Dynamic Detection of Vulnerability Exploitation in Windows

Dynamisk detektion af udnyttelse af sårbarheder i Windows

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Todo list

Abstract

Write something very clever here and read it through 10000 times

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Introduce something here

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Purpose

Tracing and logging

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Event Tracing for Windows (ETW) is a logging mechanism that is built into the kernel of Windows. It is used by kernel-mode drivers and applications to provide realtime events and tracing features. While ETW is built into most drivers and applications made by Windows, it is also available for developers to use in their own applications. As most privileged applications built into Windows utilize ETW, it is a very good source for telemetry data related to discovering exploit attempts.

In the architecture of ETW events are at the centerpiece where they are created, managed and consumed by different event components[4]. These differentiate between event *providers*, event *consumers*, and event *controllers*. All of these event components handle the workflow of ETW, either by reading or writing, or by controlling the events in some way.

2.2.1 Event components

As it can be seen on Figure 2.1 (ETW model diagram[4]), the central component of ETW is the ETW session. All ETW components communicate through the ETW session.

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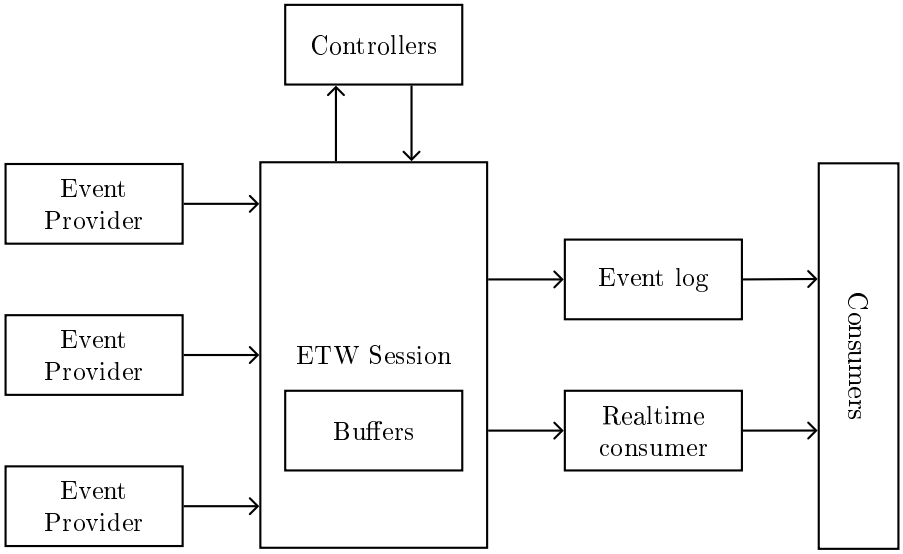


Figure 2.1: ETW model diagram[4]

Controllers

Providers

Providers are the system- and userland applications that provide events and data. They do so by registering themselves as a provider, allowing a controller to enable or disable events. By having the controller control whether events are enabled or not, allows an application to have tracing without generating alerts all the time. This is especially interesting for debugging purposes, which is usually not needed during regular usage.

Microsoft define four different types of providers depending on the version of Windows and type of application you are interested in.

Managed Object Format (MOF) (classic) providers

Windows softwarre trace preprocessor (WPP) providers

Manifest-based providers

TraceLogging providers

Consumers

Consumers are applications that consume events from providers. This is done through event *trace sessions*, where one session is created per provider. Con-

sumers have the ability to both receive events in real time from *trace sessions*, or later on by events stored in log files. Furthermore, events can be filtered by many attributes such as timestamps.

Figure shows how the different components of ETW works together to produce and consume events

add ref to figure

2.2.2 Finding providers

2.2.3 Consuming events

Mention TI provider and how it is used in many EDRs to detect malicious activity

Vulnerability analysis

3.1 CVE-2021-24086

According to Microsoft[5] CVE-2021-24 086 is a denial of service vulnerability with a CVSS:3.0 score of 7.5 / 6.5, that is a base score metrics of 7.5 and a temporal score metrics of 6.5. The vulnerability affects all supported versions of Windows and Windows Server. According to an accompanied blog post published by Microsoft [7] at the same time as the patch was released, details that the vulnerable component is the Windows TCP/IP implementation, and that the vulnerability revolves around IPv6 fragmentation. The Security Update guide and the blog post also present a workaround that can be used to temporarily mitigate the vulnerability by disabling IPv6 fragmentation.

