one endpoint: Sender and receiver are on the same machine. 28

Network Information Service
A service for distributing configurations like user information among a network. 11

Object Oriented Programming
A programming paradigm which uses objects to model real life entities. 37

Pluggable Authentication Module
Modules for user authentication. 2

port A point for traffic to flow, represented by an unsigned integer of up to 2 bytes. The name was chosen as an analogy to ports for ships. 7, 37

Process ID
The unique identifier of a process represented as an integer. 15

pseudoterminal
A mechanism of Unix to allow programs to communicate as if the other was inside a tty (*pty(7)* 2017). 2

pseudoterminal master
The master of a pty. 20

pseudoterminal slave
The slave of a pty (*pts(4)* 2013). 20

Secure Shell
An client-server-application that allows remote login and interaction with a shell. See 1.1. 2

Secure Sockets Layer
Cryptographic protocol to secure the communication between two peers via symmetric cryptography. Deprecated. 11

Session ID
The unique identifier of a session represented as an integer. 11

shell A CLI program, that reads user input line-by-line and executes those commands. 2, 7–11, 13–15, 17–20, 26–28, 32, 37, 40

socket A network socket is an endpoint for communication over ports. 16

teletype
Originally a device that could send and receive text messages. Nowadays tty refers to terminals, which emulate that behaviour (*tty(4)* 2019). 11

Telnet Secure
Telnet with SSL encryption. 7

terminal An user interface to interact with CLI programs like shells. 7, 12, 19, 20, 37, 40

the C programming language
Low-level programming language originally invented by Dennis Ritchie. 10

the C++ programming language
Descendant of C which implemented Object Oriented Programming (OOP). 10

the Go/Golang programming language
Google's programming language. 3

Transport Layer Security
Newer and recommended version of SSL. 11

Unix An originally free OS family called Unics from AT&T that re-imagined an older OS by the name of Multics. 2, 9, 11, 12, 18, 36, 37

uptime The time a computer has been running. 8

User ID
The unique identifier of a user represented as an integer. 11

window change signal
A signal supported by Unix based OSes which signals to a process that the terminal window it is running in has changed size. 11

Windows Subsystem for Linux
A subsystem provided by Windows that is able to run headless Linux distributions. 18

x-package A Go package that is not part of the standard library and that is subject to change or even entirely disappear. plural 16

X.509 An international standard for certificates in public key infrastructures. 11

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6.5. Acronym Glossary

SIGINT *interrupt signal* 15, *See* interrupt signal

SIGWINCH *window change signal* 11, 19, 32, *See* window change signal

API *Application Programming Interface* 7, 12, 16, 18, 20, 31, 40, *See* Application Programming Interface

C *the C programming language* 10, 15, 36, 37, *See* the C programming language

C++ *the C++ programming language* 10, *See* the C++ programming language

CLI *Command Line Interface* 3, 26, 37, *See* Command Line Interface

fd *file descriptor* 16, 17, 20, 26, 40, *See* file descriptor

GID *Group ID* 11, 17, 19, *See* Group ID

Go *the Go/Golang programming language* 3, 7, 10, 15–20, 28, 36, 38, 40, *See* the Go/Golang programming language

GUI *Graphical User Interface* 7, *See* Graphical User Interface

IPC *Inter-Process-Communication* 19, *See* Inter-Process-Communication

LDAP *Lightweight Directory Access Protocol* 11, 18, *See* Lightweight Directory Access Protocol

NIS *Network Information Service* 11, 18, *See* Network Information Service

OOP *Object Oriented Programming* 37, *See* Object Oriented Programming

OS *Operating System* 36, 37

PAM *Pluggable Authentication Module* 2, 7, 11, 13, 17, 29–31, 40, *See* Pluggable Authentication Module

PID *Process ID* 15, *See* Process ID

ptm *pseudoterminal master* 20, 28, 32, *See* pseudoterminal master

pts *pseudoterminal slave* 20, 28, *See* pseudoterminal slave

pty *pseudoterminal* 2, 19, 20, 23, 24, 28, 37, 39, 40, *See* pseudoterminal

SID *Session ID* 11, *See* Session ID

SSH *Secure Shell* 2, 3, 7, 8, 13, 20, 29, 31, *See* Secure Shell

SSL *Secure Sockets Layer* 11, 37, *See* Secure Sockets Layer

TELNETS *Telnet Secure* 7, *See* Telnet Secure

TLS *Transport Layer Security* 11, 17, 26–30, 40, *See* Transport Layer Security

tty *teletype* 11, 14, 20, 23, 37, 39, *See* teletype

UID *User ID* 11, 17, 19, *See* User ID

WSL *Windows Subsystem for Linux* 18, *See* Windows Subsystem for Linux

ZHAW *Zurich University of Applied Sciences* *See* Zurich University of Applied Sciences

