Cunning with CNG:

Soliciting Secrets from Schannel

DEF CON 24

1470502800

Why do you care?

What you get out of this talk

- Ability to decrypt Schannel TLS connections that use ephemeral key exchanges
- Ability to decrypt and extract private certificate and session ticket key directly from memory
- Public Cert/SNI to PID/Logon Session Mapping

AGENDA

- A very short SSL/TLS Review
- A background on Schannel & CNG
- The Secret Data
- The Forensic Context
- Demo >.>

DISCLAIM3R

This is NOT an exploit

- It's just the spec :D
- …and some implementation specific oddities

Microsoft has done nothing [especially] wrong

- To the contrary, their documentation was actually pretty great

Windows doesn't track sessions for processes that load their own TLS libs

- I'm looking at you Firefox and Chrome

Windows doesn't track sessions for process that don't use TLS…

- That'd be you TeamViewer...

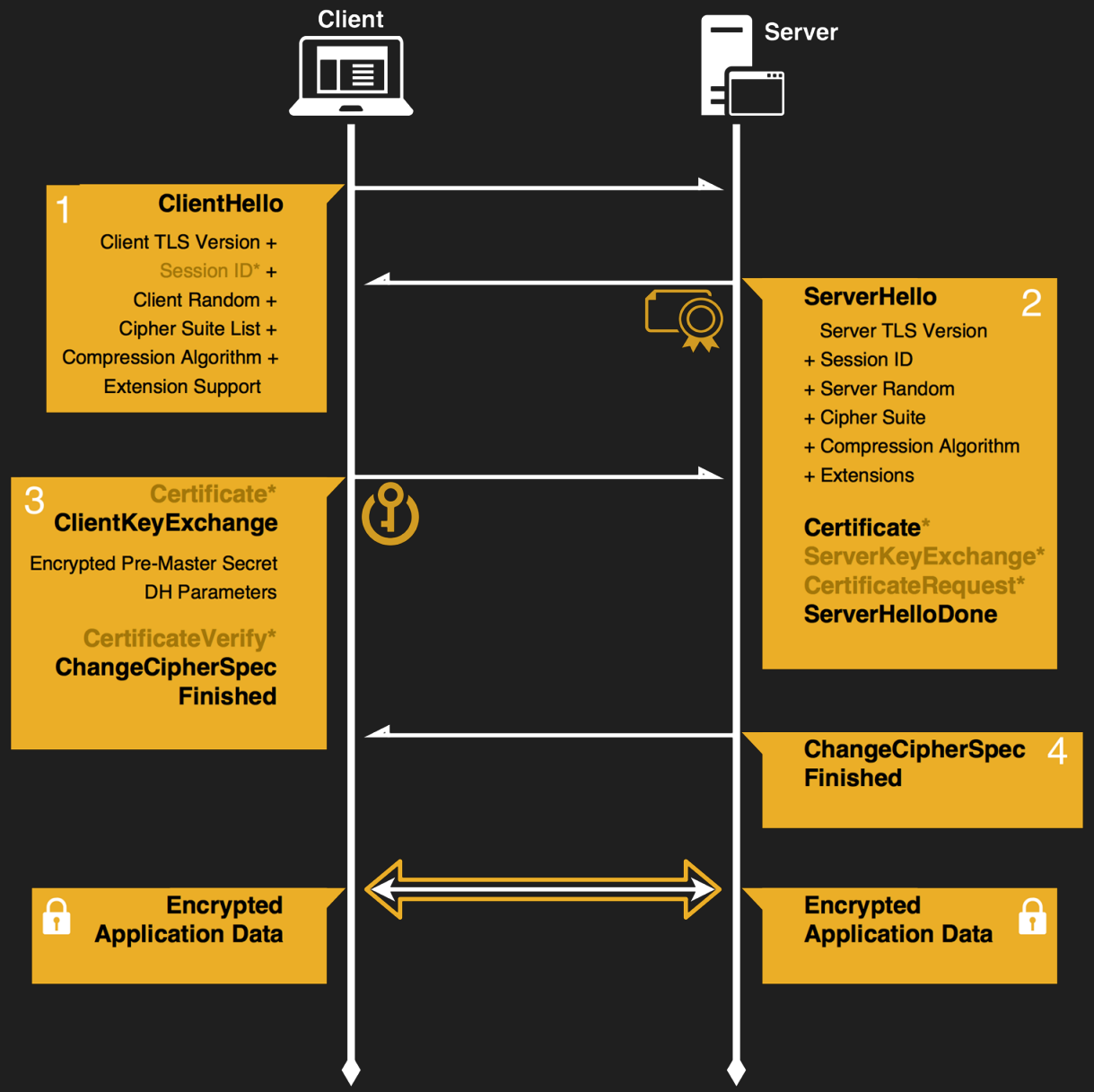
BACKGROUND

TLS, Schannel, and CNG

The now infamous TLS Handshake

[Initial Connection]

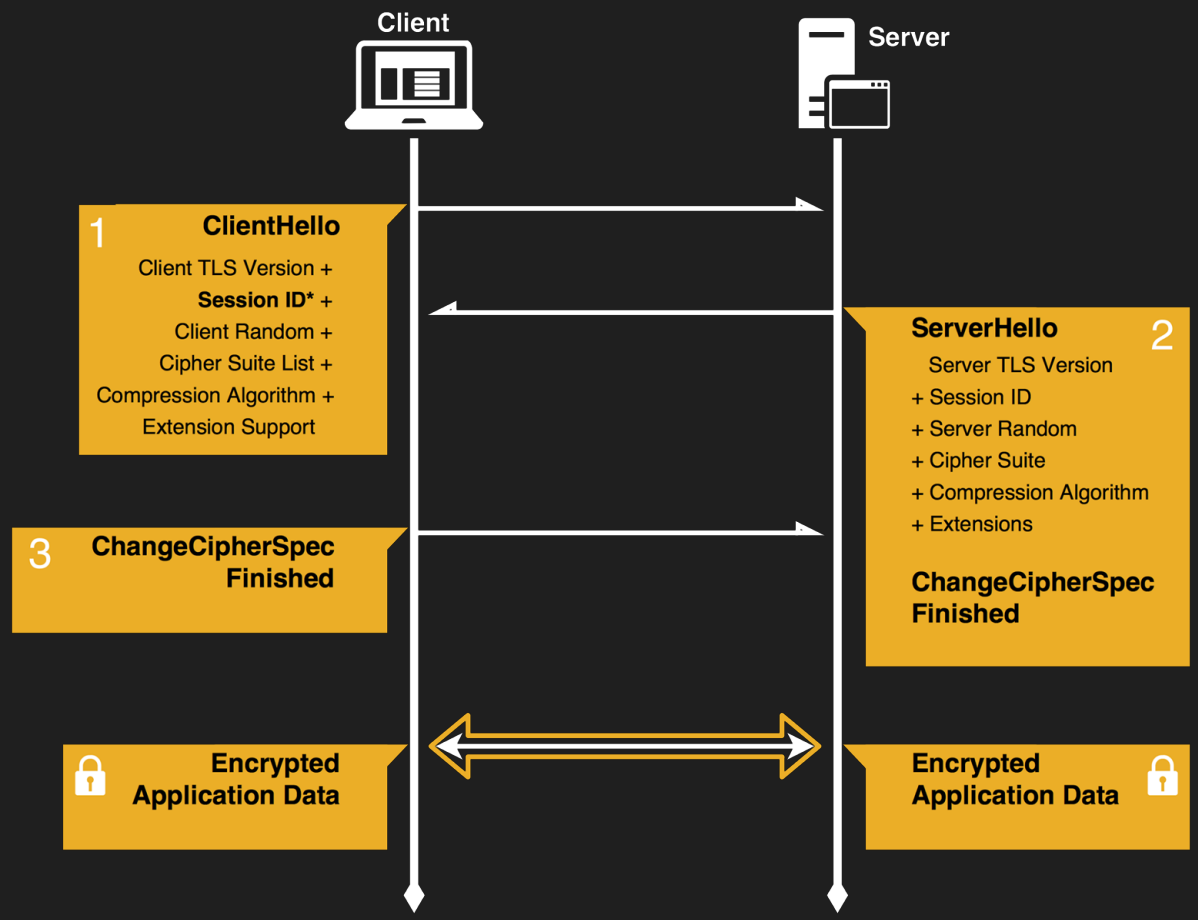




E.G.: TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256

The ~~now~~ DRi ~~infamous~~ TL~~S~~ Handshake

or, Session Resumption



P3RF3CT FORWARD S3CR3CY

What we *want* to do

- One time use keys, no sending secrets!