Figure out if this should be here

3.1.1 Public information

Due to the Microsoft Active Protetions Program (MAPP)[6] security software providers are given early access to vulnerability information. This information often include Proof of Concept (PoC)s for vulnerabilities to be patched, in order to aid security software providers to create valid detections for exploitation of soon-to-be patched vulnerabilities. Due to MAPP, some security software providers publish relevant information regarding recently patched vulnerabilities. However, the information is usually very vague in details, and can therefore only aid in the initial exploration of the vulnerability. For CVE-2021-24086, both McAfee[10] and Palo Alto[9] posted public information about CVE-2021-24086. However, both articles contained very limited details, and is therefore far from sufficient to reproduce the vulnerability. Before trying to rediscover the vulnerability, the following information is available:

- The vulnerability lies within the handling om fragmented packets in IPv6
- The relevant code lies within the `tcpip.sys` drivers
- The root cause of the vulnerability is a NULL pointer dereference in `Ip` ⌋ `v6ReassembleDatagram` of `tcpip.sys`
- The reassembled packet should contain around 0xFFFF (65535) bytes of extension headers, which is usually not possible

3.1.2 Binary diffing

The usage of binary diffing to gather information about patched vulnerabilities is well described in current research[8][11], and has been made popular and easy to do by tools such as Bindiff[12] and Diaphora[3].

write a little about how bindiffing works. Or don't idc.

If we look at figure 3.1 we can compare the function changes of the patched and not-patched `tcpip.sys`. Looking at `tcpip!Ipv6pReassembleDatagram` we can see that the similarity factor is only 0.38 telling us that a significant amount of code has been changed.

Similarity	Confid	Change	EA Primary	Name Primary	EA Secondary	Name Secondary
0.16	0.27	GI--E--	00000001C018D794	sub_00000001C018D794	00000001C015A1D6	sub_00000001C015A1D6
0.27	0.42	GI--EL-	00000001C01905B5	sub_00000001C01905B5	00000001C01568FC	IppCleanupPathPrimitive
0.31	0.73	GI--E--	00000001C0190F38	Ipv4pReassembleDatagram	00000001C0190F68	Ipv4pReassembleDatagram
0.38	0.98	GI--E--	00000001C0199FAC	Ipv6pReassembleDatagram	00000001C019A0AC	Ipv6pReassembleDatagram
0.42	0.62	-I--E--	00000001C0154959	sub_00000001C0154959	00000001C0001E42	sub_00000001C0001E42
0.54	0.96	GI-----	00000001C019A658	Ipv6pReceiveFragment	00000001C019A7F8	Ipv6pReceiveFragment

Figure 3.1: Primary matched functions of `tcpip.sys`

Diving into the binary diff of `tcpip!Ipv6pReassembleDatagram` as seen on listing 1, we can clearly see a change. The first many changes from line *5-39* are simply register changes and other insignificant changes due to how the compiler works. However, on line *41-42* a new comparison is made to ensure that the value of the register `edx` is less than 0xFFFF. This matches the statement given in subsection 3.1.1 (Public information), that the vulnerability is triggered by a package of around 0xFFFF bytes.

```
--- "a/.\\unpatched tcpip.sys"
+++ "b/.\\patched tcpip.sys"
@@ -1,6 +1,4 @@
-sub     rsp, 58h        ; Integer Subtraction
+sub     rsp, 60h        ; Integer Subtraction
 movzx   r9d, word ptr [rdx+88h] ; Move with Zero-Extend
 mov     rdi, rdx
 mov     edx, [rdx+8Ch]
-mov     bl, r8b
+mov     r13b, r8b
 add     edx, r9d        ; Add
-mov     byte ptr [rsp+98h+var_70], 0
-and     [rsp+98h+var_78], 0 ; Logical AND
 mov     [rsp+98h+length], edx
 lea     eax, [rdx+28h]  ; Load Effective Address
-mov     rdx, rdi
 mov     [rsp+98h+var_68], eax
 lea     eax, [r9+28h]   ; Load Effective Address
 mov     [rsp+98h+BytesNeeded], eax
-xor     r9d, r9d        ; Logical Exclusive OR
 mov     rax, [rcx+0D0h]
-lea     rcx, IppReassemblyNetBufferListsComplete ; Load
↪  Effective Address
-mov     r13, [rax+8]
-mov     rax, [r13+0]
+mov     r12, [rax+8]
+mov     rax, [r12]
 mov     r15, [rax+28h]
 mov     eax, gs:1A4h
 mov     r8d, eax
-mov     rax, [r13+388h]
+mov     rax, [r12+388h]
 lea     rbp, [r8+r8*2]  ; Load Effective Address
-mov     r12, [rax+r8*8]
-xor     r8d, r8d        ; Logical Exclusive OR
+mov     rcx, [rax+r8*8]
 shl     rbp, 6          ; Shift Logical Left
-add     rbp, [r15+4728h] ; Add
+add     rbp, [r15+4728h] ; Add
+mov     [rsp+98h+var_58], rcx
+cmp     edx, 0FFFFh     ; Compare Two Operands
+jbe     short loc_1C019A186 ; Jump if Below or Equal (CF=1 |
↪  ZF=1)
```

