Revealing Embedded Fingerprints: Deriving intelligence from USB stack interactions

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Image from: p1fran.com

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Agenda

Part One:

- Overview of the USB enumeration phase
- Different USB stack implementations
- USB testing platform
- Installed drivers and supported devices
- Fingerprinting techniques
- Umap demo

Part Two:

- The Windows 8 RNDIS kernel pool overflow
- Challenges faced when exploiting USB bugs
- Conclusions

Part One: Information gathering

- Why do we care?
- If you connect to a device surely you already know the platform?
- Embedded devices are mostly based on Linux anyway aren't they?
- Allows you to focus your testing on only supported functionality

USB Background stuff

Image from: blog.brickhousesecurity.com

Overview of the USB enumeration phase

- What is enumeration for?
  - Assign an address
  - Speed of communication
  - Power requirements
  - Configuration options
  - Device descriptions
  - Identify class drivers
- Lots of information exchange – implemented in many different ways

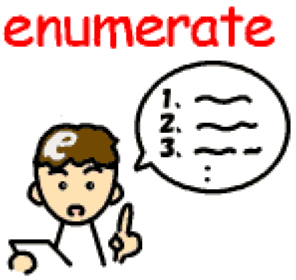


Image from :http://ewalk2.blog117.fc2.com

The USB enumeration phase

< Get **Device** descriptor
> Set Address
< Get **Device** descriptor
< Get **Configuration** descriptor
< Get **String** descriptor 0
< Get **String** descriptor 2
< Get **Configuration** descriptor
< Get **Configuration** descriptor
> Set Configuration

Enumeration phase peculiarities

- Why is the device descriptor initially requested twice?

- Why are there multiple requests for other descriptors?

- Class-specific descriptors:

< Get **Hub** descriptor

< Get **HID Report** descriptor

Typical components of a USB stack

- Host Controller hardware
- USB System software:
  - Host Controller Driver – Hardware Abstraction Layer
  - USB Driver
- Class drivers
- Application software

Image from: www.wired.com

Interacting with USB

Image from: www.nvish.com

USB interaction requirements

- Need to capture and replay USB traffic
- Full control of generated traffic
- Class decoders extremely useful
- Support for Low/High/Full speed required
- USB 3.0 a bonus

USB testing – gold-plated solution

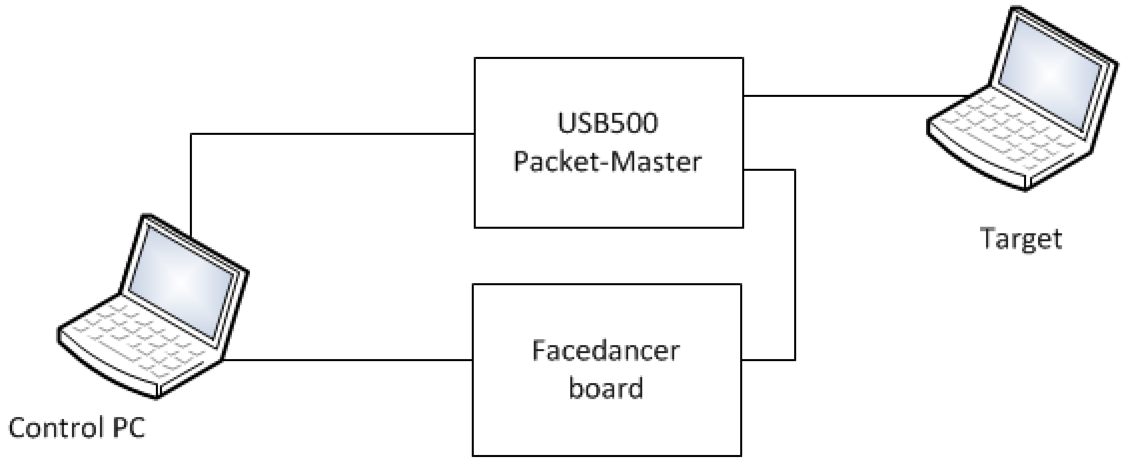
- Commercial test equipment

USB testing – the cheaper approach

- Facedancer (http://goodfet.sourceforge.net/hardware/facedancer21)