YEAR: 1992

CLASS: HUMAN

ID: WHITFIELD DIFFIE

EVENT: AUTHENTICATION AND AUTHENTICATED KEY EXCHANGES



What TLS *actually* does

- Caches values to enable resumption
  - recommends `An upper limit of 24 hours is suggested for session ID lifetimes`
- When using session ticket extension, sends the encrypted state over the network
  - basically returning to the issue with RSA, but using a more ephemeral key...

What implementations *also* do

- Store symmetric key schedules (so you can find the otherwise random keys...)
- Cache ephemeral keys and reuse for a while...

Schannel & CNG

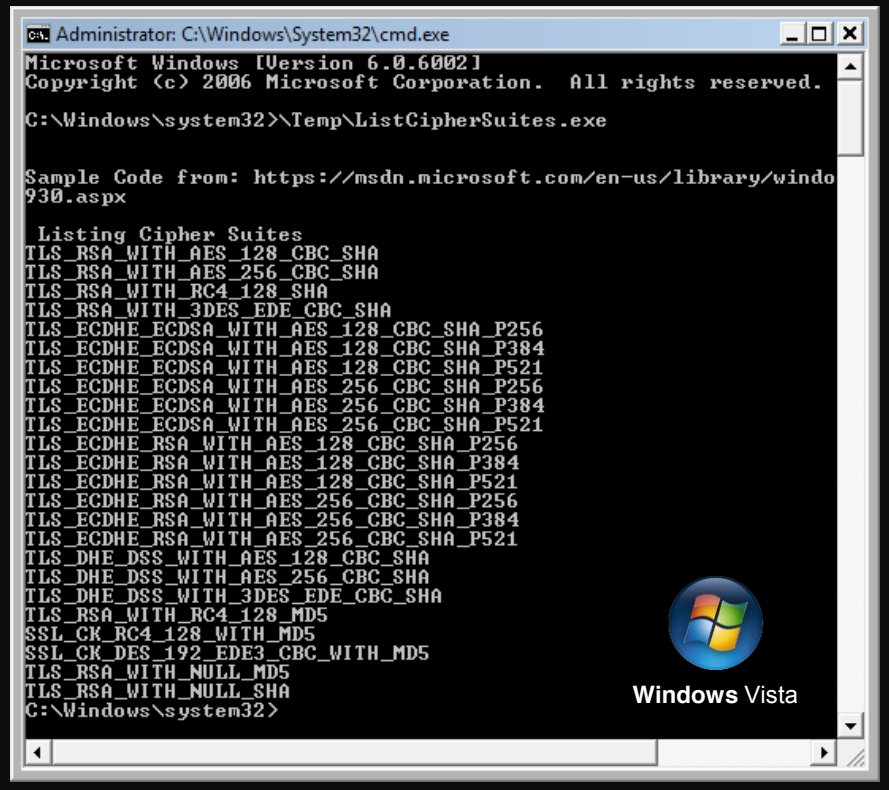
Secure Channel

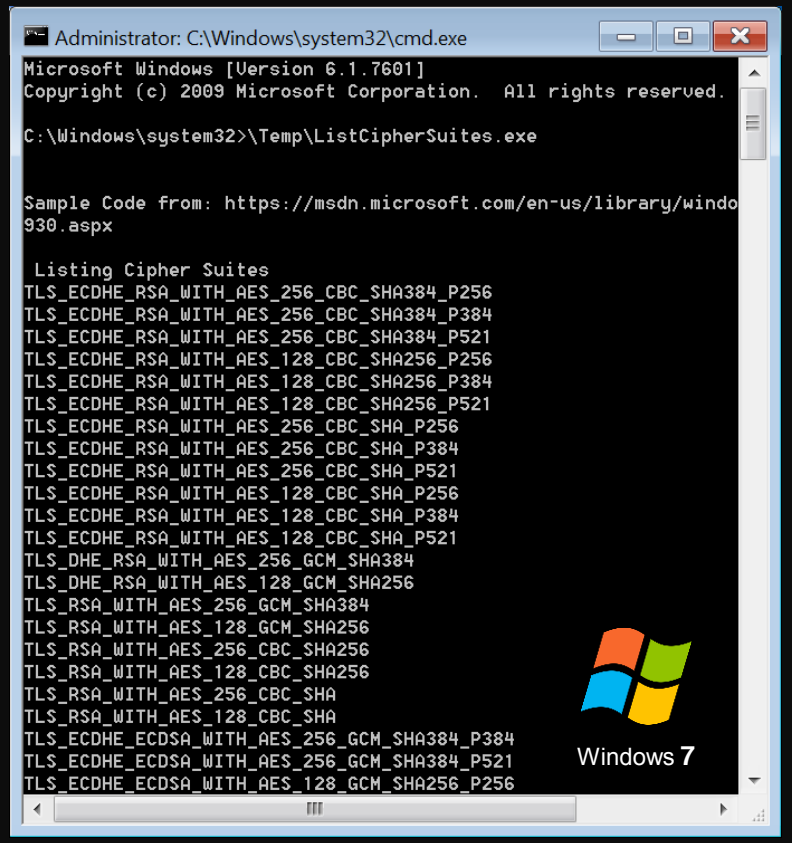
- It's TLS -> the Secure Channel for Windows!
- A library that gets loaded into the "key isolation process" **and** the "client" process
  - Technically a Security Support Provider (SSP)
- Spoiler: the Key Isolation process is LSASS

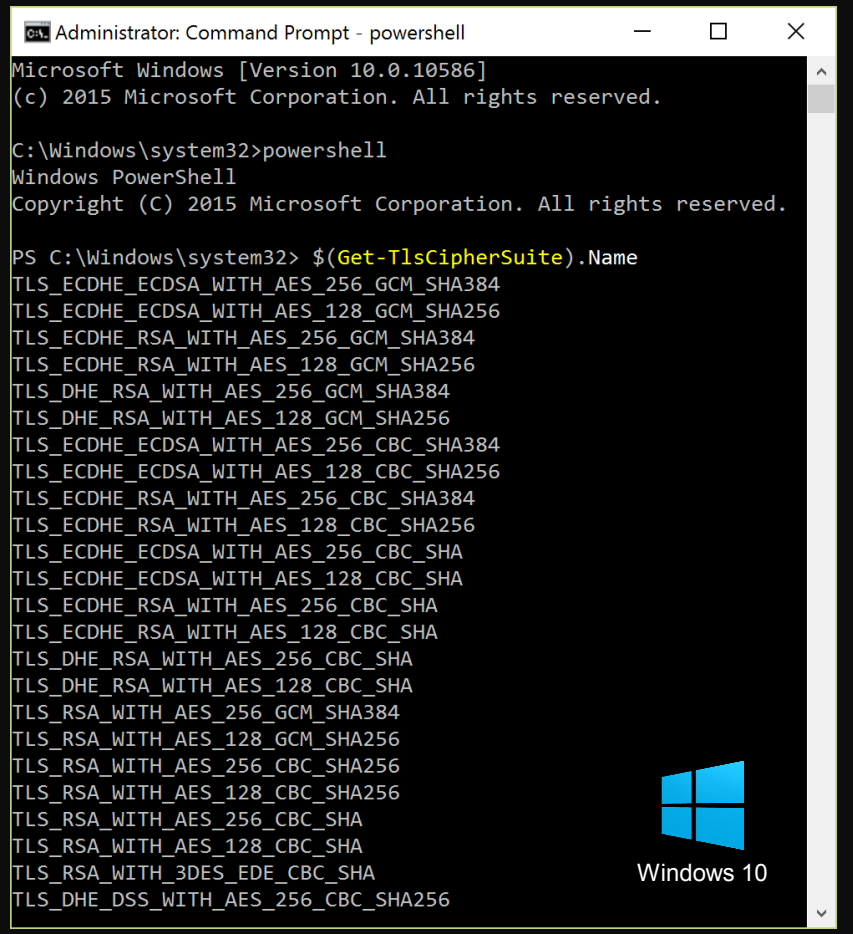
The CryptoAPI-Next Generation (CNG)

- Introduced in Vista (yes you read correctly)
- Provides Common Criteria compliance
- Used to store secrets and 'crypt them
  - Storage via the Key Storage Providers (KSPs)
  - Generic data encryption via DPAPI
  - Also brings modern ciphers to Windows (AES for example) and ECC
- Importantly, `ncrypt` gets called out as the "key storage router" and gateway to the CNG Key Isolation service

Schannel Preferred Cipher Suites









CLASS: ROBOT

QUERY: Y U STILL USE VISTA, BABY???

