Fuzzing Remote Desktop Protocol

RDP에 대한 이해부터 퍼징, 취약점 발굴까지

2023.7.3

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with Team BTS (BoB 11th)

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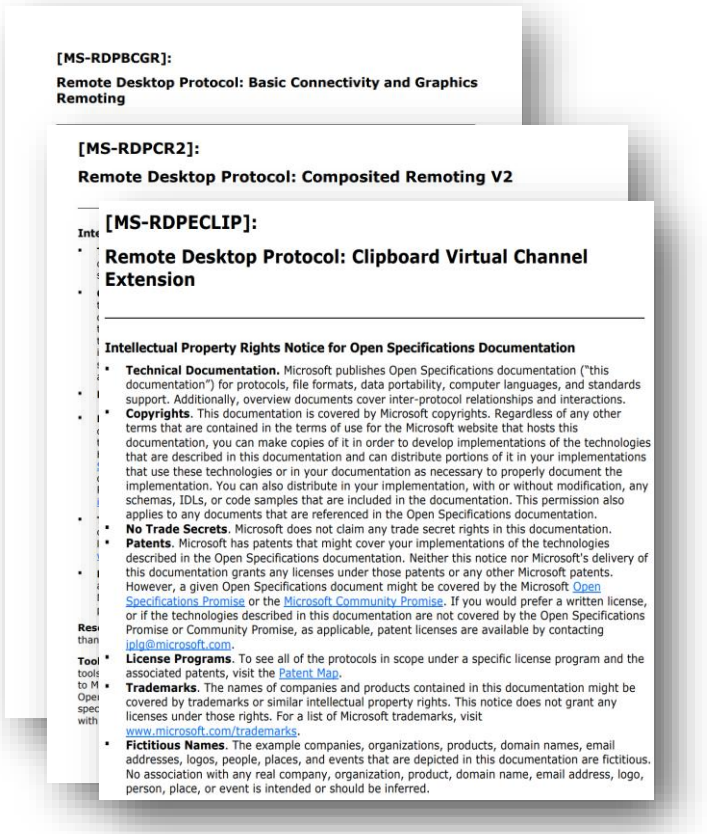
RDP 개요

What is RDP?

Microsoft 사에서 원격 데스크톱 연결을 위해 개발한 프로토콜

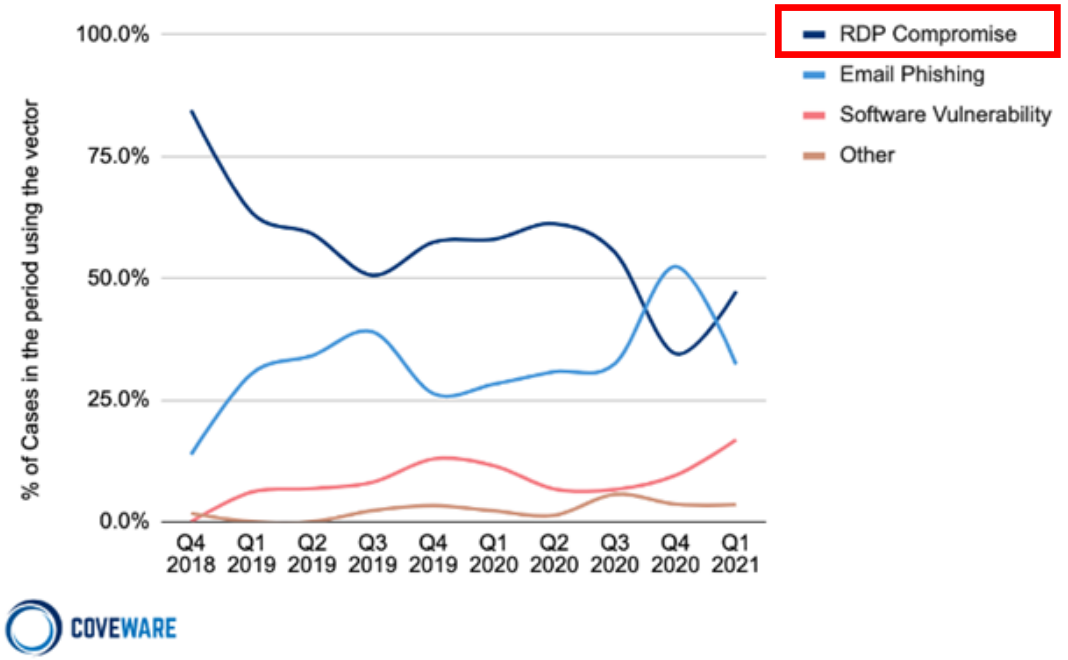


What are RDP services?

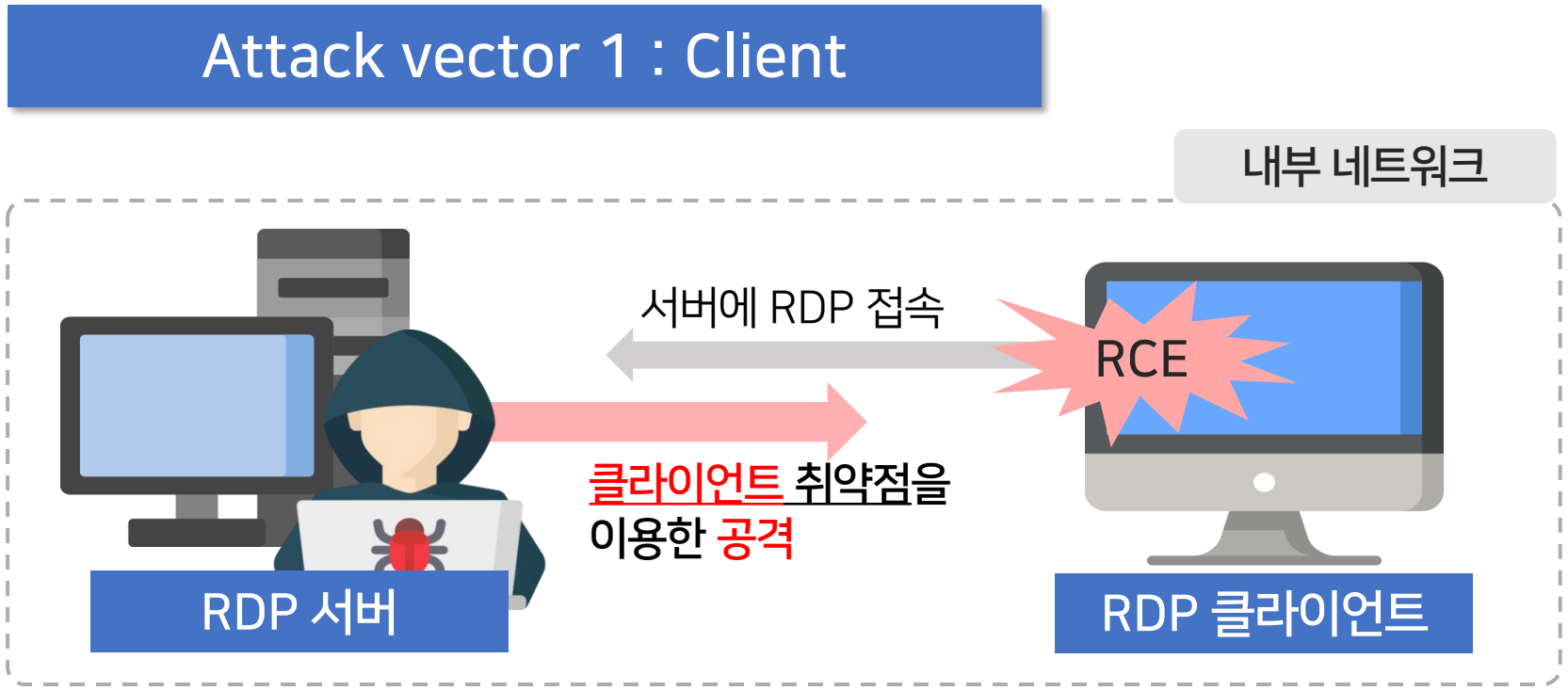
다양한 환경의 Client/Server 사이드 RDP 서비스 존재

Why RDP?

