BPFDoor - Part 2 - The Present

haxrob.net/bpfdoor-past-and-present-part-2/

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Despite the venerable `BPFDoor` malware has once again found itself in the media spotlight. Recent variants avoid existing detections, so we will take a look at samples found in significant telecommunications provider breach in April 2025.

💡

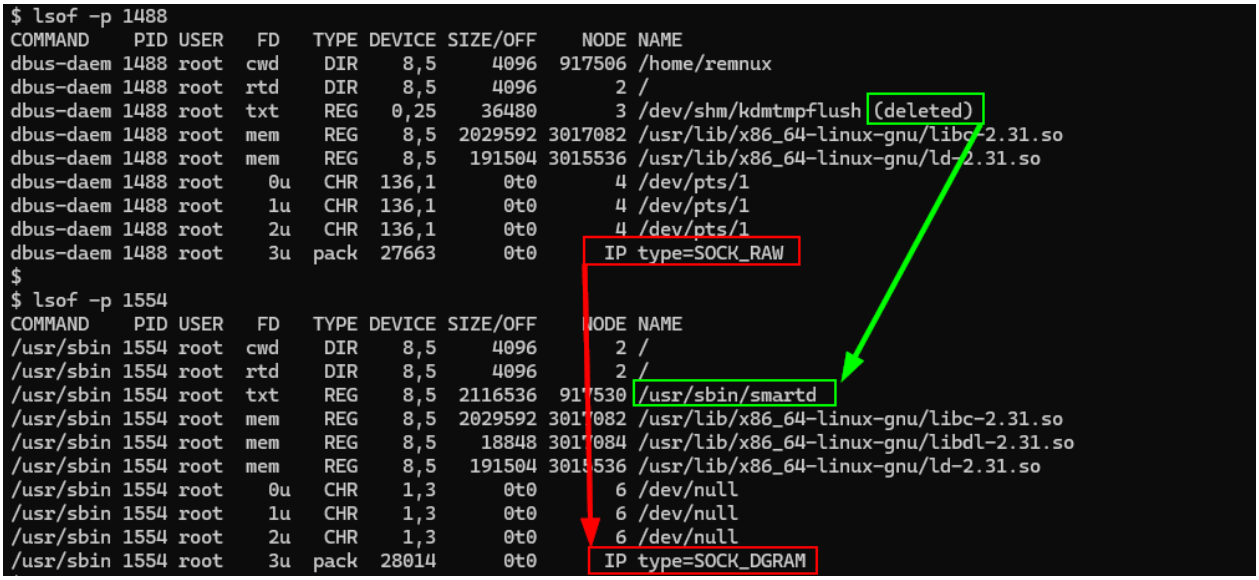
Recommended for prior reading: Trend Micro (2025), Sandfly Security (2022), Elastic (2022).

Detection evasion improvements

We will be using two following samples as references

`cf2d3d9e0246a3220d7c3cc94257447085911b32e1de0aee9d4af7dd6427597d`
`3f6f108db37d18519f47c5e4182e5e33cc795564f286ae770aa03372133d15c4`

What's changed



File descriptors for the more recent BPFDoor compared to the prior reported

- No more`SOCK_RAW` appearing. You will only find socket of type`SOCK_UDP` in `BPFDoor` open file descriptors. Despite this, the implant still accepts `ICMP`, `UDP` and `TCP` wakeup packets
- The random selection of custom process names used for masquerading has been replaced with a fixed process name.

    Mutex locks file paths are adjusted accordingly

- Removal of "fileless" feature, no longer writing to `/dev/shm` and deleting itself from disk
- Global variables / function names stripped - no more looking for binaries with `godpid`
- SSL for transport encryption with embedded certificate
- Updated BPF filter, now coming at a whopping 229 bytes long