*ListCipherSuites sample code found here: https://technet.microsoft.com/en-us/library/bb870930.aspx

Microsoft's TLS/SSL Docs

- **ClientCacheTime:** "The first time a client connects to a server through the Schannel SSP, a full TLS/SSL handshake is performed."

- "When this is complete, **the master secret, cipher suite, and certificates are stored** in the session cache on the respective client and server."*

- **ServerCacheTime:** "…Increasing ServerCacheTime above the default values **causes Lsass.exe to consume additional memory**. Each session cache element typically requires 2 to 4 KB of memory"*

- **MaximumCacheSize**: "This entry controls the maximum number of cache elements. […] **The default value is 20,000 elements**." *

*TLS/SSL Settings quoted from here: https://technet.microsoft.com/en-us/library/dn786418(v=ws.11).aspx

SCHANNEL

by the docs

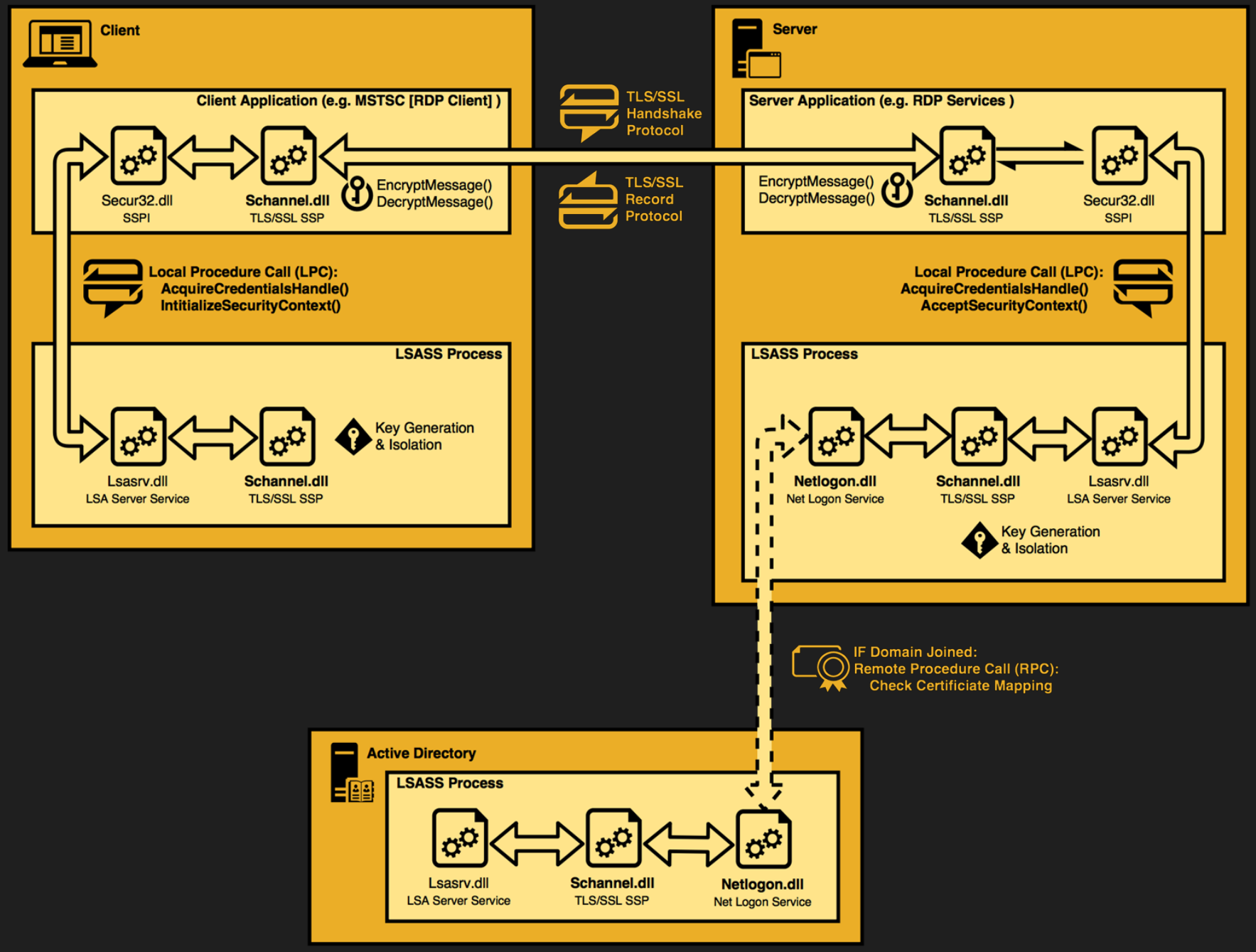


Diagram based on:
https://technet.microsoft.com/en-us/library/dn786429.aspx

CNG Key Isolation

by the docs



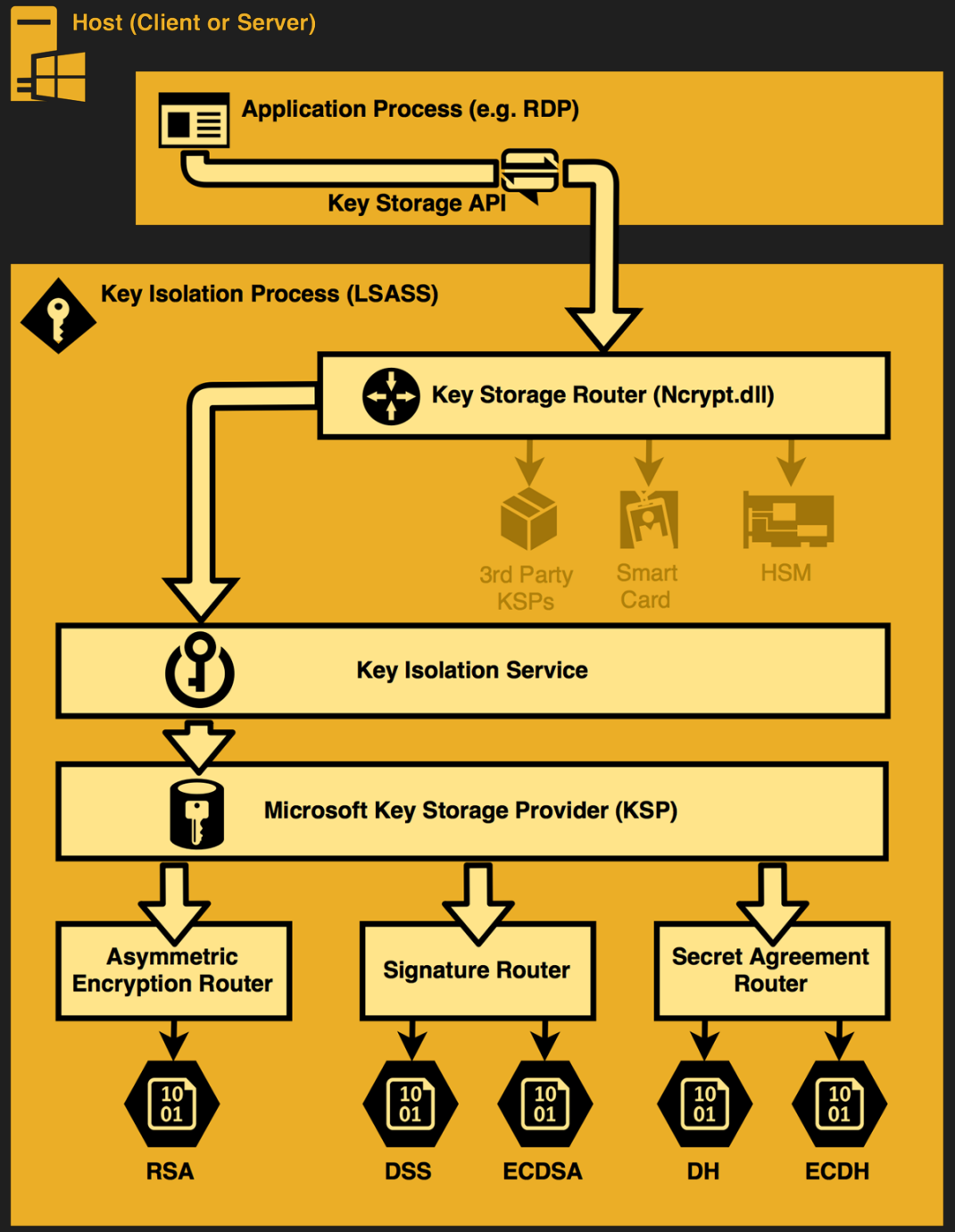


Diagram based on: https://msdn.microsoft.com/en-us/library/windows/desktop/bb204778.aspx