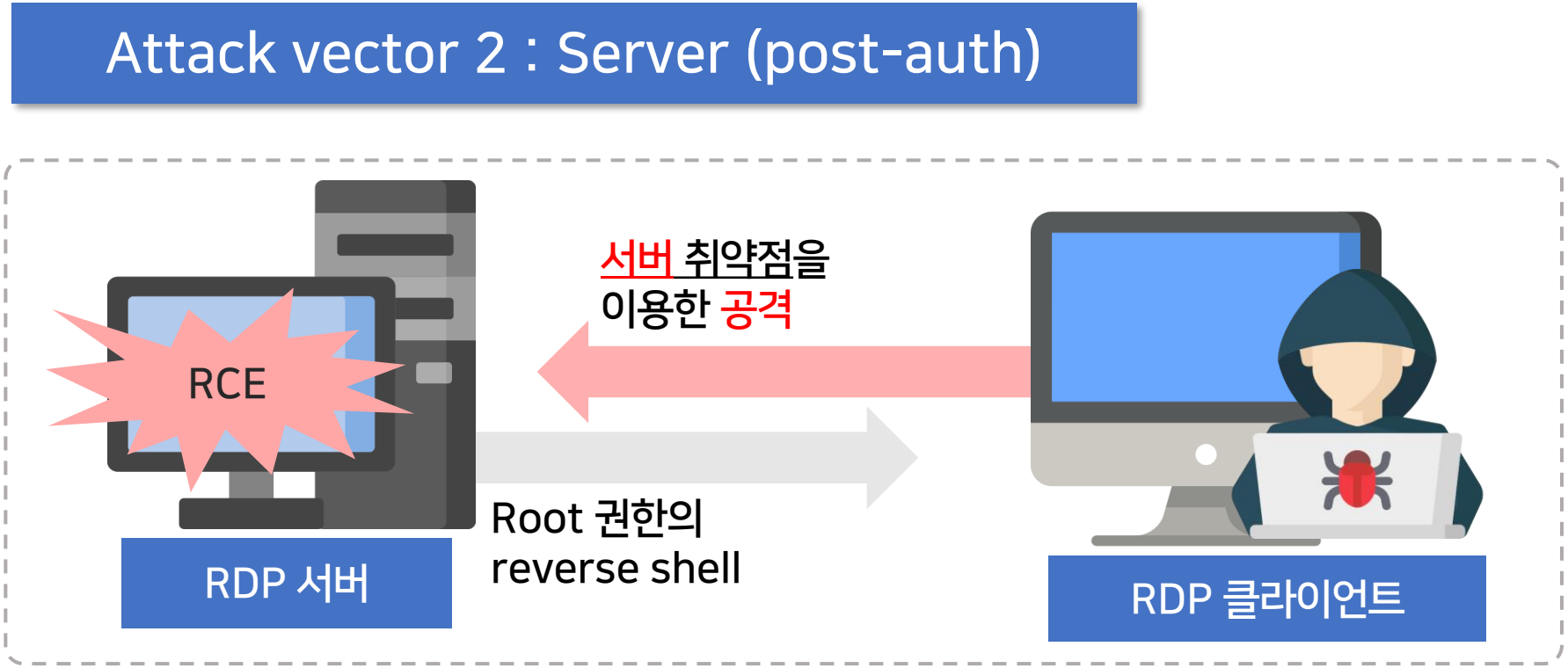
Lateral Movement			
T1021: Remote Services	27.4%	T1021.001: Remote Desktop Protocol	23.4%
		T1021.004: SSH	4.8%
		T1021.002: SMB/Windows Admin Shares	4.0%
		T1021.005: VNC	0.5%
		T1021.006: Windows Remote Management	0.2%
T1550: Use Alternate Authentication Material	0.8%	T1550.002: Pass the Hash	0.5%
		T1550.001: Application Access Token	0.2%
		T1550.003: Pass the Ticket	0.2%
T1570: Lateral Tool Transfer	0.6%		
T1534: Internal Spearphishing	0.5%		