Goodbye SOCK_RAW

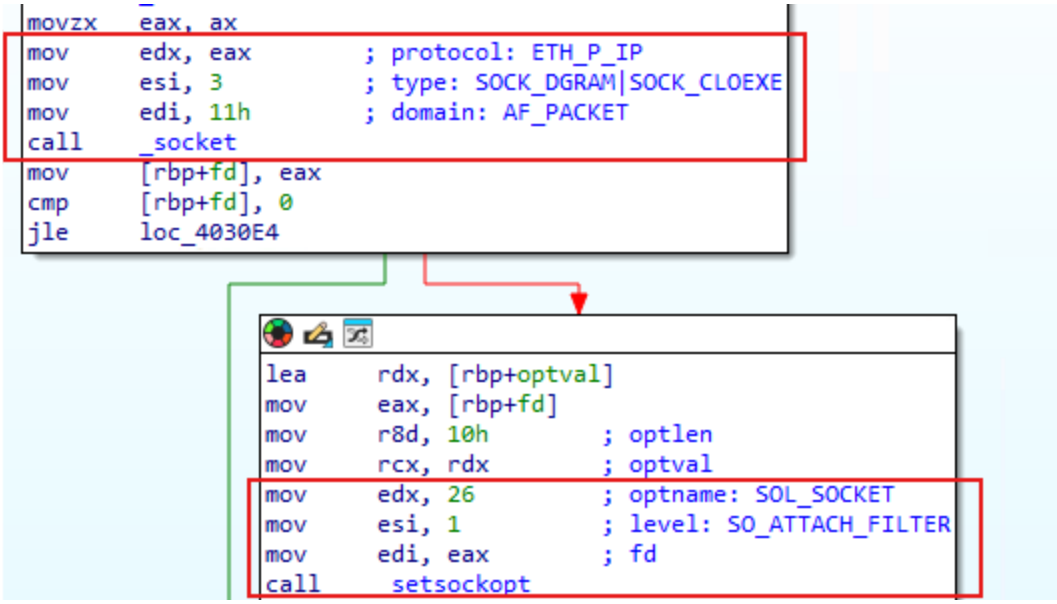
A common and useful detection opportunity is to look for unexpected processes with open raw sockets. Doing a `lsof | grep SOCK_RAW` won't surface `BPFDoor` anymore. This is how it looks now:

```
# lsof -p 4073
..
/usr/sbin 4073 root    0u   CHR  136,3      0t0       6 /dev/pts/3
/usr/sbin 4073 root    1u   CHR  136,3      0t0       6 /dev/pts/3
/usr/sbin 4073 root    2u   CHR  136,3      0t0       6 /dev/pts/3
/usr/sbin 4073 root    3u  pack  37048      0t0      IP type=SOCK_DGRAM
```

Prior, variants would open a raw socket (followed by `setsockopt` to install its `BPF` filter):

```
socket(PF_PACKET, SOCK_RAW, htons(ETH_P_IP))
..
setsockopt(sock, SOL_SOCKET, SO_ATTACH_FILTER, &filter, sizeof(filter))
```

Now we see that `SOCK_RAW` has been replaced with `SOCK_DGRAM|SOCK_CLOEXEC`



In other words we now have:
`socket(AF_PACKET, SOCK_DGRAM|SOCK_CLOEXEC, htons(ETH_P_IP))`

One would assume on a surface glance that `AF_PACKET` with `SOCK_DGRAM` would only receive `UDP` packets (`SOCK_DGRAM`), but this is not actually the case.

packet(7) states:

> "When protocol is set to htons(ETH_P_IP), then all IPv4 packets are received. All incoming packets of that protocol type will be passed to the packet socket before they are passed to the protocols implemented in the kernel."

Hence, as per the description, `ETH_P_IP` will take precedence, making the socket 'applicable' for `IP` packets of any protocol (`TCP`, `UDP`, `ICMP`). What is not apparent is that kernel will reports the socket as `SOCK_DGRAM` which is misleading unless the nuance is understood.