Background Summary

We're Looking Here



For These



Because of That



MISSION



We want to be able to see data that has been protected with TLS/SSL and subvert efforts at implementing Perfect Forward Secrecy



We want to gather any contextual information that we can use for forensic purposes, regardless of whether or not we can accomplish the above



We (as an adversary) want to be able to get access to a single process address space and be able to dump out things that would enable us to monitor/modify future traffic, or possibly impersonate the target

- We want to do this without touching disk

S3CRETS

THE K3YS



Session Keys

Master Secret

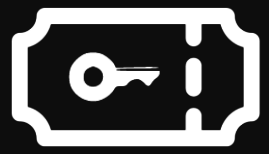
Pre-Master Secret



Ephemeral Private Key*



Persistent Private Key (Signing)



Session Ticket Key*

The Keys? What do they get us?



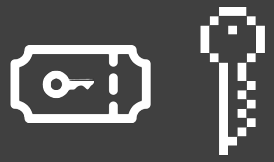


a single connection





a single session



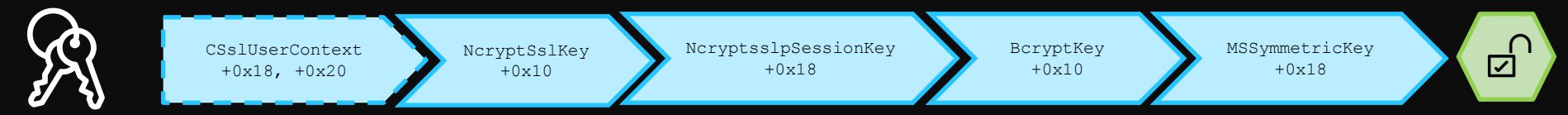

multiple sessions





multiple sessions + identity

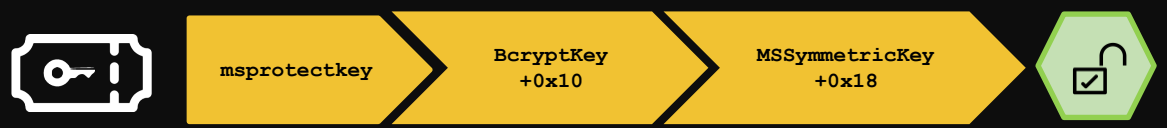
The Keys? We got ’em…all.











Session Keys

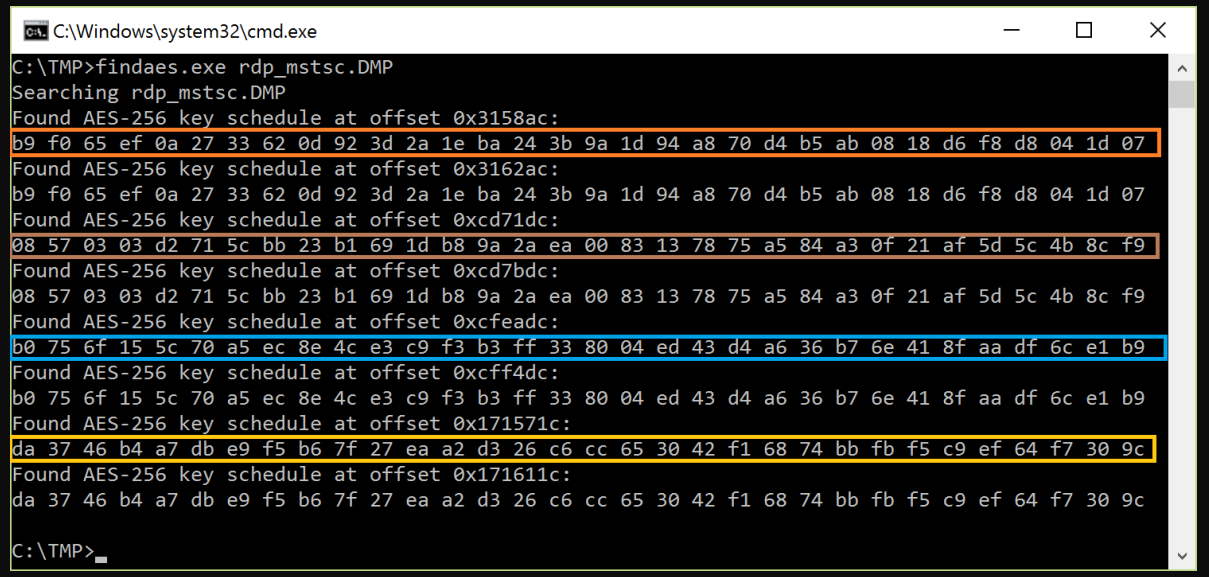
- Smallest scope / most ephemeral
- Required for symmetric encrypted comms
- Not going to be encrypted

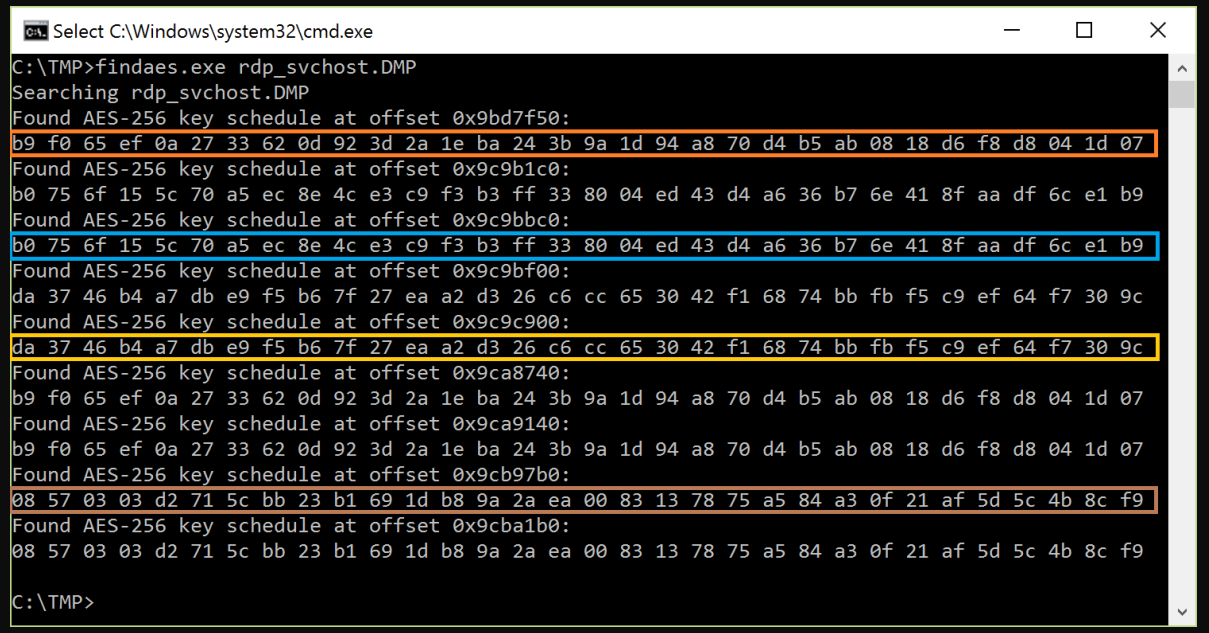
Approach Premise:

- Start with AES
- **AES keys** are relatively small and pseudo-random
- AES **key schedules** are larger and deterministic
  - … they are a “schedule” after all.
- Key schedules usually calculated once and stored*