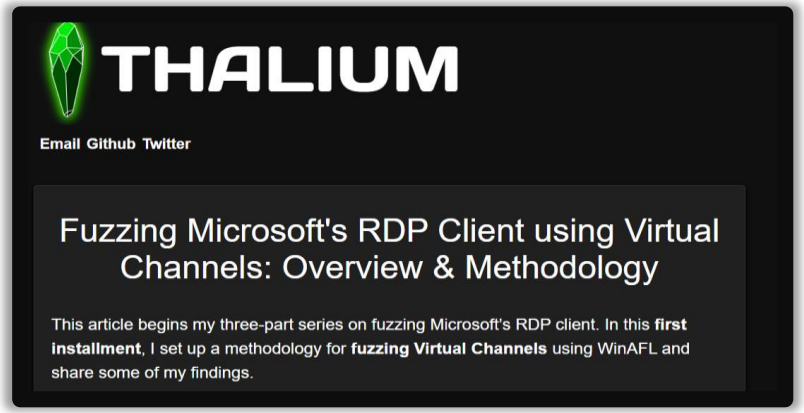
Possible Scenarios

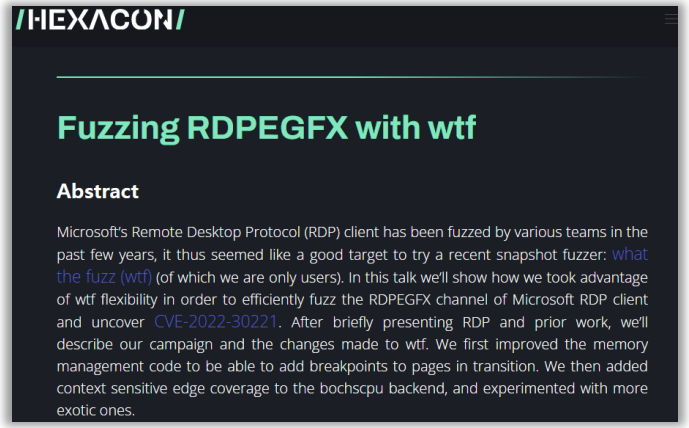


Possible Scenarios



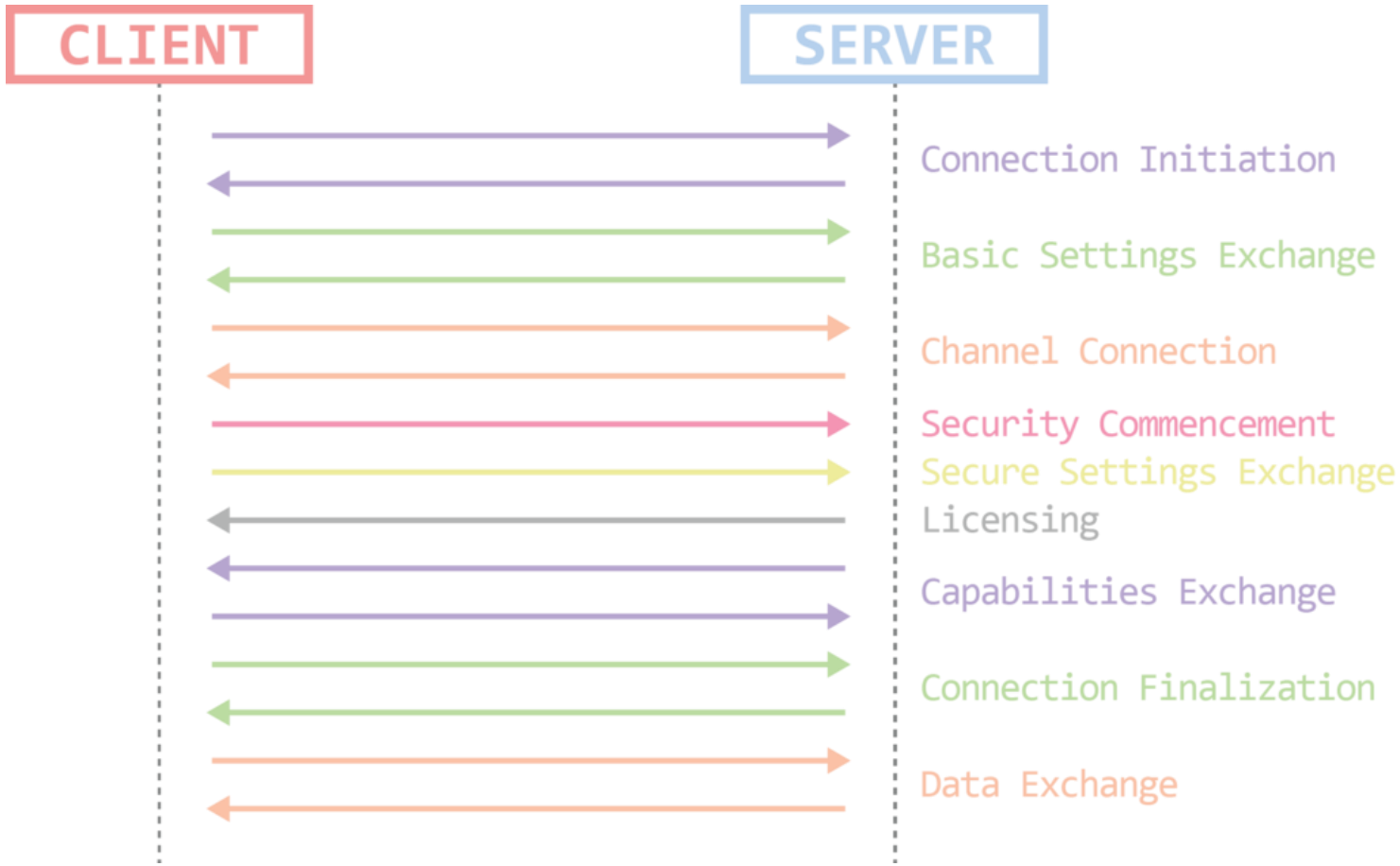
Previous Research



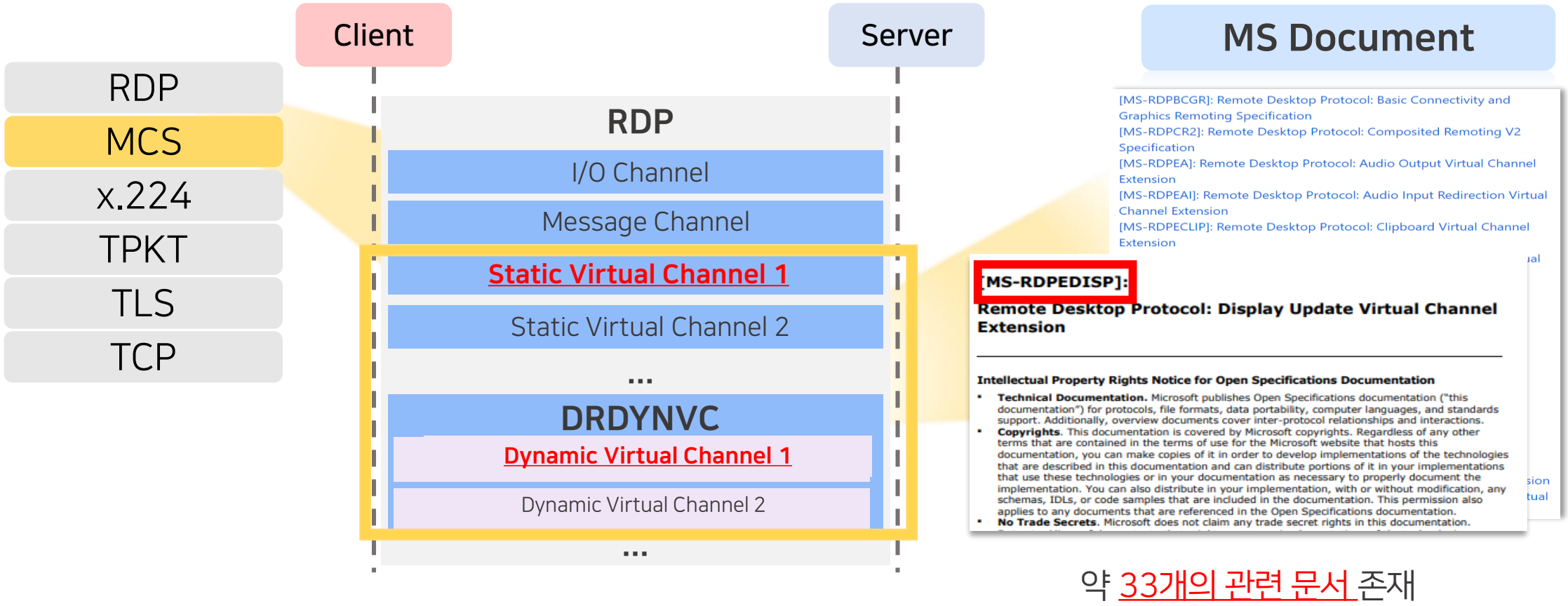


RDP 프로토콜 분석

RDP Connection



Protocol Analysis



약 33개의 관련 문서 존재

RDP Channel Analysis

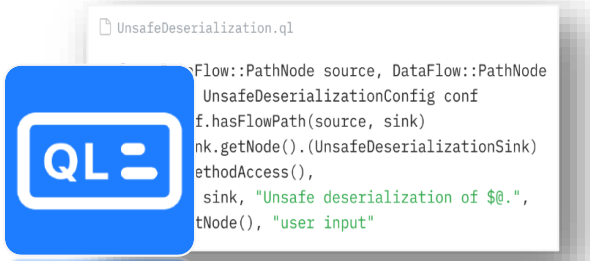
RDPEXPS OPEN	XML Paper Specification: Print	Dynamic	Device Redirection
RDPCR2	Composited Remoting V2	Dynamic	Graphics
RDPEPNP	Plug and Play	Dynamic	Device Redirection
RDPEAI	Audio Input	Dynamic	Data Redirection
RDPEV	Video	Dynamic	Data Redirection
RDPEUSB	USB Devices	Dynamic	Device Redirection
RDPEGFX	Graphic Pipeline	Dynamic	Graphics
RDPEI	Pen & Touch Input	Dynamic	Data Redirection
RDPEVOR	Video Optimized Remoting	Dynamic	Graphics
RDPEECO	Echo	Dynamic	Data Redirection
RDPEGT	Geometry Tracking	Dynamic	Graphics
RDPEDISP	Display Control	Dynamic	Graphics
RDPEAR	Authentication Redirection	Dynamic	Authentication
RDPECAM	Camera	Dynamic	Device Redirection

RDP Channel Analysis (FreeRDP Example)

채널명	취약점 분석 방법	발견된 취약점	참조 문서	채널 설명	선정 이유
parallel	코드 오디팅	Uninitialized Memory로 인한 Leak 취약점 **(총 1개)**	RDPEFS	파일 시스템 지원	가장 용이하게 Leak 취약점을 발견함.
tsmf	코드 오디팅	Heap Buffer Overflow 외 4 **(총 5개)**	RDPEV	오디오/비디오를 server에서 client으로 리다이렉션	간단한 코드 오디팅을 진행 한 후 가장 취약한 채널이라 판단됨.
video	코드 오디팅, 간단한 fuzzer	Use After free 취약점 외 1 **(총 2개)**	RDPEVOR	비디오 stream을 host에서 client로 리다이렉션	(1) 간단한 코드 오디팅을 진행 한 후 취약한 채널이라 판단됨. (2) 패킷 PDU 구현이 비교적 간단하여 Fuzzer 제작이 용이했음.
rdpgfx	AFL++ 기반 fuzzing	Out of Bound Read 취약점 외 1 **(총 2개)**	RDPGFX	그래픽 디스플레이 인코딩	디코딩이 사용되는 채널로, 취약점이 발생할만한 지점으로 판단됨.
geometry	AFL++ 기반 fuzzing	아직 발견X	RDPEGT	Host와 client 사이의 그래픽 렌더링을 조정함	패킷 PDU 구현이 간단해 AFL++ 기반 변형 Fuzzer 구현 연습을 위해 사용함.
encomsp	AFL++ 기반 fuzzing	아직 발견X	RDPEMC	다수의 커넥션의 참여자들 사이의 메시지 공유	패킷 PDU 구현이 간단해 AFL++ 기반 변형 Fuzzer 구현 연습을 위해 사용함.
rdpsnd	간단한 fuzzer	아직 발견X	RDPSND	오디오 지원	패킷 PDU 구현이 간단해 Fuzzer 제작이 용이했음.

RDP 취약점 발굴

Different Methods

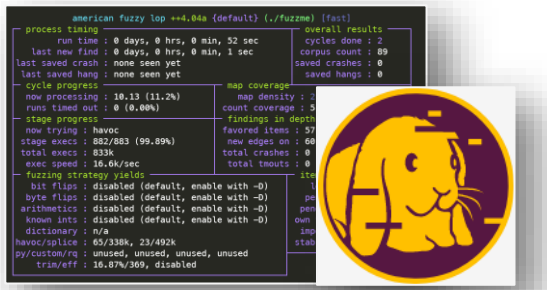


CodeQL 사용

1 비슷한 취약점 패턴 탐지 위함

2 오픈소스 대상 분석 시 사용

FreeRDP, rdesktop



AFL++ 기반 Fuzzer

1 오픈소스 대상 분석 시 사용

2 코드 양이 비교적 많은 타겟

FreeRDP, xrdp

Jackalope 기반 Fuzzer

1 윈도우, Closed-source

2 Output Filtering, Grammar Based Fuzzing

MS RDP

(FreeRDP) Using CodeQL

- 쿼리를 이용해 FreeRDP 및 다른 오픈소스 분석 진행
- 쿼리 실행 및 manual 분석 함께 진행

```
import cpp
import semmle.code.cpp.rangeanalysis.SimpleRangeAnalysis
import semmle.code.cpp.dataflow.TaintTracking
import semmle.code.cpp.models.interfaces.DataFlow
import semmle.code.cpp.controlflow.Guards
import semmle.code.cpp.dataflow.DataFlow

Quick Evaluation: isUnsafeMalloc
predicate isUnsafeMalloc(FunctionCall mallocCall) {
    exists(Function malloc |
        malloc.hasQualifiedName("malloc") and
        mallocCall.getTarget() = malloc and
        mallocCall.getArgument(0).getType().getSize() != 8 and
        not mallocCall.getArgument(0).isConstant() and
        mallocCall.getArgument(0).getNumChild() > 1 and
        (
            upperBound(mallocCall.getArgument(0).getFullyConverted()) >= 268435456*16 or
            lowerBound(mallocCall.getArgument(0).getFullyConverted()) < 0
        )
    )
}

Quick Evaluation: isUnsafeCalloc
predicate isUnsafeCalloc(FunctionCall callocCall) {
    exists(Function calloc |
        calloc.hasQualifiedName("calloc") and
        callocCall.getTarget() = calloc and
        callocCall.getArgument(1).getType().getSize() != 8 and
        not callocCall.getArgument(1).isConstant() and
        callocCall.getArgument(1).getNumChild() > 1 and
        (
            upperBound(callocCall.getArgument(1).getFullyConverted()) >= 268435456*16 or
            lowerBound(callocCall.getArgument(1).getFullyConverted()) < 0
        )
    )
}

Quick Evaluation: isUnsafeStreamNew
predicate isUnsafeStreamNew(FunctionCall streamNewCall) {
    exists(Function streamNew |
        streamNew.hasQualifiedName("Stream_New") and
        streamNewCall.getTarget() = streamNew and
        streamNewCall.getArgument(1).getType().getSize() != 8 and
        not streamNewCall.getArgument(1).isConstant() and
        streamNewCall.getArgument(1).getNumChild() > 1 and
        (
            upperBound(streamNewCall.getArgument(1).getFullyConverted()) >= 268435456*16 or
            lowerBound(streamNewCall.getArgument(1).getFullyConverted()) < 0
        )
```