The data received is slightly different as well: With `SOCK_RAW` the kernel will pass the whole packet, including the link layer, while `AF_PACKET` strips this out and will everything from the `IP` header onwards. Hence we see in the original source with `SOCK_RAW` discards the 14 byte ethernet header:

```
520                     memset(buff, 0, 512);
521                     psize = 0;
522                     r_len = recvfrom(sock, buff, 512, 0x0, NULL, NULL);
523
524                     ip = (struct sniff_ip *)(buff+14);
525                     size_ip = IP_HL(ip)*4;
526                     if (size ip < 20) continue;
```

While the newer version using `SOCK_DGRAM` assumes the first byte to be the start of the IP header:

```
58          memset(buff, 0, 1024uLL);
59          v30 = 0;
60          r_len = recvfrom(sock, buff, 1024uLL, 0, 0LL, 0LL);
61          v28 = buff;
62          size_ip = 4 * (buff[0] & 0xF);        // size_ip = IP_HL(ip)*4;
63        }
64        while ( size_ip <= 19 );
```

This very minor modification is a particularly improvement to it's stealth

Socket detection opportunities

`ss -0pb` will still surface the `BPF` filter.

```
# ss -0pb
..
 users:(("/usr/sbin/smart",pid=4535,fd=3))
        bpf filter (229):  0x30 0 0 0, 0x54 0 0 240 ..
```

Removing the `b` flag (and trimming out `systemd` related false positives), the socket is listed as `p_dgr`:

```
# ss -0p
p_dgr .... users:(("/usr/sbin/smart",pid=4812,fd=3))
```

If monitoring system calls, there are some opportunities. For example, `auditd` rules for `socket` with `AF_PACKET`. Expect false positives.

```
auditctl -a exit,always -F arch=b64 -S socket -F a0=17
```

and `setsockopt` with `SO_ATTACH_FILTER`:

```
auditctl -a exit,always -F arch=b64 -S setsockopt -F a2=26
```

No more deleted in /dev/shm

As an evasion technique, BPFDoor would copy itself into `/dev/shm`, execute itself then delete itself from disk as an anti-forensic technique.

The kernel marking a processes' executable `inode` as `(deleted)` within a temporary file system such as `/dev/shm` proclaims loudly "this deserves a closer look".

Now `BPFDoor` no longer touches `/dev/shm` nor does it deletes itself. It behaves more like a normal process with the exception of its process name masquerading with the `prctl` system call and overwriting the `envp` on the stack.

Process Names and Mutex Lock

Prior, the malware would randomly select a process name from a fixed list of common process names and a somewhat constant file path for its mutex lock. Both of these have changed - The masqueraded process name and mutex lock path may vary to better match the target environment. For reference, the original would randomly select from the following list of process names/arguments on initialization:

```
char *self[] = {
        "/sbin/udevd -d",
        "/sbin/mingetty /dev/tty7",
        "/usr/sbin/console-kit-daemon --no-daemon",
        "hald-addon-acpi: listening on acpi kernel interface /proc/acpi/event",
        "dbus-daemon --system",
        "hald-runner",
        "pickup -l -t fifo -u",
        "avahi-daemon: chroot helper",
        "/sbin/auditd -n",
        "/usr/lib/systemd/systemd-journald"
};
```

A single process name is now hard coded. For example, the following example disguises itself as `smartd`, a disk monitoring daemon:

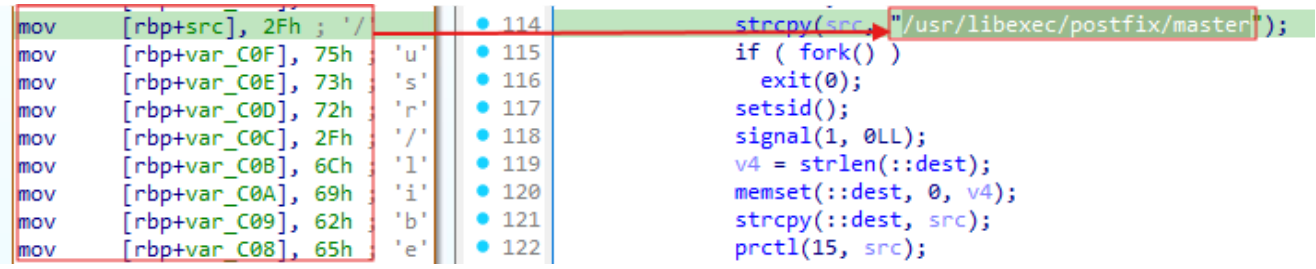
```
__int64 __fastcall main(int argc, char **argv, char **envp)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS NUMPAD "+" TO EXPAND]

  strcpy(pass, "73b9989bb8dd522b8e172f2e985810eb");
  strcpy(pass2, "d46bf5d43cffd7793665d40fc767ed86");
  src = "/usr/sbin/smartd -n -q never";
  file = "/var/run/hald-smartd.pid";
  if ( !access("/var/run/hald-smartd.pid", 4) )
    exit(0);
```