- Let’s scan for matching key schedules on both hosts

FindAES from: http://jessekornblum.com/tools/

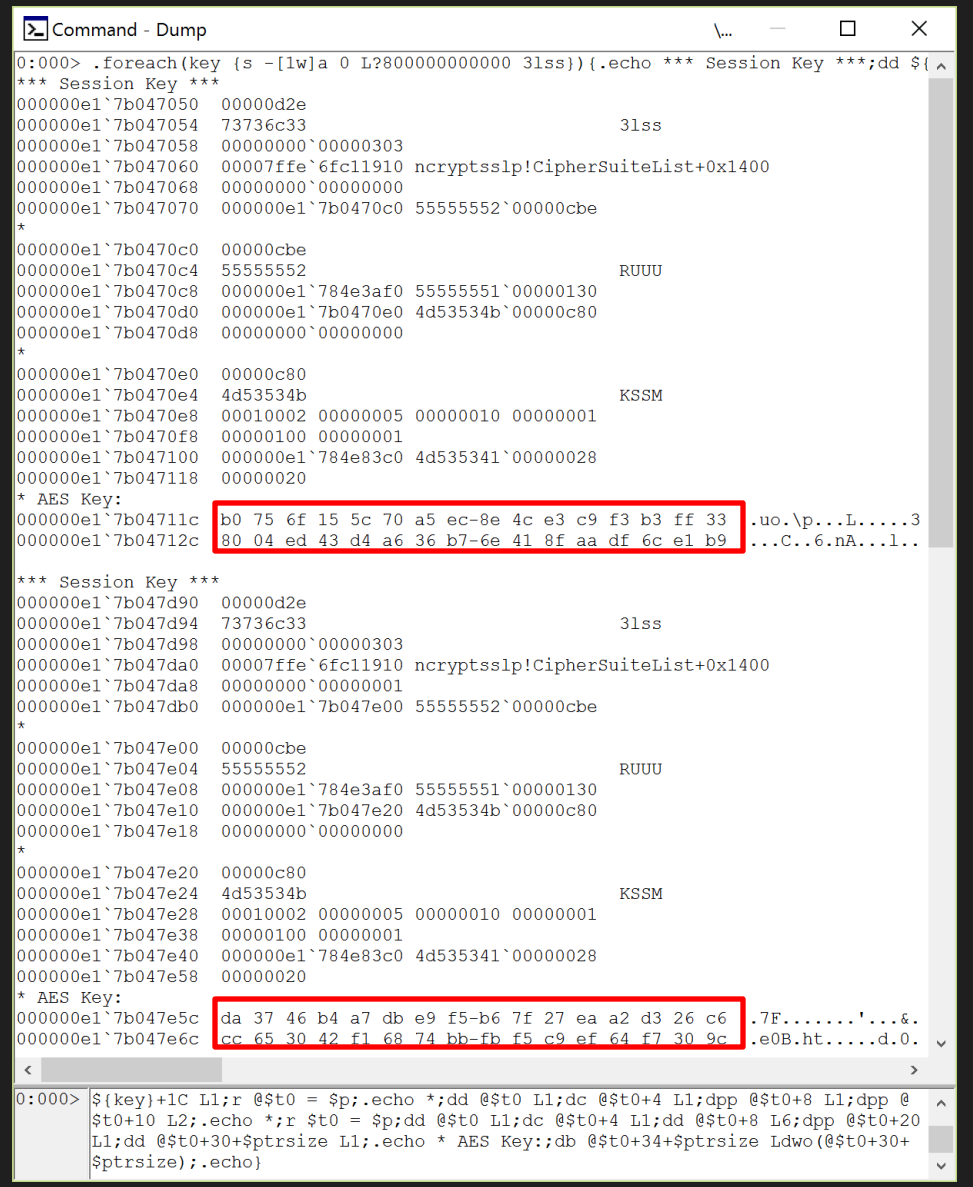




Session Keys

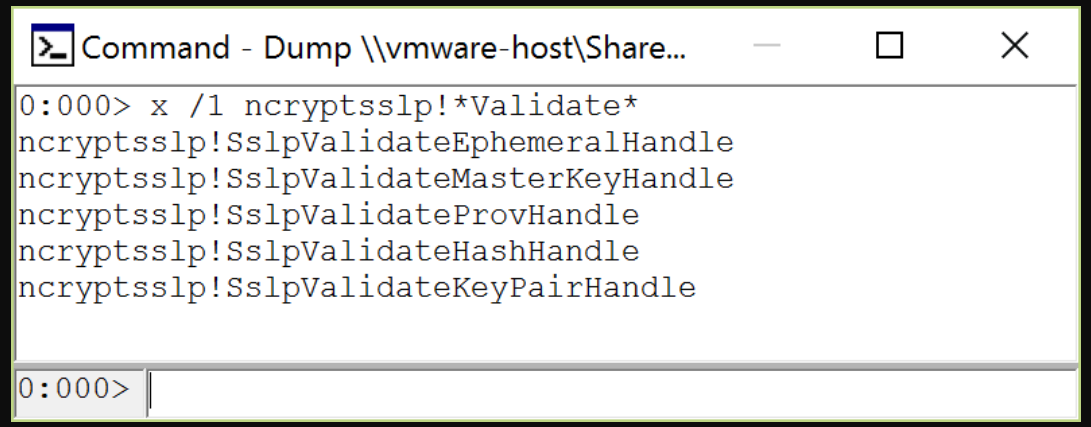


Look familiar? Bcrypt keys are used a lot: think Mimikatz

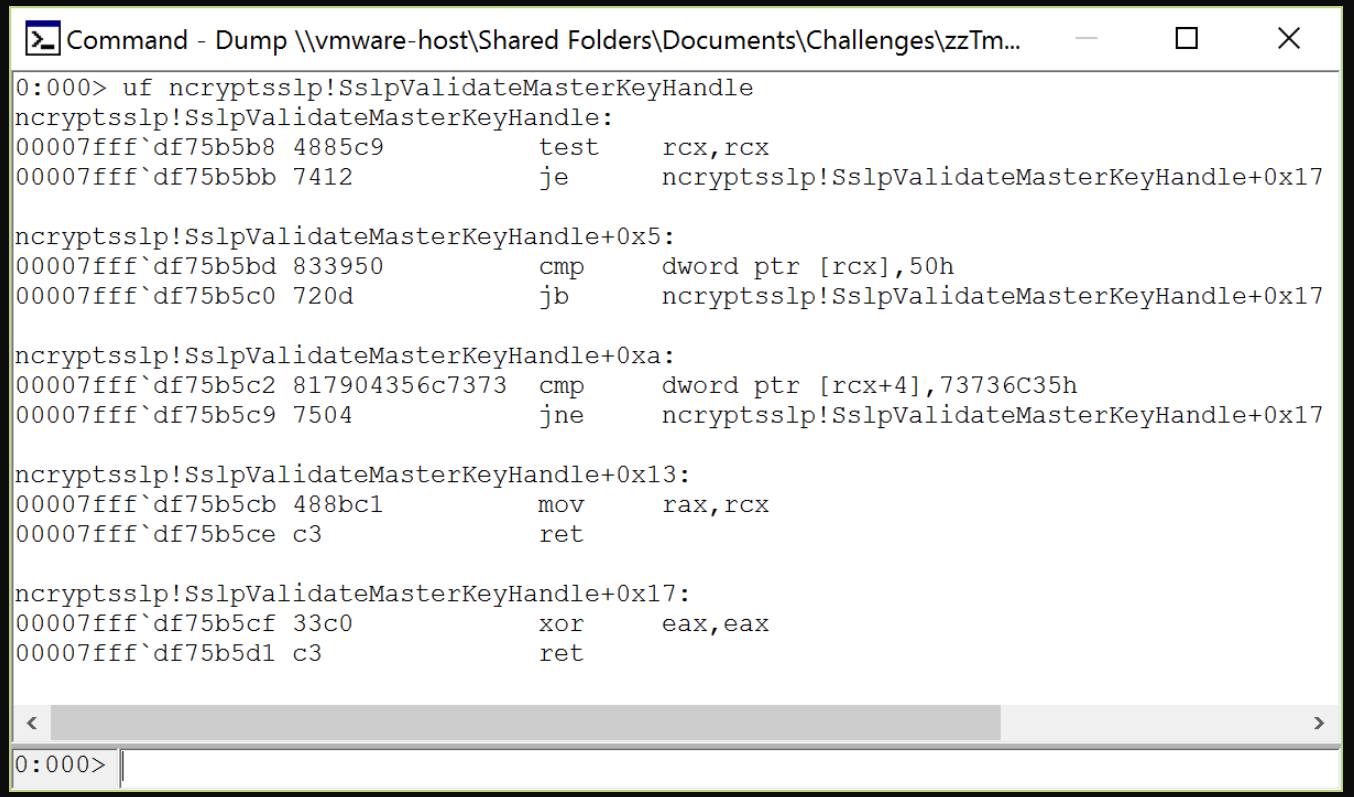


The Ncrypt SSL Provider (ncryptsslp.dll)