A. Appendix

A.1. Project Management

A.1.1. Official Statement of Tasks

Bachelor Thesis
Preventing Supply Chain Insecurity
by Authentication on Layer 2

Stephan Neuhaus

2017-06-15

1 Introduction

The SSH protocol [RFC253, RFC6668, RFC8268, RFC8308, RFC8332] is now over twelve years old in its current form. One of the problems with SSH is its complexity, both in the initial phase when key material is exchanged, but also later, for example because the server must always decide whether to return a character that has been sent to it or not (echo).

The goal of this work is a radically simplified protocol, which in its functions is similar to SSH. (N.B. the similarity concerns the functions, not necessarily the protocol details). You develop the protocol, as well as a client and a server. You demonstrate that your software can replace SSH. For a merely passing grade, this may be done by specifying and implementing a suitable protocol. For an improved grade, you show that your replacement can handle several common use cases, among them:

- Interactive session
- Rsync with the SSH replacement as transport protocol

2 Task

To this end, this thesis will

- design and implement a client–server protocol that can manage interactive sessions
- design and implement a privilege-separation architecture on the server side that allows safe dropping of privileges once a client establishes a connection

For a passing grade (4.0), the work must contain at least the following:

- in the thesis, an introduction to the problem and why the envisaged solution will solve it;
- in the thesis, a survey of related work in the area;
- in the thesis, a detailed design of the solution;

- in the thesis, an evaluation of the performance of the implemented solution; and
- in the software, a privilege-separation architecture.

These requirements do not contain anything related to security. This is not an accident.

Incorporating the following components will improve the grade. The more components are included, the better the grade will be.

- In the related work section of the thesis, a comparison of all the related work with the envisaged solution, outlining why the envisaged solution is better;
- in the thesis, a detailed analysis of the security of the solution, including possible attacks and defenses;
- use of TLS as the transport layer;
- a proof-of-concept client that can handle interactive sessions;
- a proof-of-concept client that works as a transport for rsync;

ZHAW's School of Engineering no longer provides formal language lessons for its students as part of the curriculum. I am therefore giving notice that submitting a thesis with large amounts of orthographical or grammatical errors lead to a lower grade.

The thesis can be submitted in German or English. English is prefered, but submitting in German will not lead to a lower grade.

A.1.2. Project Plan

Revised Project Plan

March 2019

1 Introduction

The work on the final thesis is divided into several sub tasks. The individual tasks and respective time planning was defined early.
As this is a field of work, we as a team are not familiar with, we have decided to change our original plan: "Project Plan" to a revised version.
The biggest difference is that the Protype is developed earlier but we are removing some security measures respectively moving it to an optional goal We are subdividing the following area of development:

- Technical research: The research starts with a collection of examined current solution to a secure data transference, followed by a list of pro and cons for the approaches that includes a preferred selection. Moreover, we would survey the current state development within that field.
- Conceptualising: Look for alternative solutions and compare them. Plan the development.
- Prototype: A unsecure SSH Client
- Testing: Do generalized tests, identify possible security vulnerability
- Rework of the secure shell: Modify the secure shell based on the newly discovered needs