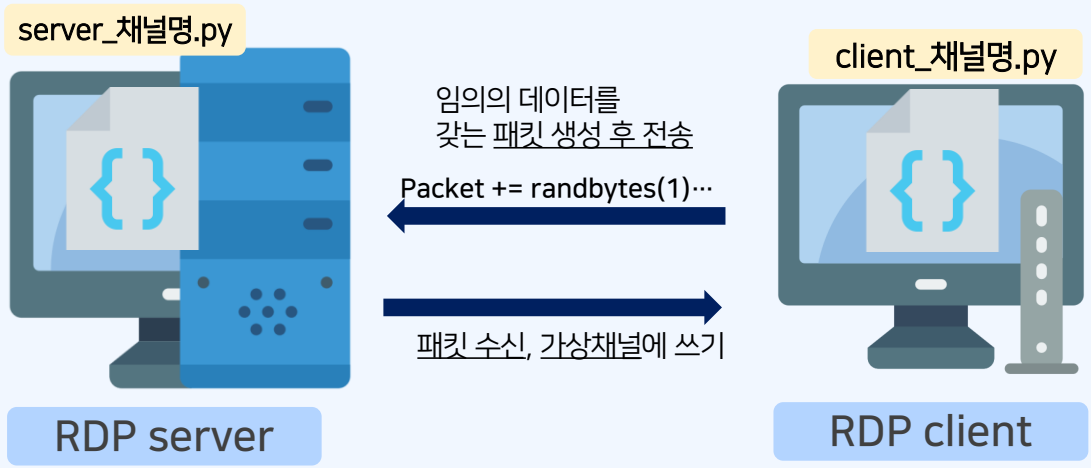
Division by Zero

스트림에서 읽어온 값이 Integer Overflow가 가능한 함수로 들어가는 패턴

Integer overflow가 가능한 함수를 통해 할당 받은 메모리가 memcpy 로 들어가는 패턴

(FreeRDP) Fuzzing with AFL ++

간단한 Generation Based-Fuzzer



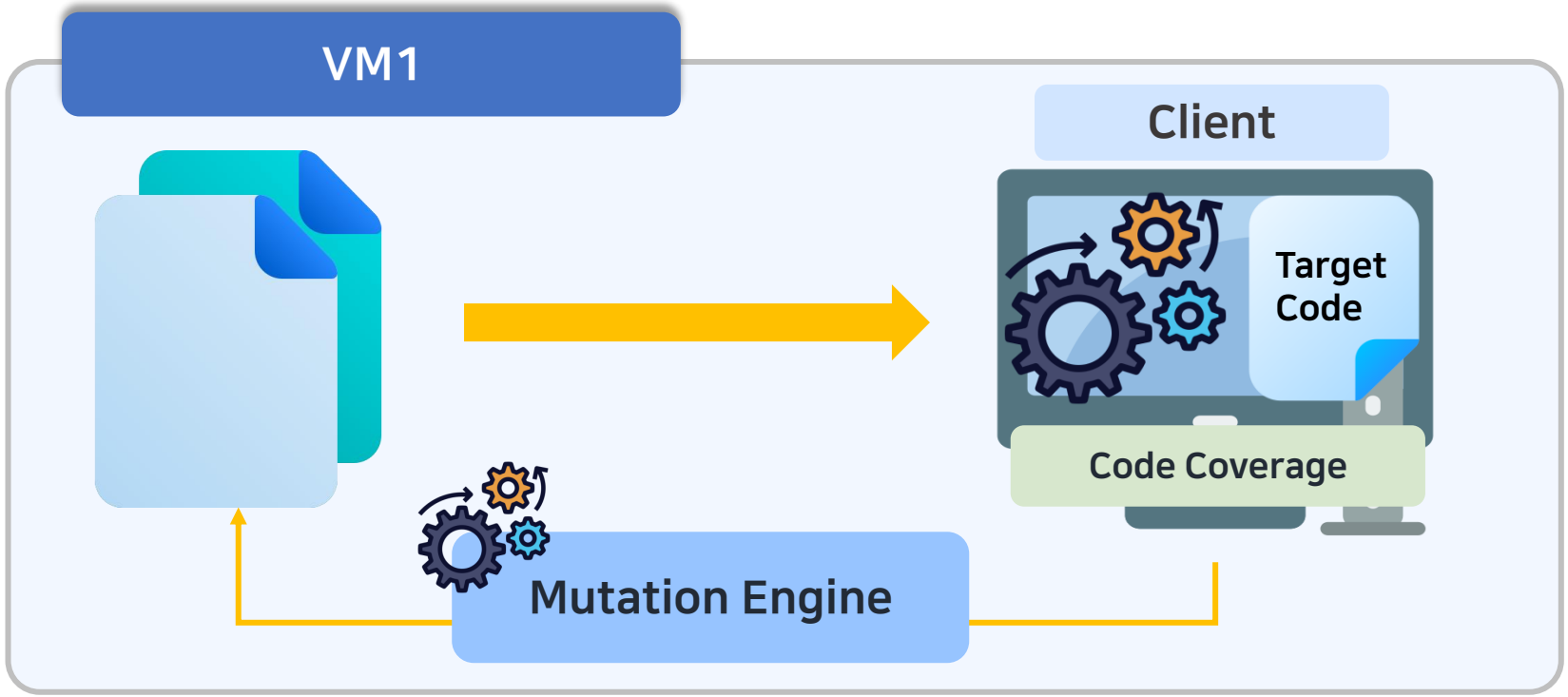
Fuzzer에서 사용할 1) **클래스를 정의내린 코드**,
2) **클래스를 상속 받아 채널 성격에 맞게 작성한 서버**, 3) **클라이언트 코드**로 구성

성능상 한계

AFL++
(American Fuzzy Lop plus plus)

1	Coverage-guided fuzzer로 확률 높이기
2	Compile time instrumentation (오픈소스)
3	Persistent 모드

(FreeRDP) Fuzzing with AFL ++



(FreeRDP) Fuzzing with AFL ++

타겟 코드

```
static UINT echo_on_data_received(IWTSVirtualChannelCallback* pChannelCallback, wStream* data)
{
    GENERIC_CHANNEL_CALLBACK* callback = (GENERIC_CHANNEL_CALLBACK*)pChannelCallback;
    BYTE* pBuffer = Stream_Pointer(data);
    UINT32 cbSize = Stream_GetRemainingLength(data);

    /* echo back what we have received. ECHO does not have any message IDs. */
    return callback->channel->Write(callback->channel, cbSize, pBuffer, NULL);
}
```

(FreeRDP) Fuzzing with AFL ++

타겟 코드

```
static UINT echo_on_data_received(IWTSVirtualChannelCallback* pChannelCallback, wStream* data)
{
    GENERIC_CHANNEL_CALLBACK* callback = (GENERIC_CHANNEL_CALLBACK*)pChannelCa ck;
    BYTE* pBuffer = Stream_Pointer(data);
    UINT32 cbSize = Stream_GetRemaining gth(data);

    /* echo back what we have receiv  ECHO does not have any message IDs */
    return callback->channel->Write allback->channel, cbSize, pBuffer, N );
}
```

구조체1

```
typedef struct
{
    IWTSVirtualChannelCallback iface;
    IWTSPlugin* plugin;
    IWTSVirtualChannelManager* channel_mgr;
    IWTSVirtualChannel* channel;
} GENERIC_CHANNEL_CALLBACK;
```

동적 디버깅으로 각각의 값 확인,
사용하지 않는 값은 NULL로 처리

구조체2

```
{
    BYTE* buffer;
    BYTE* pointer;
    size_t length;
    size_t capacity;

    DWORD count;
    wStreamPool* pool;
    BOOL isAllocatedStream;
    BOOL isOwner;
} wStream;
```

FreeRDP Stream 관련 API 사용

(FreeRDP) Fuzzing with AFL ++

GENERIC_CHANNEL_CALLBACK

```
typedef struct
{
    IWTSVirtualChannelCallback iface;
    IWTSPlugin* plugin;
    IWTSVirtualChannelManager* channel_mgr;
    IWTSVirtualChannel* channel;
} GENERIC_CHANNEL_CALLBACK;
```

```
pwndbg> p *(GENERIC_CHANNEL_CALLBACK*)0x7fffd5d657b0
$1 = {
  iface = {
    OnDataReceived = 0x7ffff7d9bd90 <echo_on_data_received>,
    OnOpen = 0x0,
    OnClose = 0x7ffff7d9bdf0 <echo_on_close>
  },
  plugin = 0x7fffe8fe9ee0,
  channel_mgr = 0x7fffe800b7c0,
  channel = 0x7fffd776ce40
}
```

```
IWTSVirtualChannel channel = (IWTSVirtualChannel*)calloc(1,
sizeof(IWTSVirtualChannel));
channel

GENERIC_CHANNEL_CALLBACK* callback =
(GENERIC_CHANNEL_CALLBACK*)calloc(1, sizeof(GENERIC_CHANNEL_CALLBACK));
callback->iface.OnDataReceived = echo_on_data_received;
callback->iface.OnOpen = NULL;
callback->iface.OnClose = echo_on_close;
callback->plugin = NULL; /* never used */
callback->channel_mgr = NULL; /* never used */
callback->channel = NULL; /* never used */
```

(FreeRDP) Fuzzing with AFL ++

Data (wStream *)

```
typedef struct
    {
        BYTE* buffer;
        BYTE* pointer;
        size_t length;
        size_t capacity;

        DWORD count;
        wStreamPool* pool;
        BOOL isAllocatedStream;
        BOOL isOwner;
    } wStream;
```



```
0x7fffe52dac60,wStream* s = Stream_New(NULL, len);
if (!Stream_EnsureRemainingCapacity(s, len))
{
        /* ERROR */
      continue;
}

Stream_Write(s, buf, len);

if (Stream_Capacity(s) != Stream_GetPosition(s))
{
      /* ERROR */
      continue;
}

Stream_SealLength(s);
Stream_SetPosition(s, 0);
```

(FreeRDP) Fuzzing with AFL ++

Harness

```
while (__AFL_LOOP(UINT_MAX)) {
    len =   AFL_FUZZ_TESTCASE_LEN;
    memset(callback, 0, sizeof(GENERIC_CHANNEL_CALLBACK));
    callback->iface.OnDataReceived = echo_on_data_received;
    callback->iface.OnOpen = NULL;
    callback->iface.OnClose = echo_on_close;
    callback->plugin = NULL;
    callback->channel_mgr = NULL;
    callback->channel = NULL;

    wStream* s = Stream_New(NULL, len);
    if (!Stream_EnsureRemainingCapacity(s, len))
    {
        continue;
    }

    Stream_Write(s, buf, len);

    if (Stream_Capacity(s) != Stream_GetPosition(s))
    {
        continue;
    }

    Stream_SealLength(s);
    Stream_SetPosition(s, 0);

    /* target function */
    echo_on_data_received(callback, s);
}
```