- Available pre-populated (http://int3.cc/collections/frontpage/products/facedancer21)

Best solution: A combination of both



- Device data can be carefully crafted
- Host response data can be captured
- Microsecond timing is also recorded
- All class-specific data is decoded

Information enumeration

Image from: network.nature.com

Target list

- Windows 8
- Ubuntu Linux 12.04 LTS
- Apple OS X Lion
- FreeBSD 5.3
- Chrome OS
- Linux-based TV STB

Installed drivers and supported devices

- Enumerating supported class types – standard USB drivers
- Enumerating all installed drivers
- Other devices already connected

Enumerating supported class types

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Where is USB class information stored?

Field	Value	Meaning
bLength	18	Valid Length
bDescriptorType	1	DEVICE
bcdUSB	0x0200	Spec Version
bDeviceClass	0x09	Hub
bDeviceSubClass	0x00	Full Speed Hub
bDeviceProtocol	0x01	

Device Descriptor

Field	Value	Meaning
bLength	9	Valid length
bDescriptorType	4	INTERFACE
bInterfaceNumber	0	Zero-based Number of this Interface.
bAlternateSetting	0	Value used to select this alternative setting for the interface identified in the prior field
bNumEndpoints	3	Number of endpoints used by this interface (excluding endpoint zero).
bInterfaceClass	0x06	Image
bInterfaceSubClass	0x01	
bInterfaceProtocol	0x01	
iInterface	0	Index of string descriptor describing this Interface

Interface Descriptor

Installed drivers and supported devices

- Drivers are referenced by class (Device and Interface descriptors)
- Also, by VID and PID:

idVendor	0x090C	Silicon Motion, Inc. - Taiwan
idProduct	0x1000	Memory Bar

- For each device class VID and PID values can be brute-forced (can easily be scripted using Facedancer)
- Although there may be some shortcuts….
- Valid PIDs and VIDs are available (http://www.linux-usb.org/usb.ids)

Enumerating installed drivers

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Not installed:

< Get **Device** descriptor
> Set Address
< Get **Device** descriptor
< Get **Configuration** descriptor
< Get **String** descriptor 0
< Get **String** descriptor 2
< Get **Configuration** descriptor
< Get **Configuration** descriptor
> Set Configuration

All communication stops after “Set Configuration”

Installed:

< Get **Device** descriptor
> Set Address
< Get **Device** descriptor
< Get **Configuration** descriptor
< Get **String** descriptor 0
< Get **String** descriptor 2
< Get **Configuration** descriptor
< Get **Configuration** descriptor
> Set Configuration
> Set Idle (HID)
< Get HID Report descriptor
> Set Report (HID)

Sniffing the bus - Other connected devices

- Data from other devices will be displayed on other addresses

FS	Bulk Transfer (SPLIT)	Addr	Endp	Data (0 bytes)	Status
⇦	Class Transfer	0x08	0x2		OK

HS	Control Transfe	Addr	Endp	Data (4 bytes)	Status
⇨	Vendor Reques	0x04	0x0	7F 54 12 4C	OK

FS	Bulk Transfer (SPLIT)	Addr	Endp	Data (0 bytes)	Status
⇦	Class Transfer	0x08	0x2		OK

FS	Bulk Transfer (SPLIT)	Addr	Endp	Data (0 bytes)	Status
⇦	Class Transfer	0x08	0x2		OK

- Controlling other devices? (untested)

Fingerprinting techniques

- Descriptor request patterns
- Timing information
- Descriptor types requested
- Responses to invalid data
- Order of Descriptor requests