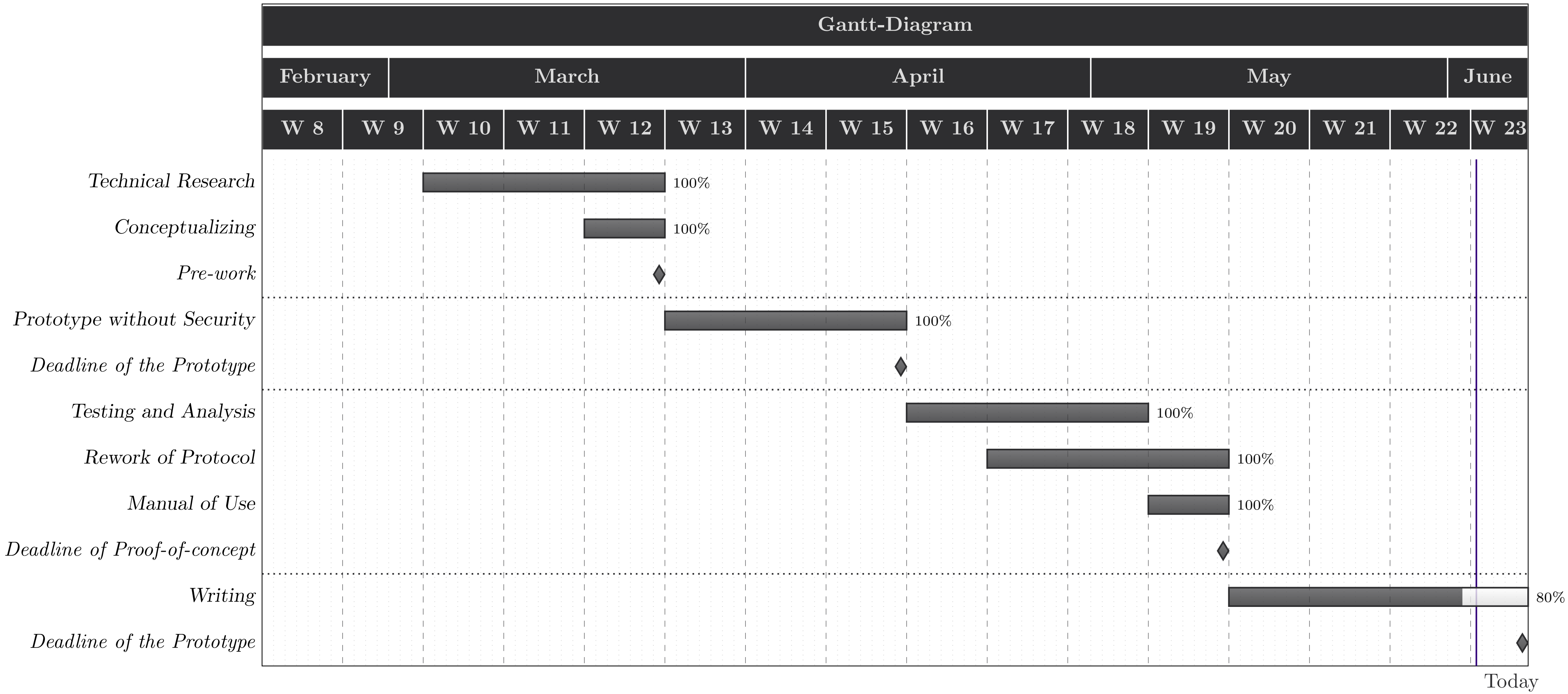
Furthermore there are specific milestone within the project process, which we would use to realign and discuss our time division.

2 Visualization

The project plan is documented in the form of a chart and is updated throughout the project. This way, deviations can be detected early and can be discussed with the supervisor and within our team.

		March				April				May				June				July
	duration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Technical research	3 weeks																	
Conceptualising	1 week																	
Pre-work	31.03																	
Prototype without security measures	4 weeks																	
Deadline of the Protoype	30.04																	
Testing and Analysis	3 weeks																	
Rework of current protocol	3 weeks																	
Manual of Use	1 week																	
Deadline of Proof of concept	10.05																	
Writing	2 weeks																	
Hand-in Date	28.06																	

Figure 1: Project plan


Gantt-Diagram
February
March
April
May
June
W 8
W 9
W 10
W 11
W 12
W 13
W 14
W 15
W 16
W 17
W 18
W 19
W 20
W 21
W 22
W 23
Technical Research
100%
Conceptualizing
100%
Pre-work
Prototype without Security
100%
Deadline of the Prototype
Testing and Analysis
100%
Rework of Protocol
100%
Manual of Use
100%
Deadline of Proof-of-concept
Writing
80%
Deadline of the Prototype
Today

A.1.3. Meeting Minutes

The meeting minutes have a disruption in style and execution beginning from the 6th meeting. Reason for this is because in the beginning of the project, Mr Schwarz was responsible for keeping the minutes, but he opted out of the project.