Ncryptsslp Validation function Symbols



Ncryptsslp Validation function Symbols



These functions do three things:

- ❑ Check the first dword for a size value
- ❑ Check the second dword for a magic ID
- ❑ Return the passed handle* if all is good

*Handles are always a pointer here

The Ncrypt SSL Provider (ncryptsslp.dll)

SSL Magic	Size (x86)	Size (x64)	Validation Functions
ssl1	0xE4	0x130	SslpValidateProvHandle
ssl2	0x24	0x30	SslpValidateHashHandle
ssl3	?	?	<none>
ssl4	0x18	0x20	SslpValidate**KeyPair**Handle
ssl5	0x48	0x50	SslpValidate**MasterKey**Handle
ssl6	0x18	0x20	SslpValidate**Ephemeral**Handle
ssl7	?	?	<none>

ssl3 was already discussed, appears in the following functions:

```
TlsGenerateSessionKeys+0x251
SPSslDecryptPacket+0x43
SPSslEncryptPacket+0x43
SPSslImportKey+0x19a
SPSslExportKey+0x76
Ssl2GenerateSessionKeys+0x22c
```

Pre-Master Secret (PMS)

- The '`ssl7`' struct appears to be used specifically for the RSA PMS
- As advised by the RFC, it gets destroyed quickly, once the Master Secret (MS) has been derived
- Client generates random data, populates the ssl7 structure, and encrypts
- In ECC the PMS is x-coordinate of the shared secret derived (which is a point on the curve), so this doesn't /seem/ to get used in that case

Functions where ssl7 appears:

```
ncryptsslp!SPSslGenerateMasterKey+0x75
ncryptsslp!SPSslGenerateMasterKey+0x5595
ncryptsslp!SPSslGeneratePreMasterKey+0x15e
ncryptsslp!TlsDecryptMasterKey+0x6b
```

Bottom line:

> **It's vestigial for our purposes - it doesn't do anything another secret can't**



Master Secret

- Basically the Holy Grail for a given connection
  - It always exists
  - It's what gets cached and used to derive the session keys
- Structure for storage is simple - secret is unencrypted (as you'd expect)
- This + **Unique ID** = decryption, natively in tools like wireshark

So...how do we get there?

_SSL_MASTER_SECRET	
4	cbStructLength
4	dwMagic ["ssl5"]
4	dwProtocolVersion
0/4	dwUnknown1* [alignment?]
4/8	pCipherSuiteListEntry
4	bIsClientCache
48	rgbMasterSecret
4	dwUnknown2 [reserved?]

Master Secret

_SSL_MASTER_SECRET	
4	cbStructLength
4	dwMagic ["ssl5"]
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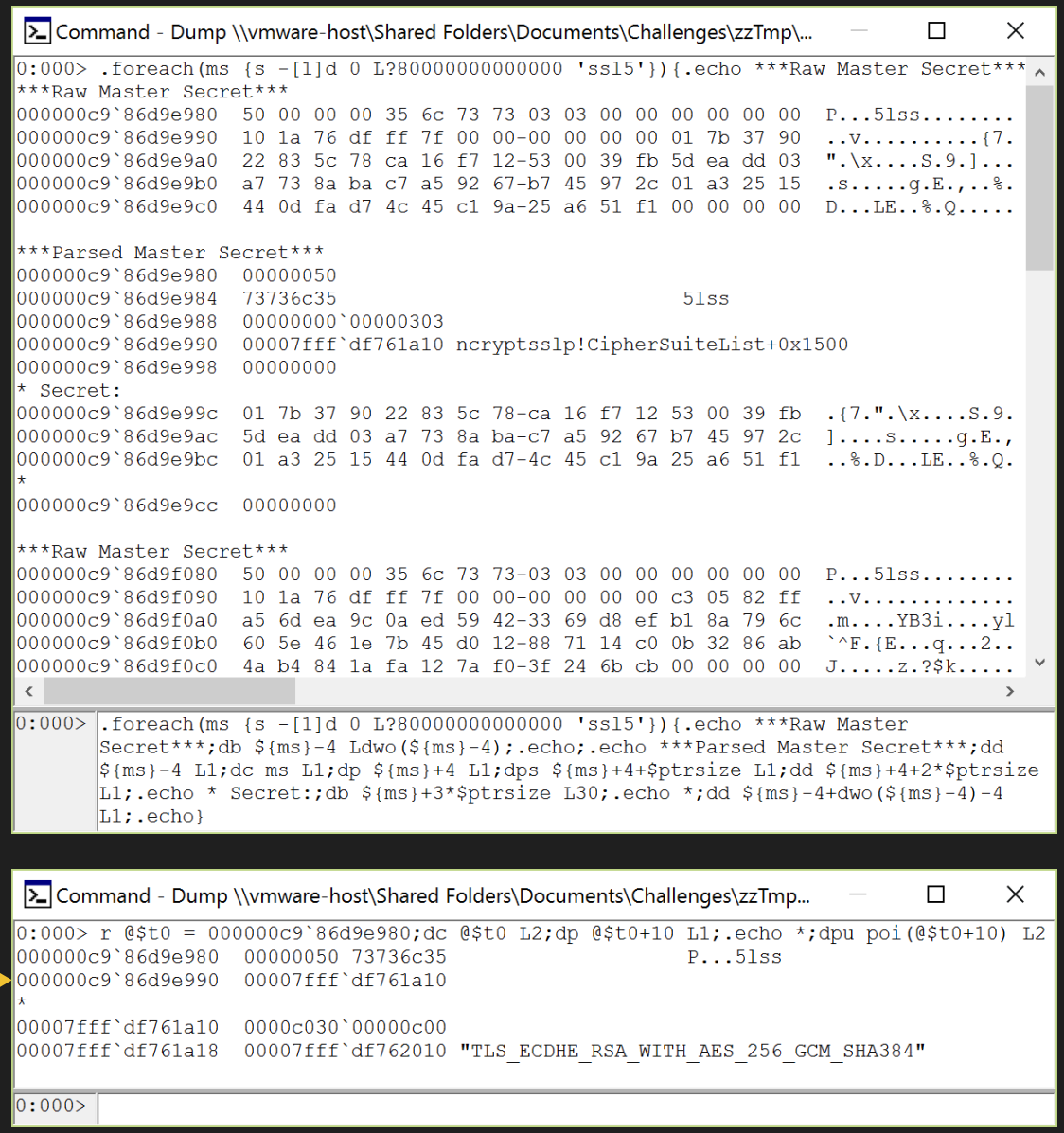