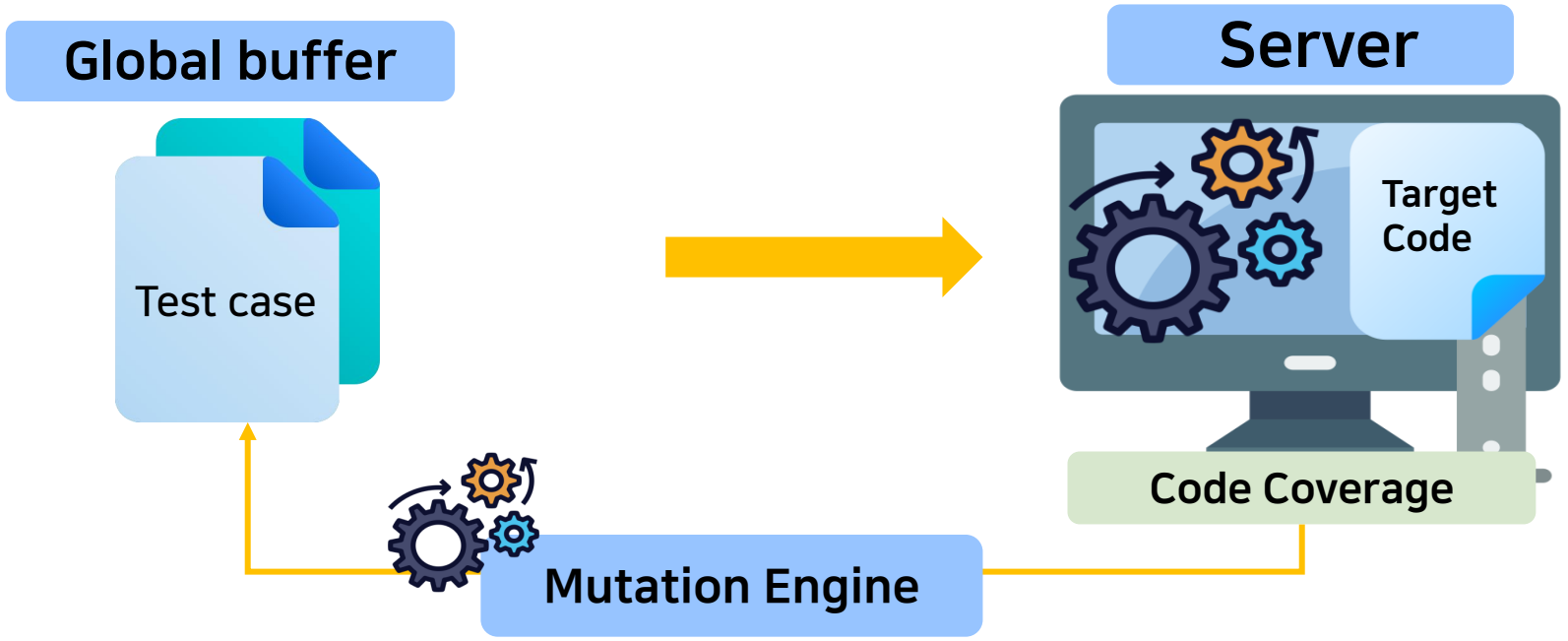
구조체1

구조체2

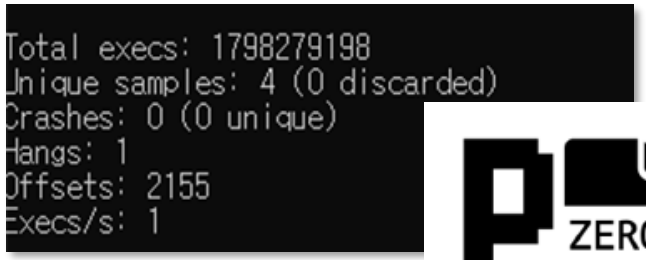
타겟 함수명

```
        american fuzzy lop ++4.04a {default} (./fuzzme) [fast]
┌─ process timing ─────────────────────┬─ overall results ─────┐
│        run time : 0 days, 0 hrs, 0 min, 23 sec │  cycles done : 574    │
│   last new find : none yet (odd, check syntax!) │  corpus count : 1     │
│ last saved crash : none seen yet     │ saved crashes : 0     │
│  last saved hang : none seen yet     │  saved hangs : 0      │
├─ cycle progress ─────┬─ map coverage ─┴───────────────────────┘
│  now processing : 0.1723 (0.0%)      │   map density : 12.31% / 12.31%
│  runs timed out : 0 (0.00%)          │ count coverage : 61.00 bits/tuple
├─ stage progress ─────┼─ findings in depth ────────────────────┐
│  now trying : havoc                  │ favored items : 1 (100.00%)
│ stage execs : 1174/1175 (99.91%)     │  new edges on : 1 (100.00%)
│ total execs : 2.02M                  │ total crashes : 0 (0 saved)
│  exec speed : 88.2k/sec              │  total tmouts : 3 (0 saved)
├─ fuzzing strategy yields ────────────┴─ item geometry ──────┐
│   bit flips : disabled (default, enable with -D)  │    levels : 1         │
│  byte flips : disabled (default, enable with -D)  │   pending : 0         │
│ arithmetics : disabled (default, enable with -D)  │  pend fav : 0         │
│  known ints : disabled (default, enable with -D)  │ own finds : 0         │
│  dictionary : n/a                                 │  imported : 0         │
│havoc/splice : 0/2.02M, 0/0                        │ stability : 100.00%   │
│py/custom/rq : unused, unused, unused, unused      │                       │
│    trim/eff : 33.33%/1, disabled                  │          [cpu001: 37%]│
└──────────────────────────────────────────────────┘──────────────────────┘
```