OS Identification

Linux-based TV STB	Windows 8
< Get Max LUN (Mass Storage)	< Get Max LUN (Mass Storage)
> **CBW: INQUIRY**	> **CBW: INQUIRY**
< MSC Data In	< MSC Data In
< CSW - Status Passed	< CSW - Status Passed
> **CBW: TEST UNIT READY**	> **CBW: INQUIRY**
< CSW - Status Passed	< MSC Data In
> **CBW: READ CAPACITY**	< CSW - Status Passed
< MSC Data In	> **CBW: READ FORMAT CAPACITIES**
< CSW - Status Passed	< MSC Data In
> **CBW: MODE SENSE**	< CSW - Status Passed

Application identification

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gphoto2 (Linux)

> Image: **OpenSession**
< Image: OK
> Image: **GetDeviceInfo**
< Image: DeviceInfo
< Image: OK
> Image: **GetStorageIDs**
< Image: StorageIDs
< Image: OK
> Image: **GetStorageInfo**
< Image: StorageInfo
< Image: OK
> Image: **CloseSession**
< Image: OK

“Photos” Metro app (Windows 8)

> Image: **OpenSession**
< Image: OK
> Image: **GetDeviceInfo**
< Image: DeviceInfo
< Image: OK
> Image: **SetDevicePropValue**
> Image: **DeviceProperty**
< Image: OK
< Image: DeviceInfoChanged

DeviceProperty includes some text:
`/Windows/6.2.9200`
`MTPClassDriver/6.2.9200.16384`

Request patterns unique elements?

- Windows 8 (HID) – 3 x **Get Configuration** descriptor requests (others have two)
- Apple OS X Lion (HID) – **Set Feature** request right after **Set Configuration**
- FreeBSD 5.3 (HID) – **Get Status** request right before **Set Configuration**
- Linux-based TV STB (Mass Storage) – Order of class-specific requests

Timing information (work in progress…)