Oh my Gosh - Meeting protocol

1 2^{nd} Meeting

Participant
Bachelor thesis supervisor - Stephan Neuhausen
Bachelor student - Raphael Emberger
Bachelor student - Kevin Schwarz
Time duration of the meeting
1 hour and 15 minutes

1.1 Objectives

1. Keeping the bachelor thesis supervisor informed on the state of affairs
2. Getting an overview on how the progress relate to the scheduled progress

1.2 Summary

In this meeting the following things were achieved:

1. Decision towards ITC and UDP was achieved
2. A rough draft of a generalized process was finalized and presented to the supervisor
   (a) Smaller misconceptions were resolved
   (b) Fields where further research is warranted was shown
3. Reiteration of the project goal
4. Further Delimitation of the project extent.
   (a) Smaller misconceptions were resolved

1.3 Tasks and resources

The following were left as tasks or as a research subject for the next meeting in descending priority:

1. Understanding shell forwarding
2. Researching the limitation of IOCTL - raw and device specific output
3. Pseudo terminals
4. Persistence in relation to Environment variables

1.4 Next meeting

The next meeting plan were not changed, the formerly decided weekly scheduled date still stands.
The next meeting is dated: [14 / 03 / 19] on the first floor of the Zürich location of the ZHAW within the Room 0.03.

Oh my Gosh - Meeting protocol

1 3rd Meeting

Participant
Bachelor thesis supervisor - Stephan Neuhausen
Bachelor student - Raphael Emberger
Bachelor student - Kevin Schwarz
Time duration of the meeting
1 hour

1.1 Objectives

1. Keeping the bachelor thesis supervisor informed on the state of affairs
2. Getting an overview on how the progress relate to the scheduled progress

1.2 Summary

In this meeting the following things were achieved:

1. General overview of a PTY
2. Certain foundation towards developing a non-secure secure shell were explained:
    (a) Smaller misconceptions were resolved
    (b) Fields where further research is warranted was shown
3. Reiteration of the project goal
4. Further Delimitation of the project extent.
    (a) Smaller misconceptions were resolved

1.3 Tasks and resources

The following were left as tasks or as a research subject for the next meeting in descending priority:

1. Understanding shell forwarding
2. Researching the limitation of IOCTL - raw and device specific output
3. Pseudo terminals
4. Persistence in relation to Environment variables

1.4 Next meeting

The next meeting plan were not changed, the formerly decided weekly scheduled date still stands.
The next meeting is dated: [14 / 03 / 19] on the first floor of the Zürich location of the ZHAW within the Room 0.03.

Oh my Gosh - Meeting protocol

1 4^{th} Meeting

Participent
Bachelor thesis supervisor - Stephan Neuhausen
Bachelor student - Raphael Emberger
Bachelor student - Kevin Schwarz
Time duration of the meeting
25 Minutes

1.1 Objectives

1. Keeping the bachelor thesis supervisor informed on the state of affairs
2. Gain an introduction to encryption

1.2 Summary

In this meeting the following things were achieved:

1. Introduction to Bash was given
2. Move up of the prototype deadline
3. Change of scheduled development plan:
   (a) Decrease of the SSH scope
   (b) Reduction of the security measures to an optional goal
   (c)

1.3 Tasks and resources

The following were left as tasks or as a research subject for the next meeting in descending priority:

1. Researching the infrastructure of GO-order
2. Researching Bash and PTY on Windows enviroment
3. First Server - Client Demo
4. Crafting a simple process diagram for the next meeting

1.4 Next meeting

The next meeting plan were not changed, the formerly decided weekly scheduled date still stands.
The next meeting is dated: [28 / 03 / 19] on the first floor of the Zürich location of the ZHAW within the Room 0.03.

Oh my Gosh - Meeting protocol

1 5th Meeting

Participent
Bachelor thesis supervisor - Stephan Neuhausen
Bachelor student - Raphael Emberger
Bachelor student - Kevin Schwarz
Time duration of the meeting
45 Minutes

1.1 Objectives

1. Keeping the bachelor thesis supervisor informed on the state of affairs
2. Demonstrate Demo

1.2 Summary

In this meeting the following things were achieved:

1. The Prototype was tested.
2. Process Diagram was explained
3. 4 open Problems were discussed:
   (a) PAM Struct and how they work
   (b) Generalized Certkey location
   (c) Use of the Prototype within Linux
   (d) Correct pipe lining and forking

1.3 Tasks and resources

The following were left as tasks or as a research subject for the next meeting in descending priority:

1. Further testing of both Linux, Apple and Windows environment
2. Solving of Pam Struct problem
3. Further development

1.4 Next meeting

The next meeting plan were modified, the formerly decided weekly scheduled date still stands.
The next meeting is dated: [5 / 04 / 19] on the first floor of the Zürich location of the ZHAW within the Room 0.13.