Other new "single process" masqueraded process names include:

- `lldpad -d`, `/var/run/lldpad.lock`
- `dbus-daemon --system`, `/var/run/system.pid`
- `/usr/libexec/hald-addon-volume`, `/var/run/hald-addon.pid`
- `/usr/sbin/console-kit`, `/var/run/console-kit.pid`

Notably, when a magic packet is received, the forked process name remains `/usr/libexec/postfix/master` and the familiar `qmgr`.

As with all BPFDoor samples, running 'strings' or similar will miss many strings. For example, in the disassembly, the `md5`password hashes above are littered with `mov` instructions. This is due to the use of the strings being defined as an array, or as a "stack string".



`bpfdoor-dump.py` can be used to extract obfuscated hashes and other strings from samples. Alternatively, check out this from elastic.co.

SSL Encryption

Vanilla`RC4` has been deprecated in the `getshell` function, replaced `SSL` using `RC4-MD5` for both `bind` mode (listening server) or the reverse connection mode (client).

```
106    v32 = BIO_new_mem_buf(certStr, -1);
107    v36 = sub_48FCD0(v32, 0LL, 0LL, 0LL);
108    SSL_CTX_use_certificate((__int64)sslCtx, v36);
109    v31 = BIO_new_mem_buf(privkeyStr, -1);
110    bio_RSAPrivateKey = PEM_read_bio_RSAPrivateKey((__int64)v31, 0LL, 0LL, 0LL);
111    SSL_CTX_use_RSAPrivateKey((__int64)sslCtx, bio_RSAPrivateKey);
112    if ( !(unsigned int)SSL_CTX_check_private_key((__int64)sslCtx) )
113    {
114      fwrite("Private key does not match the public certificate\n", 1uLL, 0x32uLL, stderr);
115      sub_4710D0(stderr);
116      return 0LL;
117    }
118    SSL_CTX_set_cipher_list((__int64)sslCtx, "RC4-MD5");
119    ssl = (void *)SSL_new((__int64 *)sslCtx);
120    SSL_set_fd(ssl, sock);
121    if ( SSL_accept((SSL *)ssl) <= 0 )
122    {
123      sub_4710D0(stderr);
124      return 0LL;
125    }
126  }
127  else                                          // reverse TCP mode
128  {
129    SSL_library_init();
130    sub_414FA0();
131    SSL_library_init();
132    v37 = (void *)sub_405A80();
133    sslCtx = (void *)SSL_CTX_new((__int64)v37);
134    if ( !sslCtx )
135      return 0LL;
136    SSL_CTX_set_cipher_list((__int64)sslCtx, "RC4-MD5");
137    ssl = (void *)SSL_new((__int64 *)sslCtx);
138    SSL_set_fd(ssl, sock);
139    if ( SSL_connect((SSL *)ssl) <= 0 )
140      return 0LL;
141  }
```

function names, vars have been renamed during decomp.