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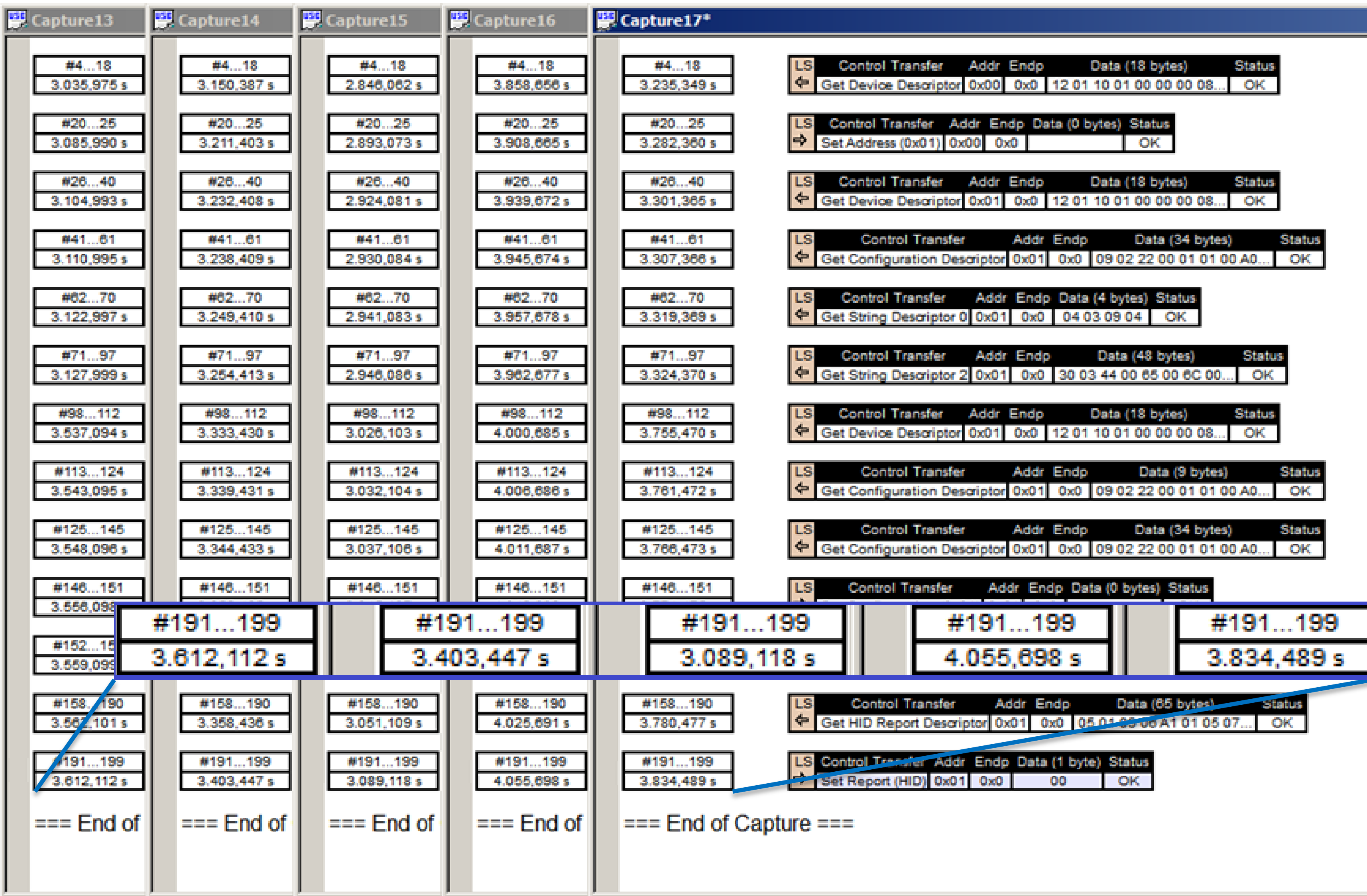
Packets	Capture13	Capture14	Capture15	Capture16	Capture17*	Speed / Dir	Control Transfer	Addr	Endp	Data	Status
#4…18	3.035,975 s	3.150,387 s	2.846,062 s	3.858,656 s	3.235,349 s	LS ⇦	Get Device Descriptor	0x00	0x0	(18 bytes) 12 01 10 01 00 00 00 08...	OK
#20…25	3.085,990 s	3.211,403 s	2.893,073 s	3.908,665 s	3.282,360 s	LS ⇨	Set Address (0x01)	0x00	0x0	(0 bytes)	OK
#26…40	3.104,993 s	3.232,408 s	2.924,081 s	3.939,672 s	3.301,365 s	LS ⇦	Get Device Descriptor	0x01	0x0	(18 bytes) 12 01 10 01 00 00 00 08...	OK
#41…61	3.110,995 s	3.238,409 s	2.930,084 s	3.945,674 s	3.307,366 s	LS ⇦	Get Configuration Descriptor	0x01	0x0	(34 bytes) 09 02 22 00 01 01 00 A0...	OK
#62…70	3.122,997 s	3.249,410 s	2.941,083 s	3.957,678 s	3.319,369 s	LS ⇦	Get String Descriptor 0	0x01	0x0	(4 bytes) 04 03 09 04	OK
#71…97	3.127,999 s	3.254,413 s	2.946,086 s	3.962,677 s	3.324,370 s	LS ⇦	Get String Descriptor 2	0x01	0x0	(48 bytes) 30 03 44 00 65 00 6C 00...	OK