Master Secret Mapped to Unique Identifier

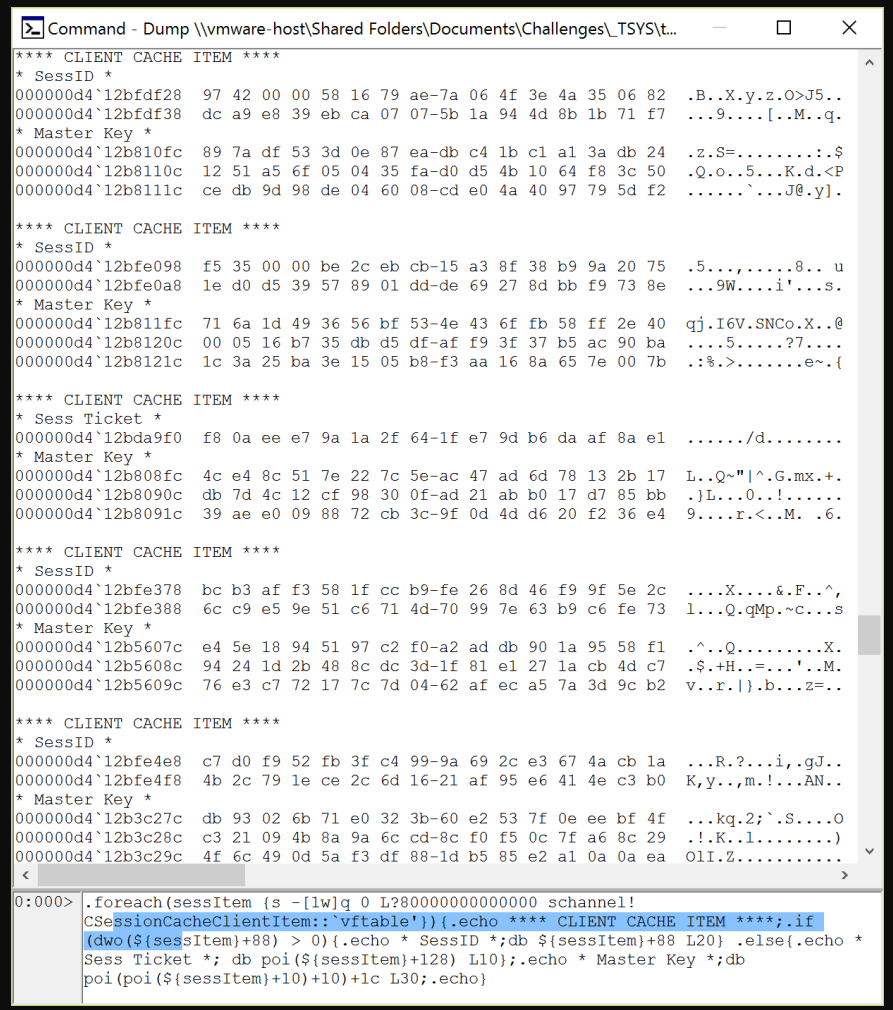
- The Master Key is linked back to a unique ID through an "**NcryptSslKey**"
- The NcryptSslKey is referenced by an "**SessionCacheItem**"
- The SessionCacheItem contains either the SessionID, or a pointer and length value for a SessionTicket
  - Instantiated as either client or server item

At this point, we can find cache items, and extract the Master Secret + Unique ID

… Houston, we has plaintext.



Master Secret Mapped to Unique Identifier



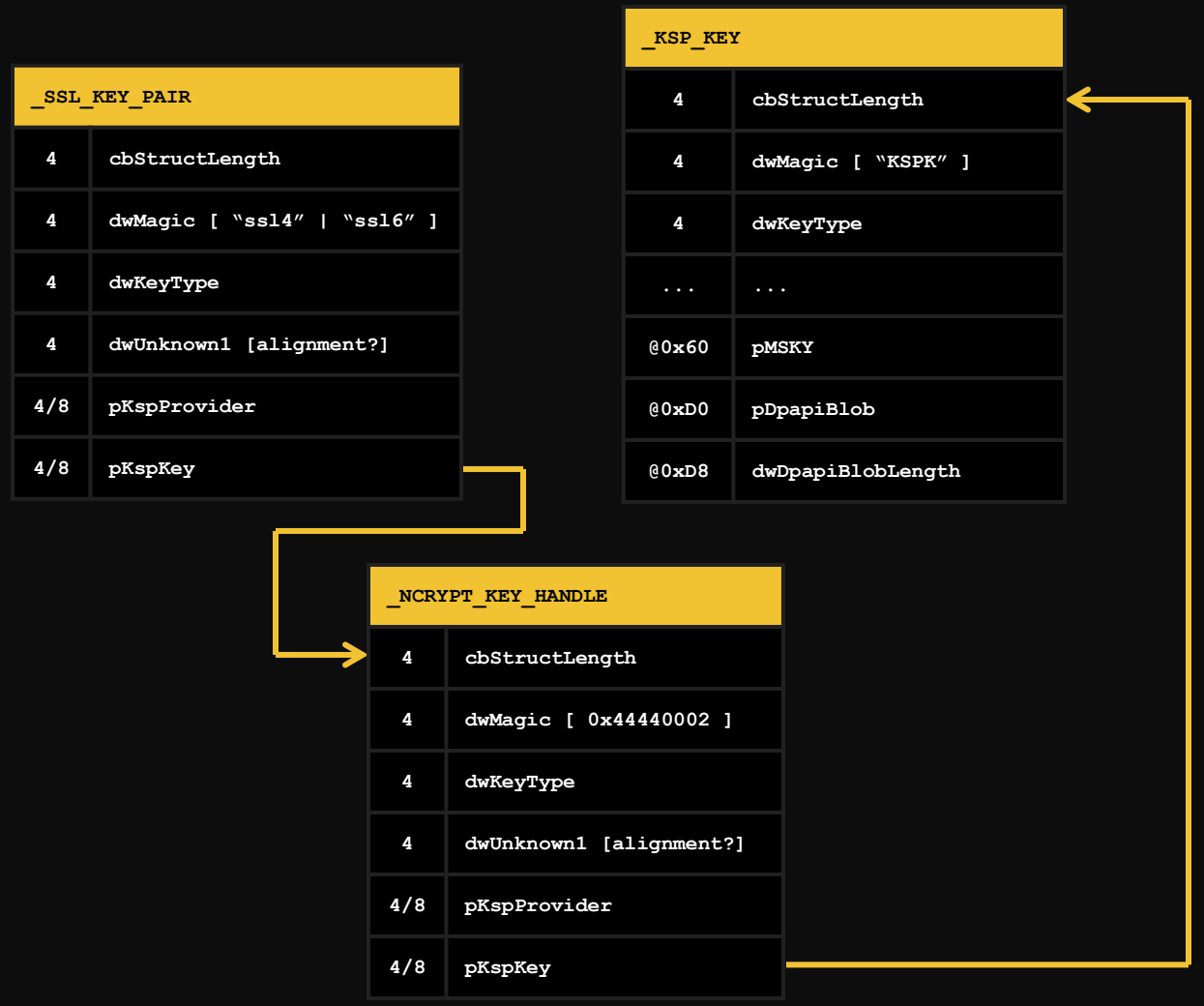
Wireshark SSL Log Format

```
RSA Session-ID:97420000581679ae7a064f3e4a350682dca9e839ebca07075b1a944d8b1b71f7 Master-Key:897adf533d0e87eadbc41bc1a13adb241251a56f050435fad0d54b1064f83c50cedb9d98de046008cde04a4097795df2

RSA Session-ID:f5350000be2cebcb15a38f38b99a20751ed0d539578901ddde69278dbbf9738e Master-Key:716a1d493656bf534e436ffb58ff2e40000516b735dbd5dfaff93f37b5ac90ba1c3a25ba3e1505b8f3aa168a657e007b

RSA Session-ID:bcb3aff3581fccb9fe268d46f99f5e2c6cc9e59e51c6714d70997e63b9c6fe73 Master-Key:e45e18945197c2f0a2addb901a9558f194241d2b488cdc3d1f81e1271acb4dc776e3c772177c7d0462afeca57a3d9cb2

RSA Session-ID:c7d0f952fb3fc4999a692ce3674acb1a4b2c791ece2c6d1621af95e6414ec3b0 Master-Key:db93026b71e0323b60e2537f0eeebf4fc321094b8a9a6ccd8cf0f50c7fa68c294f6c490d5af3df881db585e2a10a0aea
```

Wireshark SSL input formats found here: https://github.com/boundary/wireshark/blob/master/epan/dissectors/packet-ssl.c

Ephemeral & Persistent Private Keys

- Both share the same structure
- Both store secrets in a Key Storage Provider Key struct (KPSK)
- The “Key Type” is compared with different values
  - ssl6 gets compared with a list stored in bcryptprimitives
  - ssl4 gets compared with a list stored in NCRYPTPROV
- The Key Storage Provider Key (KPSK) is referenced indirectly through an “Ncrypt Key” struct*