(xrdp) Fuzzing with AFL ++



(MSRDP) Fuzzing with Jackalope



Jackalope

Windows & MacOS

Blackbox Binary 대상,
Coverage guided fuzzer

WinAFL을 만든 Project Zero에서
제작한 Fuzzer

선택 이유

가벼운 Instrumentation

관심있는 모듈인 mstscax.dll에 대해서만 Instrumentation

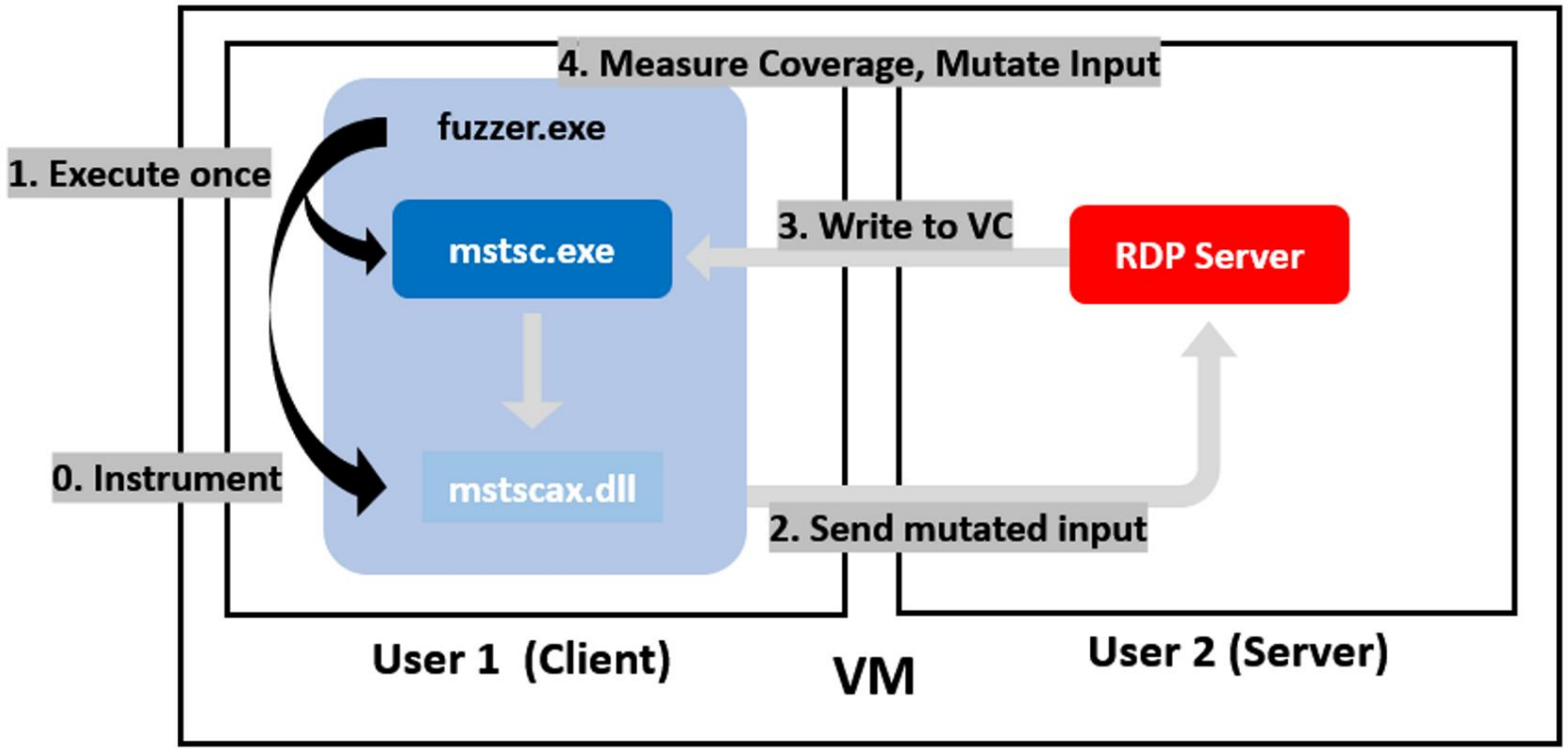
Grammar Based

MS RDP는 PDU 포맷에 맞지 않는 데이터가 들어올 경우 무시하거나 연결 끊음