Listing 1: Diff of patched and vulnerable `Ipv6pReassembleDatagram`

Looking at the raw assembly without any knowledge of what the registers contain or what parameters are passed to the function can be very confusing. To make it easier for the reader to follow, listing 2 contains the annotated decompiled code of the vulnerable and patched `tcpip!Ipv6pReassembleDatagram` function. Here the patch is easy to spot, as the call to `tcpip!NetioAllocateAndReferenceNetBufferAndNetBufferList` is replaced with the check that we also observed in listing 1. The check is there to ensure that the total packet size is less than 0xFFFF, which is the largest 16 bit value. The packet size is calculated on line *4-6* using the fragmentable and unfragmentable parts of the reassembled packet.

```
1  --- "a/.\\unpatched tcpip.sys"
2  +++ "b/.\\patched tcpip.sys"
3   void __fastcall Ipv6pReassembleDatagram(__int64 a1,
    ↪  struct_datagram *datagram, char a3) {
4   unfragmentableHeaderLength =
    ↪  datagram->unfragmentableHeaderLength;
5   packetSize = unfragmentableHeaderLength +
    ↪  datagram->fragmentableLength;
6   BytesNeeded = unfragmentableHeaderLength + 40;
7   v6 = *(_QWORD *)(*(_QWORD *)(a1 + 208) + 8i64);
8   v7 = *(_QWORD *)(*(_QWORD *)v6 + 40i64);
9   LockArray_high = HIDWORD(KeGetPcr()[1].LockArray);
10 -v11 = NetioAllocateAndReferenceNetBufferAndNetBufferList(IppRea
   ↪  ssemblyNetBufferListsComplete, datagram, 0i64, 0i64, 0,
   ↪  0);
11 +if ( packetSize > 0xFFFF )
```

Listing 2: Diff of patched and vulnerable `Ipv6pReassembleDatagram`

At this stage of the vulnerability rediscovery process, the following requirements are now available:

- We have to abuse IPv6 fragmentation in `tcpip!Ipv6pReassembleDatagram`
- We have to construct a single packet with around 0xFFFF bytes of extension headers
- We have to trigger a null dereference somewhere in `tcpip!Ipv6pReassembleDatagram`

The next section will give a primer into how IPv6 fragmentation works to better understand how we can fulfill the above-mentioned requirements.