Design and Implementation of an Alternative to SSH

Meeting Minutes

1 Attendees

Present: Stephan Neuhaus, Raphael Emberger
Absent: Kevin Schwarz*(illness)*

2 Initiation

The meeting took place on the *Friday, 5th of April 2019, 13:00* in *ZL0.13, Lagerstrasse 45, Zürich*. Raphael Emberger was resonsible for the minutes.

3 Points of discussion

3.1 Process forking unsuccessful

Attempts on forking a sub-process were unsuccessful. The reason for this was that the standard library of Go doesn't allow such mechanics, as Go was designed with go-routines in mind instead.

Solution A quick test with cgo yielded a viable solution to the problem: Using the C-routine fork() a fork was successful.

3.2 Shell instantiating and forwarding

Attempts in forwarding the client connection to a server-side shell's stdin and its stdout and stderr to the connection of the client were unsuccessful.

Solution One quick tests showed that hooking up the std* pipes to a local shell process with Go worked just fine. Therefore it was deemed feasible to transfer the entire interface to the client.

3.3 Participation of Mr. Schwarz

Up until this date, the participation of Mr Schwarz was remarkable little in terms of writing on the code base of the project. The present parties agreed on this matter.

Solution It was decided to give Mr Schwarz a choice of action: Either he starts to participate heavily in the project from now on or he opts out of the project entirely.

4 Old Business

- **Login attempts in Linux fail:** This problem was deemed lower priority, as Login works on the WSL and can still be dealt with in later stages of the project.

Next Meeting

Friday, 5th of April 2019, 13:00 in *ZL0.13, Lagerstrasse 45, Zürich*

Zürcher Hochschule
für Angewandte Wissenschaften

School of Engineering

Design and Implementation of an Alternative to SSH

Meeting Minutes

1 Attendees

Present: Stephan Neuhaus, Raphael Emberger, Kevin Schwarz

2 Initiation

The meeting took place on the *Friday, 12th of April 2019, 13:00* in *ZL0.13, Lagerstrasse 45, Zürich*. Raphael Emberger was resonsible for the minutes.

3 Points of discussion

3.1 Participation of Mr. Schwarz

Mr Schwarz decided to opt out of the project because of time issues. Mr Neuhaus will therefore adapt the outline of the project.

3.2 Reading user data works

The new module to read user data via the getpwnam(3) API has been implemented using cgo. It can read all the required data(i.e. the user shell which wasn't supported in the go standard library).

3.3 Forking implemented, but causes problems

Forking has been implemented via cgo but after forking, the net.Conn object cannot be used by the child process. There is also the to further investigate, whether after forking a new process actually gets started, as a quick look at the processes didn't reveal that a fork has been processed.

Solution To counter this problem it is suggested to do the connection build up via cgo using the C-socket API. This returns an integer as a file descriptor, which shouldn't cause problems when forking.

3.4 Remote start and handling of a shell has issues

After successfully hooking up the channels from the client to the shell process, almost all mechanics work as expected with exception of missing characters like the PS{1,2,3,4} prompts.

Solution It is suggested to compare the environment variables of the child shell process and the usual terminals to see if there are deal breaking differences. Adjusting the child shells environment variables might fix the problem.

4 Old Business

- **Login attempts in Linux fail:** This problem was deemed lower priority, as Login works on the WSL and can still be dealt with in later stages of the project.

Next Meeting

Friday, 26th of April 2019, 13:00 in *ZL0.13, Lagerstrasse 45, Zürich*

Design and Implementation of an Alternative to SSH

Meeting Minutes

1 Attendees

Present: Stephan Neuhaus, Raphael Emberger

2 Initiation

The meeting took place on the *Friday, 26th of April 2019, 13:00* in *ZL0.13, Lagerstrasse 45, Zürich*. Raphael Emberger was resonsible for the minutes.

3 Points of discussion

3.1 Login and shell usage

The remote login, starting and usage of a user shell works now. It still does not behave like intended, as there are warnings printed on the screen and every line written gets echoed back, but overall, it works.