#98…112	3.537,094 s	3.333,430 s	3.026,103 s	4.000,685 s	3.755,470 s	LS ⇦	Get Device Descriptor	0x01	0x0	(18 bytes) 12 01 10 01 00 00 00 08...	OK
#113…124	3.543,095 s	3.339,431 s	3.032,104 s	4.006,686 s	3.761,472 s	LS ⇦	Get Configuration Descriptor	0x01	0x0	(9 bytes) 09 02 22 00 01 01 00 A0...	OK
#125…145	3.548,096 s	3.344,433 s	3.037,106 s	4.011,687 s	3.766,473 s	LS ⇦	Get Configuration Descriptor	0x01	0x0	(34 bytes) 09 02 22 00 01 01 00 A0...	OK
#146…151	3.556,098 s	3.352,435 s	3.045,107 s	4.019,689 s	3.774,475 s	LS ⇨	Set Configuration (0x01)	0x01	0x0	(0 bytes)	OK
#152…157	3.559,099 s	3.355,437 s	3.048,109 s	4.022,690 s	3.777,476 s	LS ⇨	Set Idle (HID) Indefinite, All	0x01	0x0	(0 bytes)	OK
#158…190	3.562,101 s	3.358,436 s	3.051,109 s	4.025,691 s	3.780,477 s	LS ⇦	Get HID Report Descriptor	0x01	0x0	(65 bytes) 05 01 09 06 A1 01 05 07...	OK
#191…199	3.612,112 s	3.403,447 s	3.089,118 s	4.055,698 s	3.834,489 s	LS ⇨	Set Report (HID)	0x01	0x0	(1 byte) 00	OK
=== End of	=== End of	=== End of	=== End of	=== End of	=== End of Capture ===						