3.1.3 IPv6 fragmentation primer

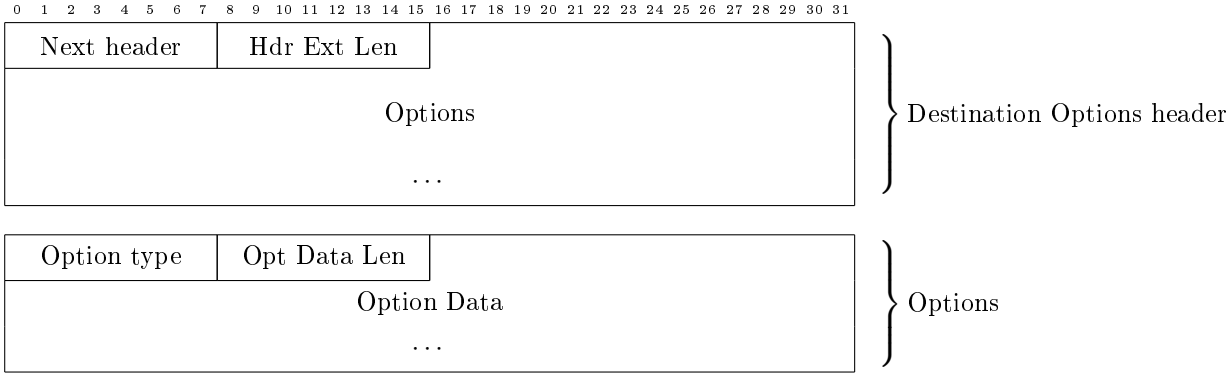
When the size of a packet is larger than the Maximum transmission unit (MTU) of the outbound interface, IPv6 fragmentation is used. The MTU of most standard network equipment and desktop computers is 1500 bytes. Therefore if you have an IPv6 packet that is larger than 1500 bytes, the packet must be fragmented. This is done by splitting the packet into a number of fragments, that each has to be decorated with the IPv6 fragment header. This header is a part of the specification for IPv6 Extension Headers[2, sec. 4.5]. The IPv6 Extension Headers specification specify a number of headers situated between the IPv6 header and the upper-layer header in a packet. The full list of extension headers can be seen in the following list:

1. Hop-by-Hop Options
2. *Fragment*
3. *Destination Options*
4. Routing
5. Authentication
6. Encapsulating Security Payload

As mentioned in section 3.1.1, the vulnerability is triggered when around 0xFFFF bytes of extension headers are present in the packet. Therefore, the following sections will describe both the *Destination Options* and *Fragment* extension headers in enough detail to support the exploitation of CVE-2021-24086.

IPv6 Destination Options extension header

IPv6 Destination Options are a way of defining options that should be handled by the destination node. In our case this would be the device that we are trying to attack using CVE-2021-24086. The specification can be seen on Figure 3.2 (IPv6 Destination Options Header [2, sec. 4.6]). The header is essentially structured as a list of options, where it is up to the receiver of a packet to support certain options.



Where

Next Header is an 8-bit selector identifying the initial header type of the Fragmentable part of the original packet.

Hdr Ext Len is an 8-bit unsigned integer describing the length of the Destination Option header in 8-octets units excluding the first 8 octets

Options is a variable-length field. See below

And

Option Type is an 8-bit identifier of the option type

Opt Data Len is an 8-bit unsigned integer describing the length of the *Data Option* field in octets

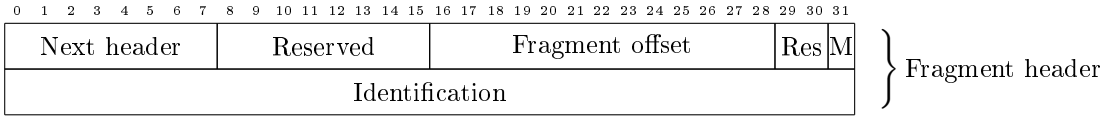
Options is a variable-length field with data specified by the option type

Figure 3.2: IPv6 Destination Options Header [2, sec. 4.6]

By default, only one option exist, the *PadN option*[2, sec. 4.2] which is used to create padding between two options. While this may not seem overly exciting, it is a very important part of how we can exploit CVE-2021-24086. Most other extension headers contain data that must be valid, such as routing options, which makes it hard to create a valid packet with around 0xFFFF bytes of extension headers. Destination Options does not have this limitation, as we can simply fill it with an arbitrary number of *PadN* options.

IPv6 Fragment extension header

Moving on to the IPv6 Fragment extension header, which, as mentioned earlier, is a header placed when you split an IPv6 packet into smaller fragments. IPv6 fragments are mostly used to send packets larger than the configured MTU, on either the sender or receiver side. The specification is detailed on figure Figure 3.3 (IPv6 Fragment Header [2, sec. 4.5]). The header contains an offset that points to where the fragment data fits into the entire packet.