3.2 Pty echoes stdin back to stdout on client

As described in the point above, when entering shell commands on the shell after remote login, the written lines gets echoed back after hitting enter.

Solution The reason this was so, is because the terminal on the client was still in the *cooked* mode rather than the *raw* mode, which behaves differently from the default *cooked* mode, which read line by line and catches and interprets signals like [Ctrl]+[C] or [Ctrl]+[D]. Setting the terminal into *raw* mode should solve the issue as explained in "The Linux Programming Interface".

3.3 Transfer of SIGWINCH/ioctl

As described in the first point of discussion, when dropping into the remote shell, there are warnings displayed about a problem with ioctl.

Solution In "The Linux Programming Interface" it is also mentioned that making the child the session leader would solve this issue.

3.4 Login with test user fails

Trying to login with the test user results in an error when starting the shell because of missing files.

Solution This issue was easily solved as the script for setting up the test user was faulty: It didn't properly create the home directory of the test user and since the process which dropped privilege after login didn't have root rights anymore, it couldn't enter the home directory. Therefore, the directory owner and permissions were amended.

3.5 Forking abandoned

3.4 of the last meeting suggested using the C-style sockets to pass the file descriptors to the child process, which should solve the issue with forking and still using the net.Conn object. This has been implemented and after some adjustment worked out well.

4 Old Business

- **Login attempts in Linux fail** This problem was deemed lower priority, as Login works on the WSL and can still be dealt with in later stages of the project.

Next Meeting

Friday, 3th of March 2019, 12:30 in *ZL0.13, Lagerstrasse 45, Zürich*

Design and Implementation of an Alternative to SSH

Meeting Minutes

1 Attendees

Present: Stephan Neuhaus, Raphael Emberger

2 Initiation

The meeting took place on the *Friday, 3th of May 2019, 13:00* in *ZL0.13, Lagerstrasse 45, Zürich*. Raphael Emberger was resonsible for the minutes.

3 Points of discussion

3.1 Pty echoes stdin back to stdout on client

The suggested solution from last meetings 3.2 of setting the client terminal into raw mode worked out well and has since been implemented like this.

3.2 SockAddr

The x-package `unix` provides wrappers for common Unix API calls. Most of the handling with sockets could be transferred to their methods, except `getpeername(3)`, which was implemented in the old way using CGo. The reason being that the returned `SockAddr` interace from `accept(3)` and `getpeername(3)` couldn't be casted(or rather: type-asserted) to be used as `SockAddrInet4` struct.

Solution After some experiments and searching the internet, it was revealed that the type assertion had to use pointers instead.

3.3 Role of login in the application

Just relying on `login` to perform all the important steps to log a user in is not a viable solution, as this would make log in via keys impossible. Therefore, it was made so the server decides whether to attempt to log in via keys or just to call `login`. Key authentication has been implemented as well and doesn't rely on `login`.

3.4 Documentation and bug-fixes before new features

It was deemed better to stop implementing new features as time is about to run out. Therefore, it is suggested to invest 80% of the remaining time to write on the documentation and 20% on bug-fixing. Only after everything has been finished, can new features be implemented - if at all.

3.5 Documentation chapter renaming

The original template for the BSc thesis has chapters named ”Theoretical Principles” and ”Method” in them, which will be renamed to the more appropriate ”Design” and ”Implementation”. The latter will not reflect the progress in a chronological order but instead order it point by point.

3.6 Login attempts in Linux fail

Relying on `login` finally solved the problem of logging in on a specific linux distribution. The log in via keys also works, as the problem was originally PEM dependent, which gets omitted when authenticating via keys.

Next Meeting

Friday, 10th of March 2019, 12:30 in *ZL0.13, Lagerstrasse 45, Zürich*

Design and Implementation of an Alternative to SSH

Meeting Minutes

1 Attendees

Present: Stephan Neuhaus, Raphael Emberger

2 Initiation

The meeting took place on the *Friday, 10th of May 2019, 12:20* in *ZL0.13, Lagerstrasse 45, Zürich*. Raphael Emberger was resonsible for the minutes.

3 Points of discussion

3.1 File descriptors and Go

After resolving last weeks issue with `SockAddr`(3.2), the same approach enabled us to get the fd of a connection: By type-asserting it as `*net.TCPConn`, which had a function that returns the underlying file, which in turn had a function for returning the underlying fd.