Timing information (work in progress…)



Using timing information? (work in progress…)

- Large amount of variance over entire enumeration phase:
  - 4.055s, 3.834s, 3.612s, 3.403s, 3.089s

- Much greater accuracy between specific requests:
  - Between String Descriptor #0 and #2 requests - 5002us, 5003us, 5003us, 4999us, 5001us

- If we know the OS can we potentially determine the processor speed?

Descriptor types requested

- Microsoft OS Descriptors (MOD)
- Used for “unusual” devices classes
- Devices that support Microsoft OS Descriptors must store a special USB string descriptor in firmware at the fixed string index of 0xEE. The request is:

bmRequestType	bRequest	wValue	wIndex	wLength	Data
1000 0000B	GET_DESCRIPTOR	0x03EE	0x0000	0x12	Returned String

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Responses to invalid data

- Different USB stacks respond to invalid data in different ways
- Maximum and minimum values
- Logically incorrect values
- Missing data
- In some cases: Crashes (potential vulnerabilities)
- Other cases: Unique behaviour

Image from: windows7.iyogi.com

Invalid data unique elements?

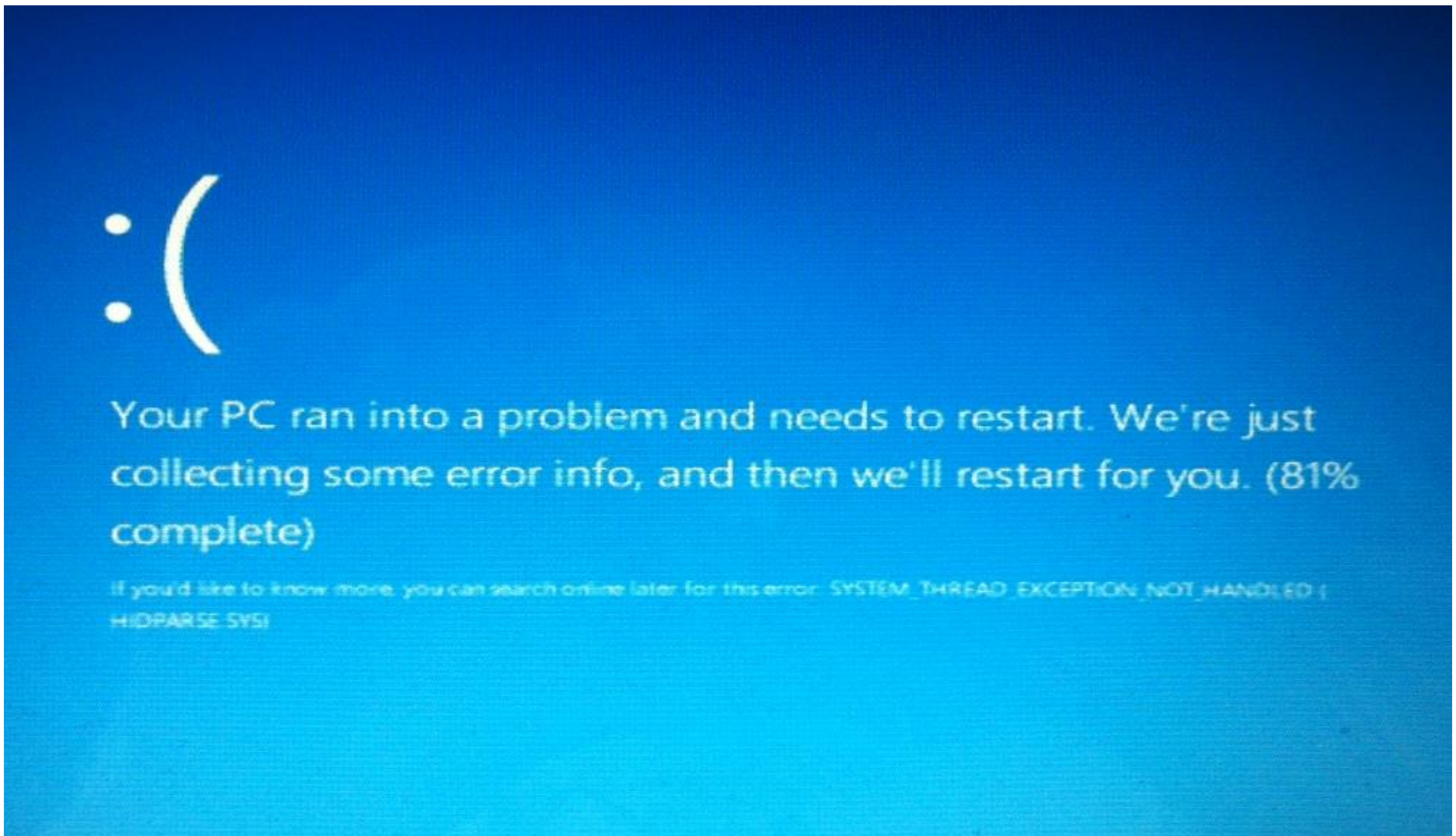
Windows (all versions)

If you send a specific, logically incorrect HID Report descriptor this happens:

Invalid data unique elements?

Windows (all versions)

If you send a specific, logically incorrect HID Report descriptor this happens:



Demo: umap

https://github.com/nccgroup/umap

Image from: us.cdn4.123rf.com

Umap overview

- Supported device classes can be enumerated
- Operating system information can be enumerated
- Devices with specific VID/PID/REV can be emulated
- The enumeration phase and class-specific data can be fuzzed
- Endpoint protection systems configuration can be assessed
- Endpoint protection systems USB protection can be circumvented
- USB host implementations can be comprehensively tested

Part Two: Potentially exploitable USB bugs

Image from: www.biro-media.hr

The Windows 8 RNDIS kernel pool overflow

- MS13-027

- *usb8023x.sys* - default (Microsoft-signed) Windows Remote NDIS driver that provides network connectivity over USB.