The hardcoded certificate and private key (used in `bind` / server mode, with `SSL_accept` is extractable with `strings`. In all samples analyzed, 3 unique self-signed certificates were identified.

```
-----BEGIN CERTIFICATE-----
MIIB+zCCAWQCCQCtA0agZ+qO5jANBgkqhkiG9w0BAQsFADBCMQswCQYDVQQGEwJY
WDEVMBMGA1UEBwwMRGVmYXVsdCBDaXR5MRwwGgYDVQQKDBNEZWZhdWx0IENvbXBh
bnkgTHRkMB4XDTIxMTEyMzAyMTc0NloXDTMxMTEyMTAyMTc0NlowQjELMAkGA1UE
BhMCWFgxFTATBgNVBAcMDERlZmF1bHQgQ2l0eTEcMBoGA1UECgwTRGVmYXVsdCBD
b21wYW55IEx0ZDCBnzANBgkqhkiG9w0BAQEFAAOBjQAwgYkCgYEAx1JvO+nqr24g
wc8at6x1NtZt7DoDi1/Ge/F70zz4gbxX/OxhOxXKexYrphsHXBzYVEWOyof9Vnok
ST7GKdRiRg6OS90WfdWFoVN2EdxwBN+BdozmwRBG1DAdqAhbeUcUFeZO0Fbuo7fr
FvTfsC31khj6ioKJl0d4kfo2zLk6WhcCAwEAATANBgkqhkiG9w0BAQsFAAOBgQA1
iC/5g+eN3Hq/627tMbLhipNUtC0OEdtpq20mbUIMXTRYh4kZPAah1LZqx2h72BV1
i8pYJo34kZ/3HyV6UJtBf/jJv1fprEWvo2Lj8YrCpagXh82i7353GUeiKFVr0gx+
4ruTus1m0bX1NZN6XRAbgzar7bfki0HHjWxJB8NRLQ==
-----END CERTIFICATE-----

openssl x509 --in cert.pem -noout -dates -fingerprint
notBefore=Nov 23 02:17:46 2021 GMT
notAfter=Nov 21 02:17:46 2031 GMT
SHA1 Fingerprint=85:CA:7E:BB:F1:1F:53:45:4E:DA:BB:27:DD:DC:59:DB:52:C2:0E:08
```

This change may explain one reason the newer samples are statically compiled, resulting in a much larger file executable file size - with the benefit of avoiding any linking issues with the SSL library.

Password hashes

Embedded passwords in older samples have been replaced with salted hashes. Where hashing was used, the same constant salt is present: `I5*AYbs@LdaWbsO`

```
__int64 __fastcall auth(const char *incoming_pass)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS NUMPAD "+" TO EXPAND]

  result = 0;
  memset(salt_pass, 0, sizeof(salt_pass));
  v11 = 0;
  *salt = 0LL;
  v6 = 0LL;
  v7 = 0LL;
  v8 = 0LL;
  v9 = 0LL;
  strcpy(_salt, "I5*AYbs@LdaWbsO");
  strcpy(salt, _salt);
  if ( incoming_pass )
    strncat(salt, incoming_pass, 14uLL);
  sub_4033BE(salt, salt_pass);
  v1 = strlen(revshell_pass);
  result = memcmp(revshell_pass, salt_pass, v1);
  if ( !result )
    return 0LL;
  v3 = strlen(bind_pass);
  result = memcmp(bind_pass, salt_pass, v3);
  if ( result )
    return 2LL;
  else
    return 1LL;
}
```

The first character of the password is used as an instruction on which mode to invoke. Passwords must start with either a `m`, `s` or `j`. This means the the search space for cracking the password hashes is reduced by one character which can make a huge difference in the time to brute force the key space, reducing the maximum length from 14 to 13 characters.

```
129   switch ( SBYTE2(password) )
130   {
131     case 'm':
132       puts("[+] Monitor packet send.");
133       direct = 2;
134       break;
135     case 's':
136       if ( raw == 2 || raw == 3 )
137       {
138         puts("[-] Mode error.");
139         return -1;
140       }
141       if ( raw == 1 && inaddr == -1 )
142       {
143         puts("[-] missing -l ");
144         return -1;
145       }
146       puts("[+] Direct connection mode");
147       direct = 1;
148       break;
149     case 'j':
150       puts("[+] Reserve connection mode");
151       if ( !v25 )
152       {
```

6227cb77cb4ab1d066eebf14e825dbc0a0a7f1e9

We can crack these hashes with [hashcat](), using mode `20` - `md5($salt.$pass)`

For example:

```
hashcat -a 3 -m 20 hash:I5*AYbs@LdaWbsO j?1?1?1?1?1?1?1?1?1 -1 ?l?u -i
```