3.2 Privilege dropping

After authenticating the user via keys, the host process spawns a shell with the appropriate privileges. For more secure handling, it was deemed best to drop privilege for the entire host process after authenticating via keys. Despite running with root rights(to enable a user to login as any user), the process receives an exception when calling `unix.Setuid` or `unix.Setgid`. The reason was assumed to be related to Go's infamous Go-routines.

3.3 Current State of Documentation

The current state of the documentation is still insufficient. There are 4 weeks until the deadline. It is suggested to write more on the documentation.

Next Meeting

Friday, 17th of March 2019, 13:00 in *ZL0.13, Lagerstrasse 45, Zürich*

Design and Implementation of an Alternative to SSH

Meeting Minutes

1 Attendees

Present: Stephan Neuhaus, Raphael Emberger

2 Initiation

The meeting took place on the *Friday, 17th of May 2019, 12:30* in *ZL0.13, Lagerstrasse 45, Zürich*. Raphael Emberger was resonsible for the minutes.

3 Points of discussion

3.1 Referencing Linux Man Pages

As the code base heavily relies on the Linux API, it was decided to include bibtex references to the manual pages to improve readability.

3.2 Clarification of Design of Public Key Cryptography

When describing public key cryptography, the current state of the documentation doesn't go into further detail other than describing the flow of actions when authenticating via public key cryptography. This part has to be improved.

3.3 Login as Root possible

The current state of the implementation allows a client to authenticate itself and log in as root on the server. This is a point that should be improved, but can be postponed for now.

Solution When using `login(1)` to authenticate and log in a user, the `-f` flag can be used to specify a specific user. The client could already ask the user before communication with the server, which user should be used when logging in. This is partially already implemented.

3.4 Keys remain in memory

The current state of the implementation of the client still retains the private key in memory when performing key authentication. This could be a possible vulnerability which could be used by a third party as an attack vector to obtain said key.

3.5 Keys not stored optimally

The public key up to today stored the full public key inside a directory structure in the root user's home directory. This could cause problems when storing keys and should be changed to the way `ssh` stores authorized public keys: By storing the authorized keys for a server-side user in hashed format in its home directory.

3.6 RSync not implemented yet

The layout of the tasks mentions `rsync` compatibility as both a required use-case for a passing grade and an optional extra feature. This has been amended by Mr Neuhaus by stating explicitly, that `rsync` compatibility is optional.

3.7 Separate bibliography for man page references

As references to the Linux manual pages take up a considerable part of the overall references, it was considered to split it up into a manual-only bibliography and a normal bibliography. This suggestion was rejected as it was deemed tolerable to have one single bibliography.

3.8 Picture for the Publication Tool

The official Publication Tool requires a picture to be attached to the abstract when handing it in to the online tool. As this thesis is centered around a CLI application, no picture has been made so far. It was suggested to simply take a screenshot of the application in operation.

Next Meeting

The next meeting doesn't have a set date, time or place, as it was deemed a better option to organize a new meeting whenever the need for one arises.

Design and Implementation of an Alternative to SSH

Meeting Minutes

1 Attendees

Present: Stephan Neuhaus, Raphael Emberger

2 Initiation

The meeting took place on the *Friday, 31th of May 2019, 12:30* in *ZL0.13, Lagerstrasse 45, Zürich*. Raphael Emberger was responsible for the minutes.

3 Points of discussion

3.1 Time Issues

Because of the lack of participation from a peer, Raphael was occupied with the labs of the AI2 course for over two days, which led to more pressure in finishing the thesis.

3.2 Project stopped working

When connecting to the server, the host application cannot open the connection from the file descriptor and throws a "Bad file-descriptor" error. This happens on the WSL.

Using a native Linux distribution solved this issue.

3.3 Formal Requirements

It was stressed to find out more about the formal requirements, lest the whole thesis might face tribulations due to formal details.

3.4 Attendance of Mr. Schwarz at the Presentation

It was suggested to include Mr. Schwarz in the presentation of the thesis as he was part of the team for a considerable amount of time. He has no obligation to present himself but may attend the presentation itself.

Next Meeting

There will not be any further meetings.

A.2. Others

Please refer to the USB-stick that has been handed in with this thesis. The Git repository for the code (private) is located at: `https://github.engineering.zhaw.ch/neut/oh-my-gosh` and the documentation (clear-net) at: `https://github.engineering.zhaw.ch/neut/oh-my-gosh-bericht`.