- When the following USB descriptor field is manipulated a Bug check occurs indicating a kernel pool overwrite:

  Configuration descriptor: bNumInterfaces field > actual number of USB interfaces

The Bug Check

```
BAD_POOL_HEADER (19)
The pool is already corrupt at the time of the current request.

<Truncated for brevity>

Arguments:
Arg1: 00000020, a pool block header size is corrupt.
Arg2: 83e38610, The pool entry we were looking for within the page.
Arg3: 83e38690, The next pool entry.
Arg4: 08100008, (reserved)

<Truncated for brevity>

WARNING: SystemResourcesList->Flink chain invalid. Resource may be
corrupted, or already deleted.

WARNING: SystemResourcesList->Blink chain invalid. Resource may be
corrupted, or already deleted.

SYMBOL_NAME:  usb8023x!SelectConfiguration+1bd
```

The SelectConfiguration() function

```
SelectConfiguration(x)          mov     edi, edi
SelectConfiguration(x)+2        push    ebp
SelectConfiguration(x)+3        mov     ebp, esp
SelectConfiguration(x)+5        sub     esp, 10h
SelectConfiguration(x)+8        push    ebx
SelectConfiguration(x)+9        push    esi
SelectConfiguration(x)+A        mov     esi, [ebp+ptr_Pool_U802]
SelectConfiguration(x)+D        push    edi
SelectConfiguration(x)+E        mov     edi, [esi+1Ch]  ; points to start of configuration descriptor
SelectConfiguration(x)+11       mov     al, [edi+4]     ; al = bNumInterfaces
SelectConfiguration(x)+14       cmp     al, 2           ; compares with 2 (what it should be)
SelectConfiguration(x)+16       jb      loc_11877       ; no jump
SelectConfiguration(x)+1C       movzx   eax, al
SelectConfiguration(x)+1F       lea     eax, ds:8[eax*8] ; multiply bNuminterfaces by 8 then add 8 = 24
SelectConfiguration(x)+26       push    eax
SelectConfiguration(x)+27       call    _AllocPool@4    ; AllocPool(x)
SelectConfiguration(x)+2C       mov     [ebp+ptr_Pool_U802_24_bytes], eax
SelectConfiguration(x)+2F       test    eax, eax
SelectConfiguration(x)+31       jz      loc_11877       ; no jump (AllocPool was successful)
SelectConfiguration(x)+37       xor     ebx, ebx
SelectConfiguration(x)+39       cmp     [edi+4], bl     ; compares bNumInterfaces with 0
SelectConfiguration(x)+3C       jbe     short loc_1171F ; no jump
SelectConfiguration(x)+3E       mov     esi, eax
```

The crash point

```
SelectConfiguration(x)+9B   yet_more_interfaces_to_parse:           ; CODE XREF: SelectConfiguration(x)+CE↓j
SelectConfiguration(x)+9B                push    0FFFFFFFFh
SelectConfiguration(x)+9D                push    0FFFFFFFFh
SelectConfiguration(x)+9F                push    0FFFFFFFFh
SelectConfiguration(x)+A1                push    0
SelectConfiguration(x)+A3                push    ecx
SelectConfiguration(x)+A4                push    edi
SelectConfiguration(x)+A5                push    edi
SelectConfiguration(x)+A6                call    ds:__imp__USBD_ParseConfigurationDescriptorEx@28
SelectConfiguration(x)+AC                test    eax, eax
SelectConfiguration(x)+AE                jz      short loc_11770
SelectConfiguration(x)+B0                mov     al, [eax+5]
SelectConfiguration(x)+B3                mov     [esi+4], al
SelectConfiguration(x)+B6                jmp     short loc_11774
SelectConfiguration(x)+B8   ; ---------------------------------------------------------------------------
SelectConfiguration(x)+B8
SelectConfiguration(x)+B8   loc_11770:                              ; CODE XREF: SelectConfiguration(x)+AE↑j
SelectConfiguration(x)+B8                mov     byte ptr [esi+4], 0 ; writes one null byte over the first byte of the next pool header
SelectConfiguration(x)+B8                                        ; this is where the corruption occurs
SelectConfiguration(x)+BC
SelectConfiguration(x)+BC   loc_11774:                              ; CODE XREF: SelectConfiguration(x)+B6↑j
SelectConfiguration(x)+BC                movzx   eax, word ptr [esi]
SelectConfiguration(x)+BF                mov     ecx, [ebp+ptr_Pool_U802_24_bytes]
SelectConfiguration(x)+C2                add     esi, eax
SelectConfiguration(x)+C4                movzx   eax, byte ptr [edi+4]
SelectConfiguration(x)+C8                inc     ecx
SelectConfiguration(x)+C9                mov     [ebp+ptr_Pool_U802_24_bytes], ecx
SelectConfiguration(x)+CC                cmp     ecx, eax
SelectConfiguration(x)+CE                jb      short yet_more_interfaces_to_parse
```