Here are some hashes taken from samples with their corresponding plain-text password. *Cracked hashes that include acronyms which can identify the victim organisation have been omitted.*

```
aa73d4574fd91b9648d73b01ea1920f3:I5*AYbs@LdaWbsO:joinfare
5609e5e3d3e7efd85e219901ab06bb61:I5*AYbs@LdaWbsO:jberemote
215c5b9279d3e462eceb9af3b5028c05:I5*AYbs@LdaWbsO:justgetso
629849fe5277500a777087d78ddc5dde:I5*AYbs@LdaWbsO:jusrbackso
5fb2ce4f90c53071b12e65d52445d33d:I5*AYbs@LdaWbsO:javatelnet
73b9989bb8dd522b8e172f2e985810eb:I5*AYbs@LdaWbsO:justgetdata
05b37b412e1d1bfdc6b8643d3c869b01:I5*AYbs@LdaWbsO:justgetcheck
8528eba01dca94e6b0d7c4c8cc39889f:I5*AYbs@LdaWbsO:justgotowork
4cf71dacf1750e2a9f122fba74b86a5d:I5*AYbs@LdaWbsO:senttome
3de78247e0e1c9ca3c291bc060d9b622:I5*AYbs@LdaWbsO:setdefault
d46bf5d43cffd7793665d40fc767ed86:I5*AYbs@LdaWbsO:sentandconn
3d45acc78e9d6de380b3cbdccf38af0a:I5*AYbs@LdaWbsO:setopenview
```

`bpfdoor-dump.py` can be used to extract the hashes and generate the respective hashcat commands.

YARA Rules

Testing against both Elastic.co's set of `BPFDoor` `yara` rules from 2022 does identify the newer statically compiled, stripped samples due to the rule `Linux_Trojan_BPFDoor_5` including:

```
{ D0 48 89 45 F8 48 8B 45 F8 0F B6 40 0C C0 E8 04 0F B6 C0 C1 }
```

This corresponds to the instructions in the `packet_loop` function which calculates the offset of the `TCP` header for extracting the magic bytes in the `TCP` wakeup packets. But the ruleset does miss quite a few samples. For maximum coverage, use with Florian Roth's ruleset.

signature-base/yara/mal_lnx_implant_may22.yar at 391a990859091dbc4c21d15db335b371090f606e · Neo23x0/signature-base

YARA signature and IOC database for my scanners and tools - Neo23x0/signature-base

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Neo23x0/
signature-base

YARA signature and IOC database for my scanners and tools

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For additional coverage on the latest variants, including the early `NotBPDDoor` , the following YARA rules can be used:

```
rule bpfdoor_cert_variant
{
   meta:
      description = "Detects BPFDoor SSL versions"
      reference = ""
      date = "2025-04-31"
      hash1 = "3f6f108db37d18519f47c5e4182e5e33cc795564f286ae770aa03372133d15c4"
      hash2 = "724bd9163641666e035cef81701856fc9ff2dada2509d55dec14588fd1b5e801"
      hash3 = "7804f1dfb5d80a80830829c06ae65b410073748038f965f688dbd84d02eb0008"
      hash4 = "28bfb3f2067c77b83898ef4e41c9fc573e6aaa8581da9b59bddb782205a0b091"
      hash5 = "29564c19a15b06dd5be2a73d7543288f5b4e9e6668bbd5e48d3093fb6ddf1fdb"
      author = "@haxrob"
   strings:
      $s1 = "ttcompat" fullword ascii
      $s2 = "Private key does not match the public certificate" fullword ascii
      $s3 = "HISTFILE=/dev/null" fullword ascii
   condition:
      uint16(0) == 0x457f and (all of them)
}

rule notbpfdoor
{
   meta:
      description = "Detects early (2015/2016) variant"
      reference = ""
      date = "2025-04-31"
      hash1 = "ebffd115918f6d181da6d8f5592dffb3e4f08cd4e93dcf7b7f1a2397af0580d9"
      hash2 = "b2d3c212e71ddbaf015d8793d30317e764131c9beda7971901620d90e6887b30"
      author = "@haxrob"
   strings:
      $s1 = "ttcompat" fullword ascii
      $s2 = "auto install failed, plz manual install it!" fullword ascii
      $s3 = "unset LC_TIME" fullword ascii
   condition:
      uint16(0) == 0x457f and (all of them)
}
```