Where

Next Header is an 8-bit selector identifying the initial header type of the Fragmentable part of the original packet.

Reserved is an 8-bit reserved field. Initialized to zero.

Fragment Offset is a 13-bit unsigned integer stating the offset.

Res is a 2-bit reserved field that is initialized to zero by the transmitter and ignored by the receiver.

M flag is a 1-bit boolean field describing if this is the last fragment. 1 = more fragments, 0 = last fragment.

Identificiation is a 32-bit identifier that is unique to fragments from the same package.

Figure 3.3: IPv6 Fragment Header [2, sec. 4.5]

Every packet that is fragmented has an unique identification, as specified in Figure 3.3 (IPv6 Fragment Header [2, sec. 4.5]). According to the specification[2, sec. 4.5], this identification must be different than any other fragmented packet sent recently[1].

A packet destined to be fragmented goes through two different processes, fragmentation and reassembly. Fragmentation happens on the sender side whereas reassembly is handled by the recipient of the packet.

[1] Recently is very loosely defined by RFC 8200[2] as the *"maximum likely lifetime of a packet, including transit time from source to destination and time spent awaiting reassembly with other fragments of the same packet."*[2, sec. 4.5]

Fragmentation is done by the sender and is a fairly simple concept. Looking at figure Figure 3.4 (IPv6 fragmentation[1]), it can be seen that an IPv6 packet contains two parts, an unfragmentable and a fragmentable part. The unfragmentable part is the IPv6 headers and the following two IPv6 extension headers, as they are processed by nodes en route:

- Hop-by-Hop Options Headers
- Routing Header

The rest of the IPv6 packet, including the Destination Options header, is handled as a fragmentable part.

Reassembly Reassembling the fragmented packet is done by the receiver and is essentially the fragmentation process in reverse. So here the receiver will convert a number of fragments into a single packet that can be handled as a standard IPv6 packet. The split of a fragmented packet can be seen on figure Figure 3.4 (IPv6 fragmentation[1]). Here it is easy to see that every fragment contains the unfragmentable part before any fragmented data.

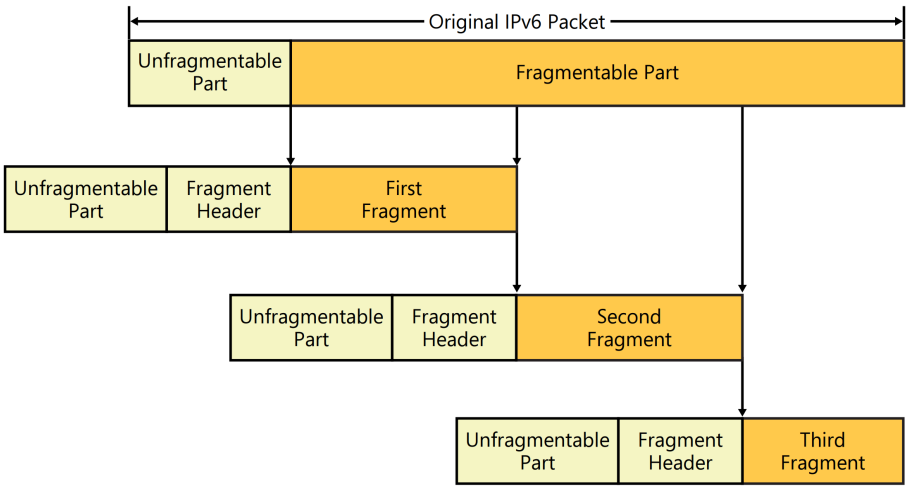


Figure 3.4: IPv6 fragmentation[1]

3.1.4 Root-cause analysis

3.1.5 Triggering the vulnerability

Detection

4.1 Event Tracing for Windows (ETW)

4.2 Hooking and DTrace

4.3 Implementation

Scaling and extensibility

Conclusion

Conclude something please

Abbreviations

ETW Event Tracing for Windows. 3–5, 14

MAPP Microsoft Active Protetions Program. 6

MOF Managed Object Format. 4

MTU Maximum transmission unit. 10, 12

PoC Proof of Concept. 6

WPP Windows softwarre trace preprocessor. 4

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Appendices

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