Analysis #1

When bNumInterfaces = 3 (one more than it should be) and bNumEndpoints = 2 (valid value)

Next kernel pool:

```
849c3b28  10 00 0a 04 56 61 64 6c-6b 8f 94 85 28 8c 90 85  ....Vadlk...(...
```

becomes:

```
849c3b28  00 00 0a 04 56 61 64 6c-6b 8f 94 85 28 8c 90 85  ....Vadlk...(...
```

So we’re overwriting "PreviousSize" in the next nt!_POOL_HEADER - this is what triggered the original Bug Check when ExFreePool() is called

Analysis #2

When bNumInterfaces = 3 (one more than it should be) and bNumEndpoints = 5 (three more than it should be)

Next kernel pool:

```
84064740  17 00 03 00 46 72 65 65-48 2d 09 84 30 a8 17 84  ....FreeH-..0...
```

becomes:

```
84064740  17 00 03 00 00 72 65 65-48 2d 09 84 30 a8 17 84  .....reeH-..0...
```

So we’re now overwriting "PoolTag" in the next nt!_POOL_HEADER

What’s going on?

```
kd> dt nt!_POOL_HEADER
- +0x000 PreviousSize : Pos 0, 8 Bits
- +0x000 PoolIndex : Pos 8, 8 Bits
- +0x000 BlockSize : Pos 16, 8 Bits
- +0x000 PoolType : Pos 24, 8 Bits
- +0x004 PoolTag : Uint4B
- +0x008 ProcessBilled : Ptr64 _EPROCESS
```

By manipulating bNumInterfaces and bNumEndpoints in a USB Configuration descriptor we appear to have a degree of control over where in the next adjacent kernel memory pool we can overwrite a single byte with a null (the null write occurs four bytes after the end of the pool I control and I can also control its size and some elements of its contents so could also potentially overwrite the next pool header with something useful)

Some pseudo code

```
for (i=0; i<something->count; i++)
  {
    list[i].descriptor = USBD_ParseConfigurationDescriptorEx (...);

    if(!list[i].descriptor)
      break;
  }

list[i].descriptor = NULL;

newthing = USB_CreateConfigurationRequestEx(thing, list);

if(newthing)
  {
    ptr = &newthing->somemember;
    for (i=0; i<something->count; i++)
      {
        descriptor = USBD_ParseConfigurationDescriptorEx (...);

        if(descriptor)
          {
            ptr->someothermember = descriptor->whatever;
          }
        else
          {
            ptr->someothermember = 0;  // this is where I believe the corruption happens
          }
        ptr = ptr + ptr->Length;
      }
  }
```

Challenges faced when exploiting USB bugs

- Lack of feedback channel
- The bug is often in kernel code
- Descriptors are generally very size-constrained
- Typical impact of USB exploitation typically restricted to privilege escalation
- Modern operating systems e.g. Windows 8 have comprehensive exploit mitigation

Image from: leadershipfreak.wordpress.com

Conclusions

- The USB enumeration phase reveals useful information for fingerprinting
- Class-specific communication is potentially even more revealing
- Even vendors with mature SDL processes have USB bugs
- USB bugs can potentially be exploited, to provide privilege escalation
- …but it is extremely difficult to achieve reliably

Questions?

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