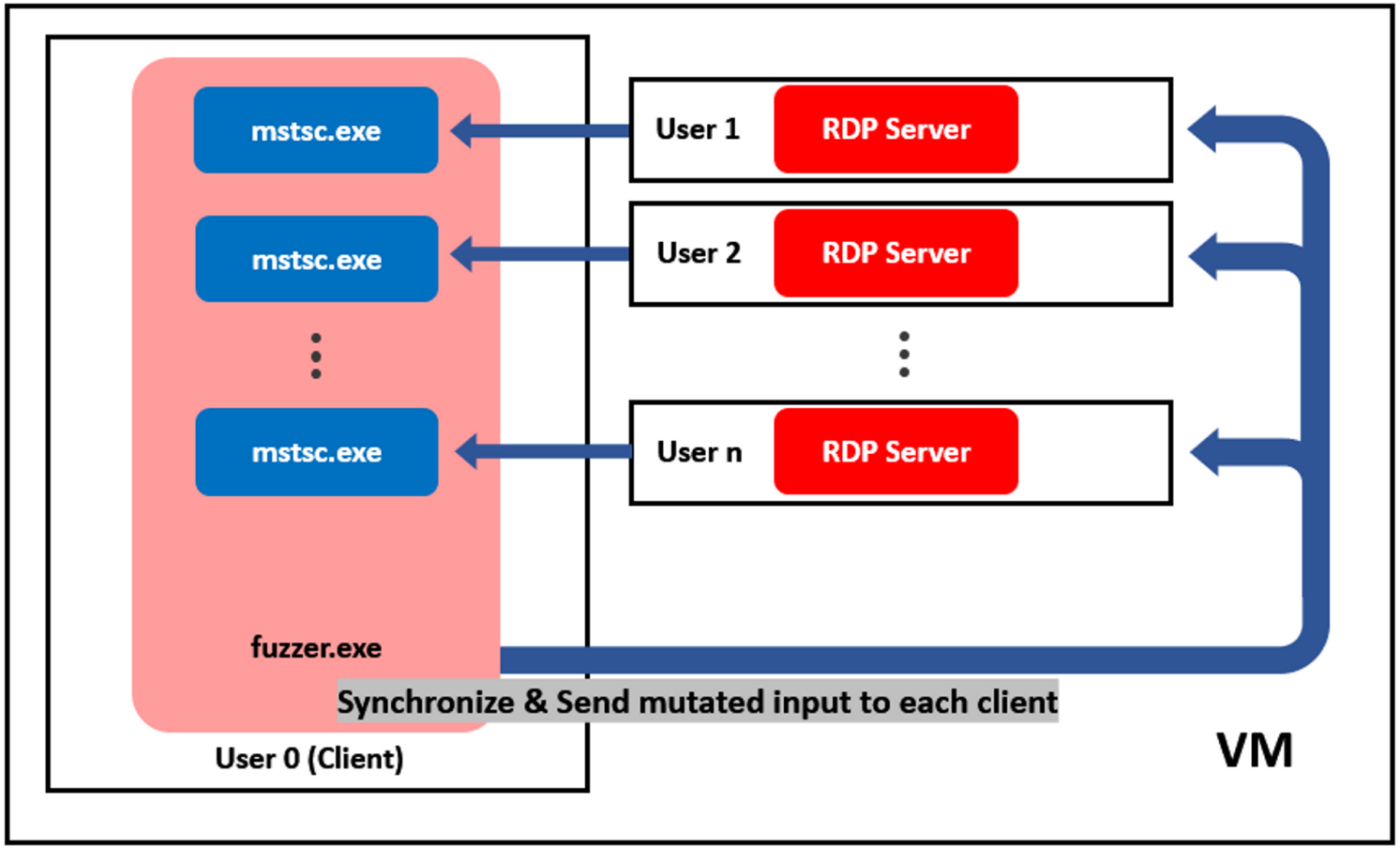
용이한 Custom

Mutator, Sample Delivery 용이하게 변경 가능함

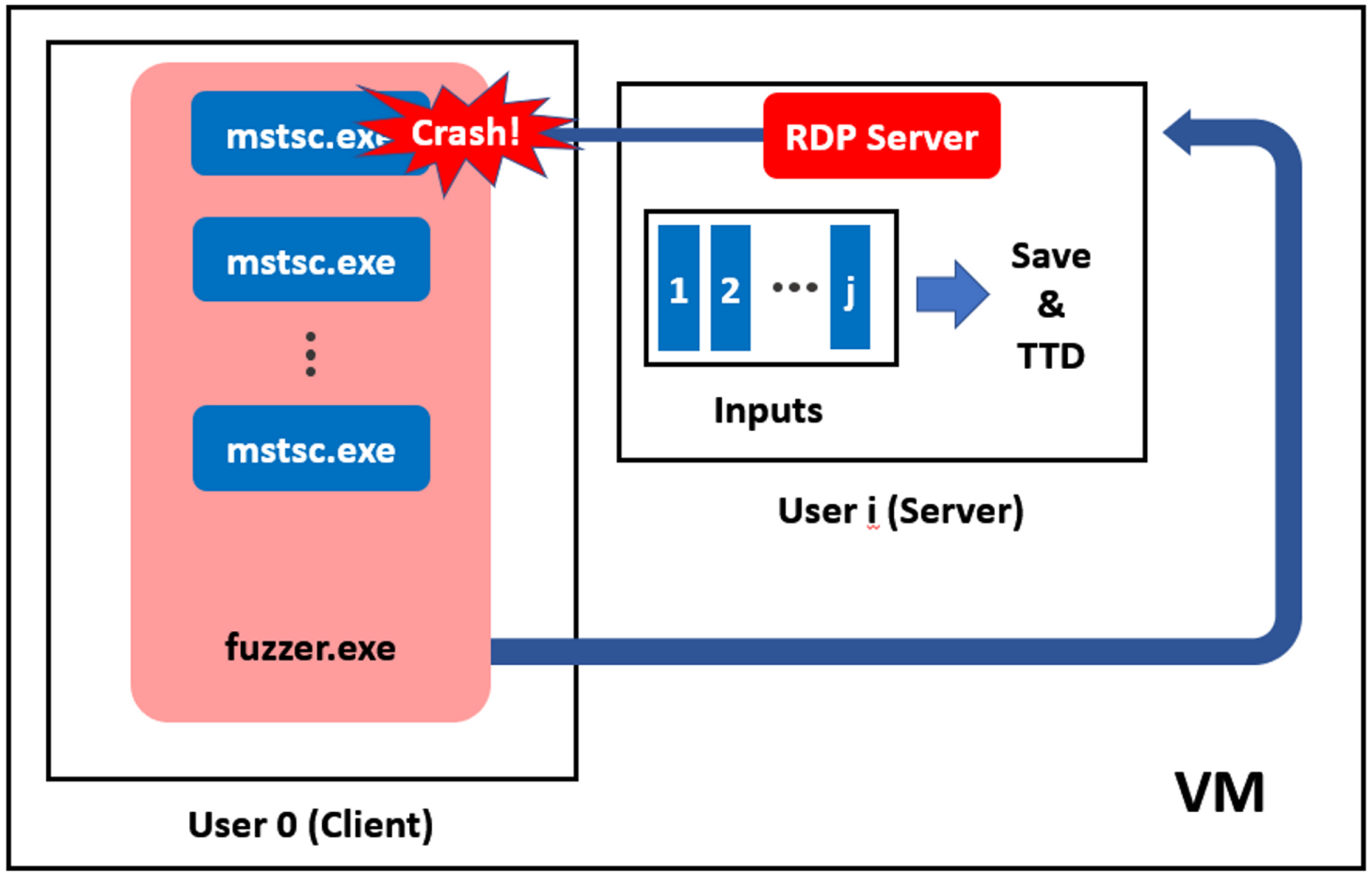
(MSRDP) Fuzzing with Jackalope



(MSRDP) Fuzzing with Jackalope



(MSRDP) Fuzzing with Jackalope



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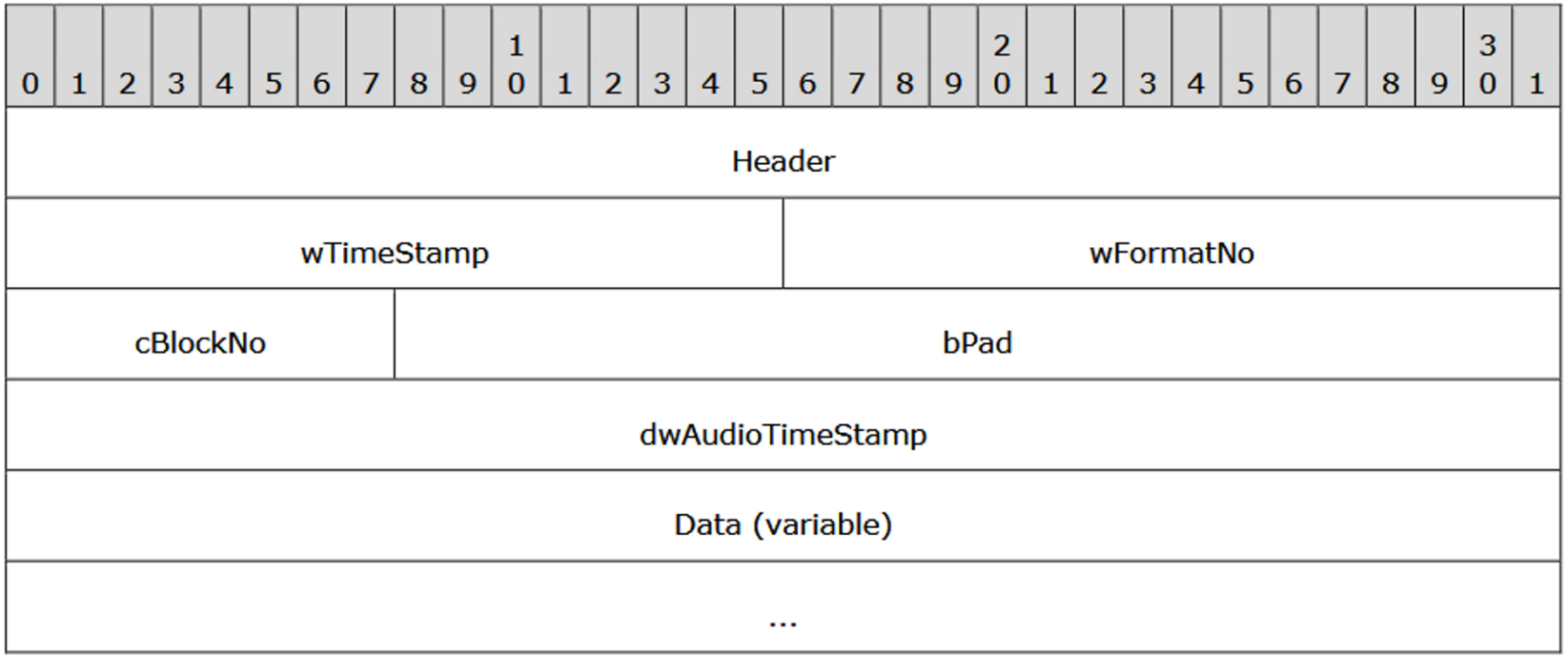
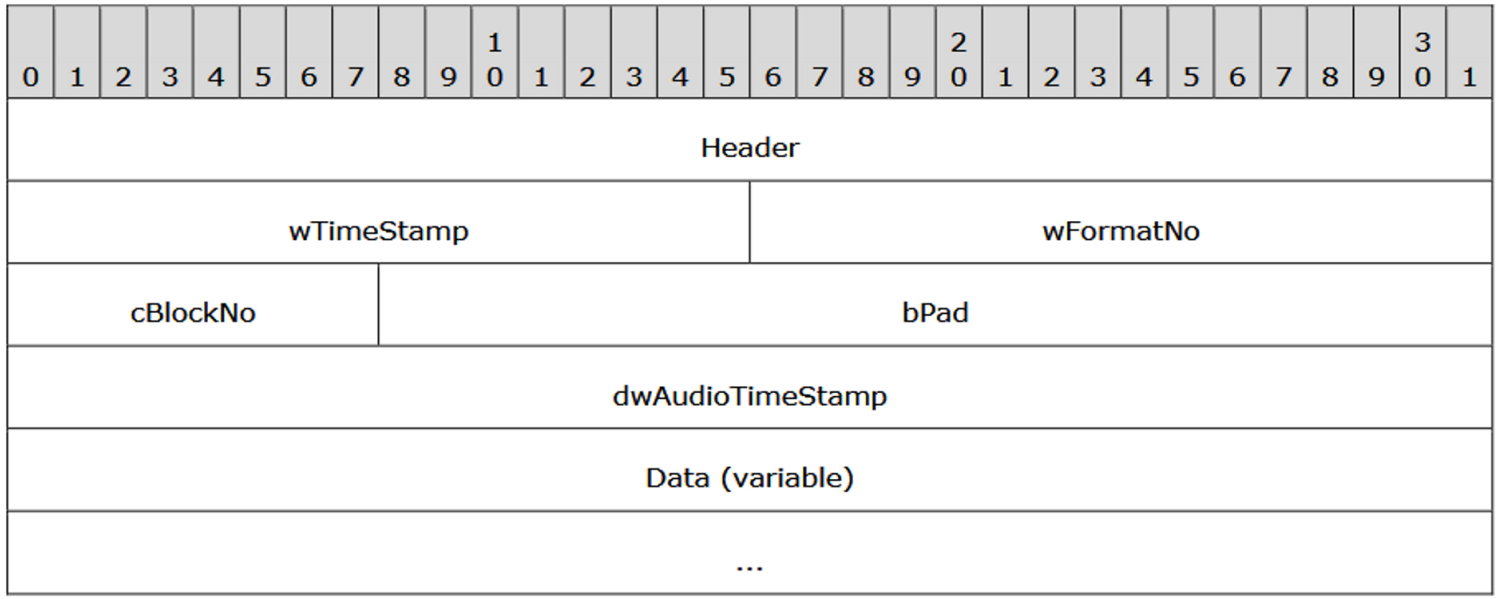


(MSRDP) Fuzzing with Jackalope



Grammar

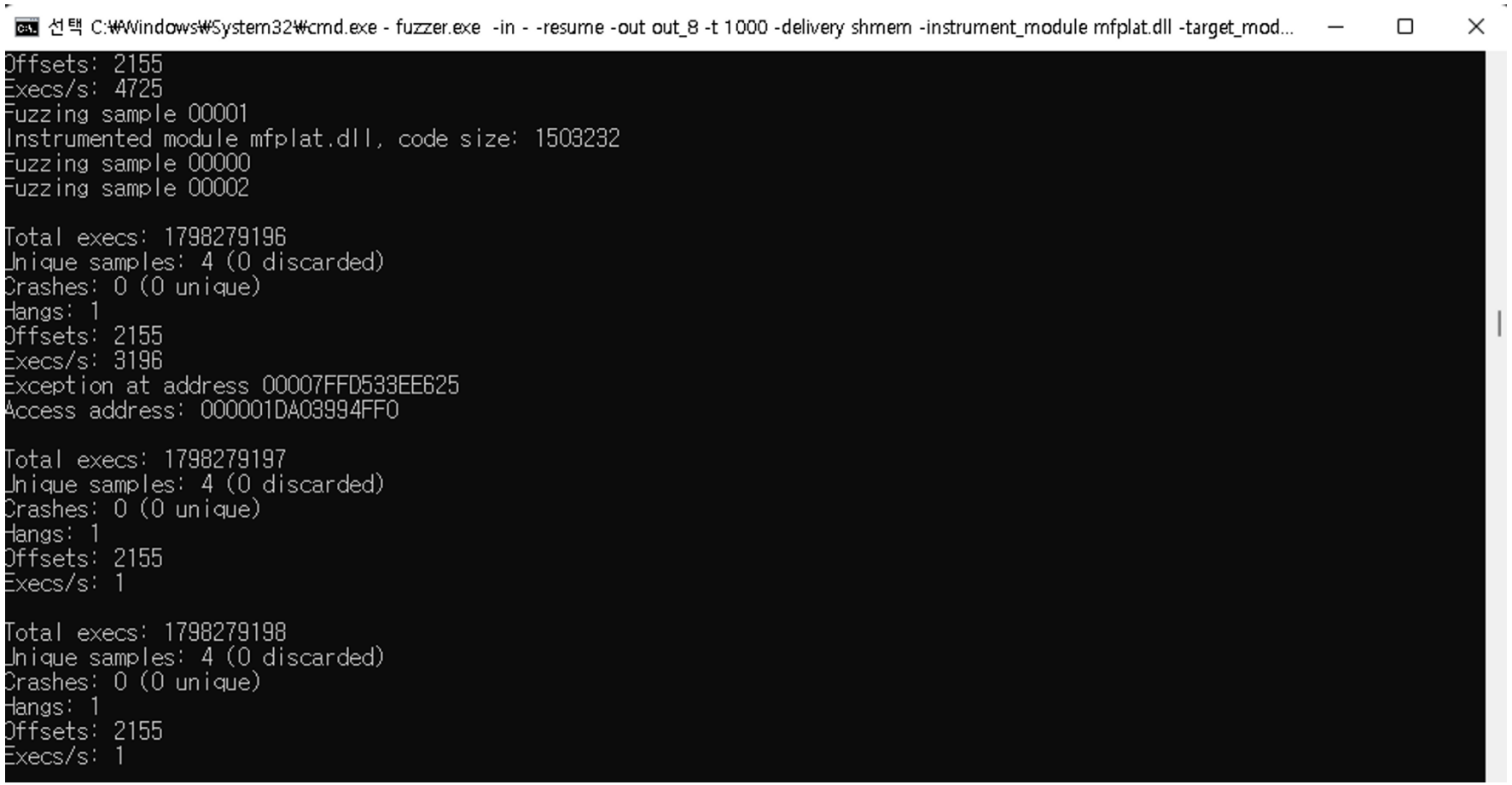
Jackalope: AST 기반 Grammar

➡ 더 복잡한 문법구조의 RDP PDU

ex.
특정 필드 길이의 PDU 메타데이터 필드

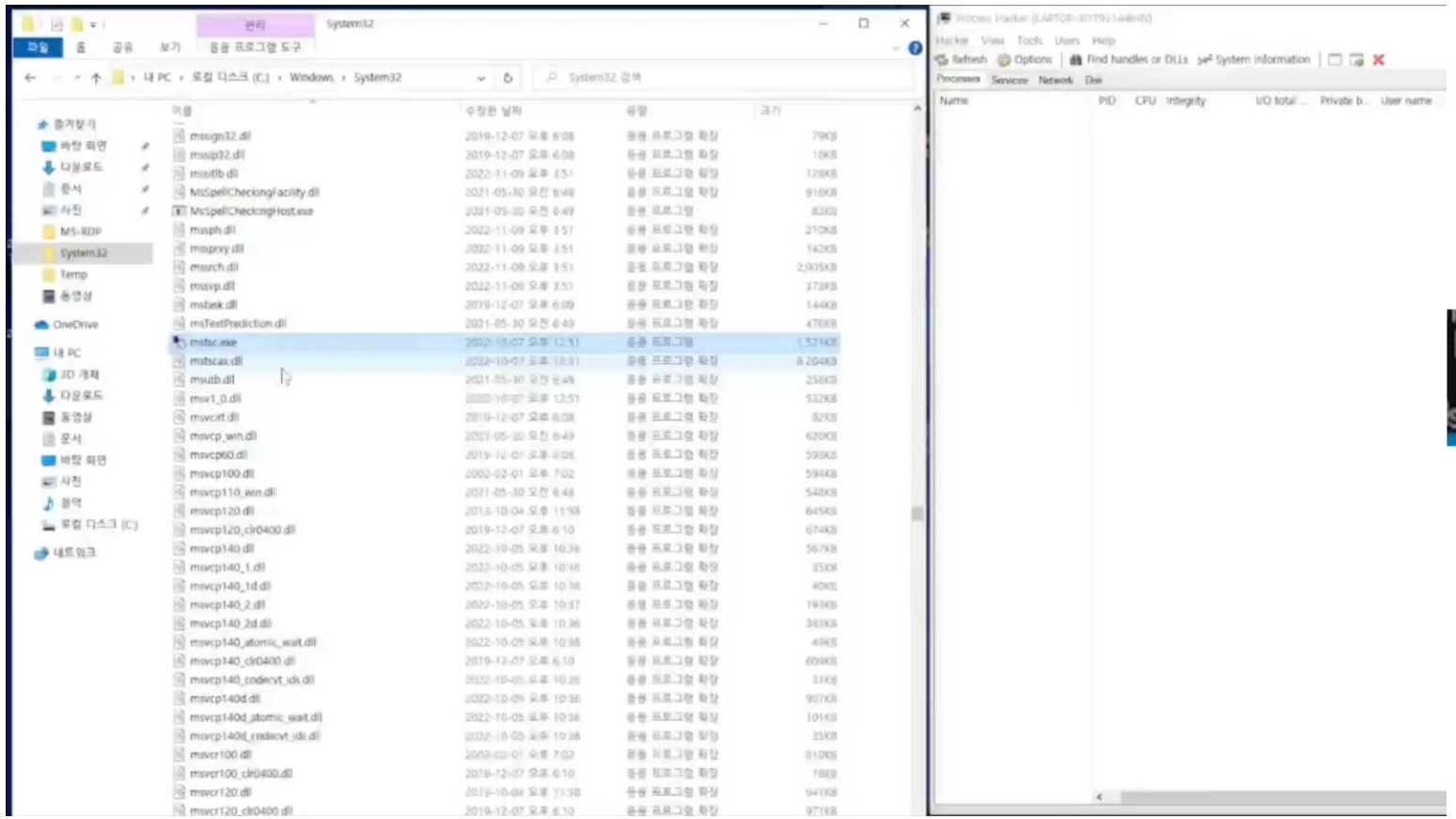
<root>=<0x0dff><length size=2 exclude><word><word><byte><0xffffff><dword><repeat_bytes min=0 max=65535 p=0.99>

(MSRDP) Fuzzing with Jackalope



결 론

(MSRDP) CVE-2023-28267



0x7ff802420000

0x7ff802420000

PoC를 통해 구한 클라이언트의 이미지 베이스 주소
= 실제 로드된 모듈 주소

What did we find?

Target	CVE	Vulnerability
FreeRDP	CVE-2022-39282	Read of uninitialized memory with parallel port redirection
	CVE-2022-39283	RDP client read out of bounds data and display it
	CVE-2022-39316	Out of bound read in zgfx decoder
	CVE-2022-39317	Undefined behaviour in zgfx decoder
	CVE-2022-39318	Division by zero in urbdrc channel
	CVE-2022-39319	Missing length validation in urbdrc channel
	CVE-2022-39320	Heap buffer overflow in urbdrc channel
	CVE-2022-39347	Missing input length validation in `drive` channel
	CVE-2022-41877	Missing path sanitation with `drive` channel

What did we find?

Target	CVE	Vulnerability
XRDP	CVE-2022-23468	Buffer Overflow in xrdp_login_wnd_create
	CVE-2022-23477	Buffer Overflow in audin_send_open
	CVE-2022-23478	Out of Bound Write in xrdp_mm_trans_process_drdynvc_channel_open
	CVE-2022-23479	Buffer Overflow in xrdp_mm_chan_data_in
	CVE-2022-23480	Buffer Overflow in devredir_proc_client_devlist_announce
	CVE-2022-23481	Out of Bound Read in xrdp_caps_process_confirm_active
	CVE-2022-23482	Out of Bound Read in xrdp_caps_process_confirm_active
	CVE-2022-23483	Out of Bound Read in libxrdp_send_to_channel
	CVE-2022-23484	Integer Overflow in xrdp_mm_process_rail_update_window
	CVE-2022-23493	Out of Bound Read in xrdp_mm_trans_process_drdynvc_channel_close
Microsoft Terminal Service Client	CVE-2023-28267	Microsoft Windows Remote Desktop Connection Uninitialized Variable Information Disclosure Vulnerability

How did we contribute?

2.9.0

Notewhorth changes:

- Backported #8252: Support sending server redirection PDU
- Backported #8406: Ensure X11 client cursor is never smaller 1x1
- Backported #8403: Fixed multiple client side input validation issues (CVE-2022-39316, CVE-2022-39317, CVE-2022-39318, CVE-2022-39319, CVE-2022-39320, CVE-2022-41877, CVE-2022-39347)
- Backported #7282: Proxy server now discards input events sent before activation was received
- Backported #8324: Internal replacements for md4, md5 and hmac-md5
  For the time being the RDP protocol requires these outdated hash algorithms. So any distribution that wants to ship a working FreeRDP should check the options WITH_INTERNAL_MD4 (and depending on OpenSSL deprecation status WITH_INTERNAL_MD5)

Fixed issues:

- Backported #8341: Null checks in winpr_Digest_Free
- Backported #8335: Missing NULL return in winpr_Digest_New
- Backported #8192: Support for audin version 2 microphone channel
- Backported #7282: Discard input events before activation (Fixes #8374)

For a complete and detailed change log since the last release run:
git log 2.8.1..2.9.0

Thanks to "Team BT5 (BoB 11th)" for reporting the security issues.

xrdp v0.9.21

Release notes for xrdp v0.9.21 (2022/12/10)

General announcements

- Running xrdp and xrdp-sesman on separate hosts is still supported by this release, but is now deprecated. This is not secure. A future v1.0 release will replace the TCP socket used between these processes with a Unix Domain Socket, and then cross-host running will not be possible.

Security fixes

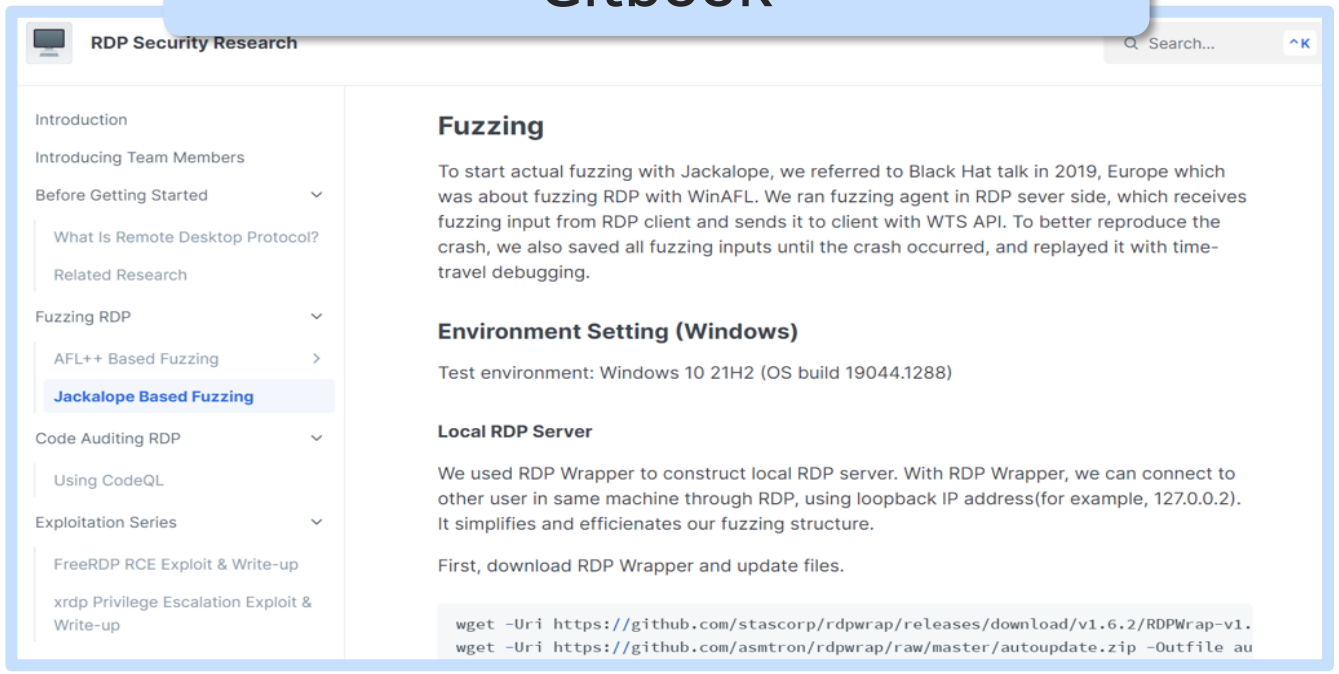
This update is recommended for all xrdp users and provides following important security fixes:

- CVE-2022-23468
- CVE-2022-23477
- CVE-2022-23478
- CVE-2022-23479
- CVE-2022-23480
- CVE-2022-23481
- CVE-2022-23483
- CVE-2022-23482
- CVE-2022-23484
- CVE-2022-23493

These security issues are reported by Team BT5 (BoB 11th). We appreciate their great help with making and reviewing patches.

More about RDP security..

Gitbook



https://bob11-btss-organization.gitbook.io/rdp-security-research/

Thank you