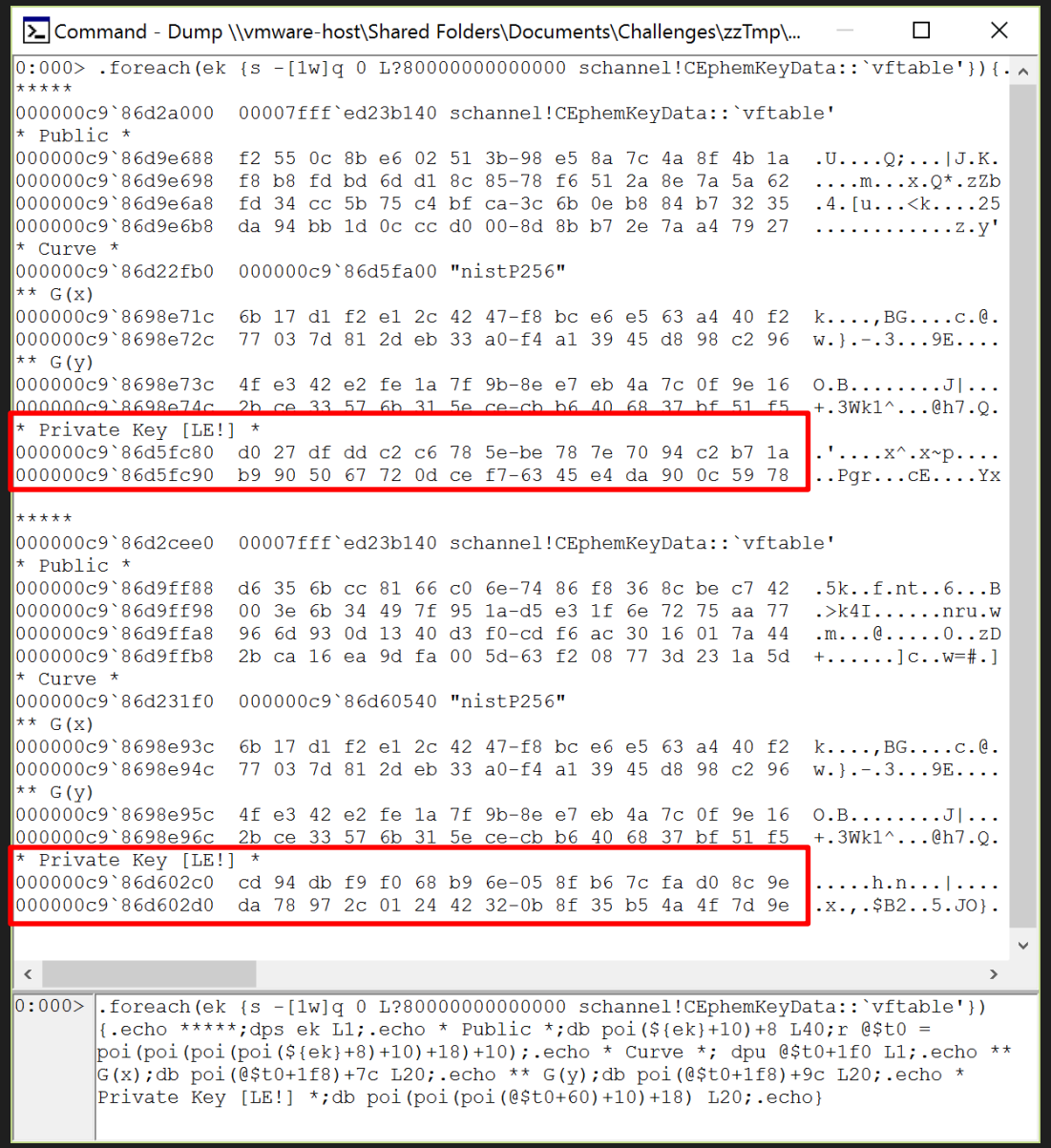


*NcryptKey not to be confused with NcryptSslKey

Ephemeral Private Key

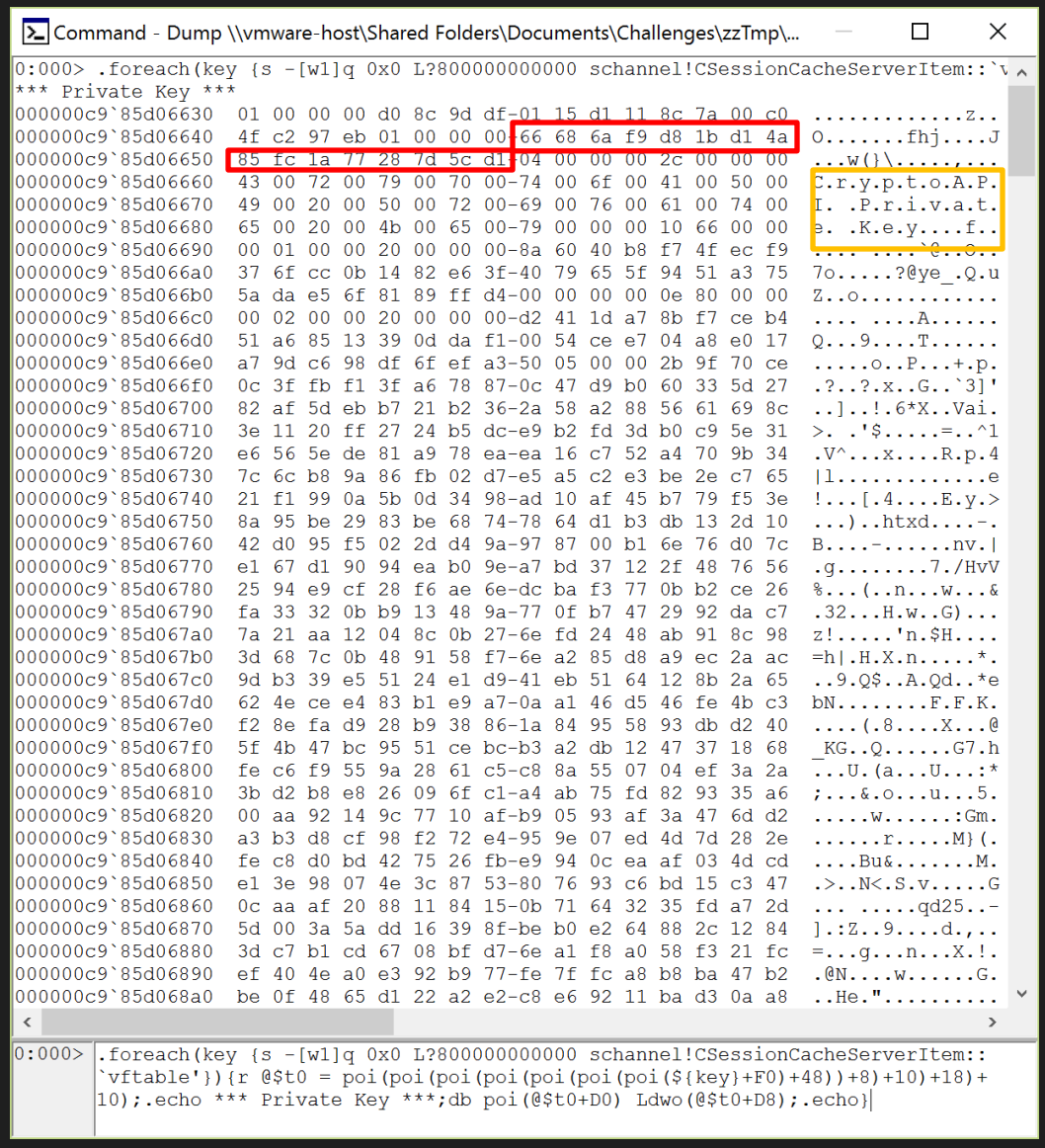
- **For performance, reused across connections**
  - Given the public connection params, we can derive the PMS and subsequently MS
- **Stored unencrypted in a LE byte array**
  - Inside of MSKY struct
- The curve parameters are stored in the KPSK
  - Other parameters (A&B, etc) are stored in MSKY w/ the key
- Verified by generating the Public & comparing
  - The Public Key is also stored in the first pointer of the `CEphemData` struct that points to "`ssl6`"

In-line with suggestion of this paper: http://dualec.org/DualECTLS.pdf



“Persistent” Private Key

- The RSA Key that is stored on disk
  - Unique instance for each private RSA Key – by default, the system has several
  - E.g. one for Terminal Services
- RSA Keys are DPAPI protected
  - Lots of research about protection / exporting
  - Note the MK GUID highlighted from the Blob
- The Key is linked to a given Server Cache Item
- Verified by comparing the DPAPI blob in memory to protected certificate on disk
  - Also verified through decryption

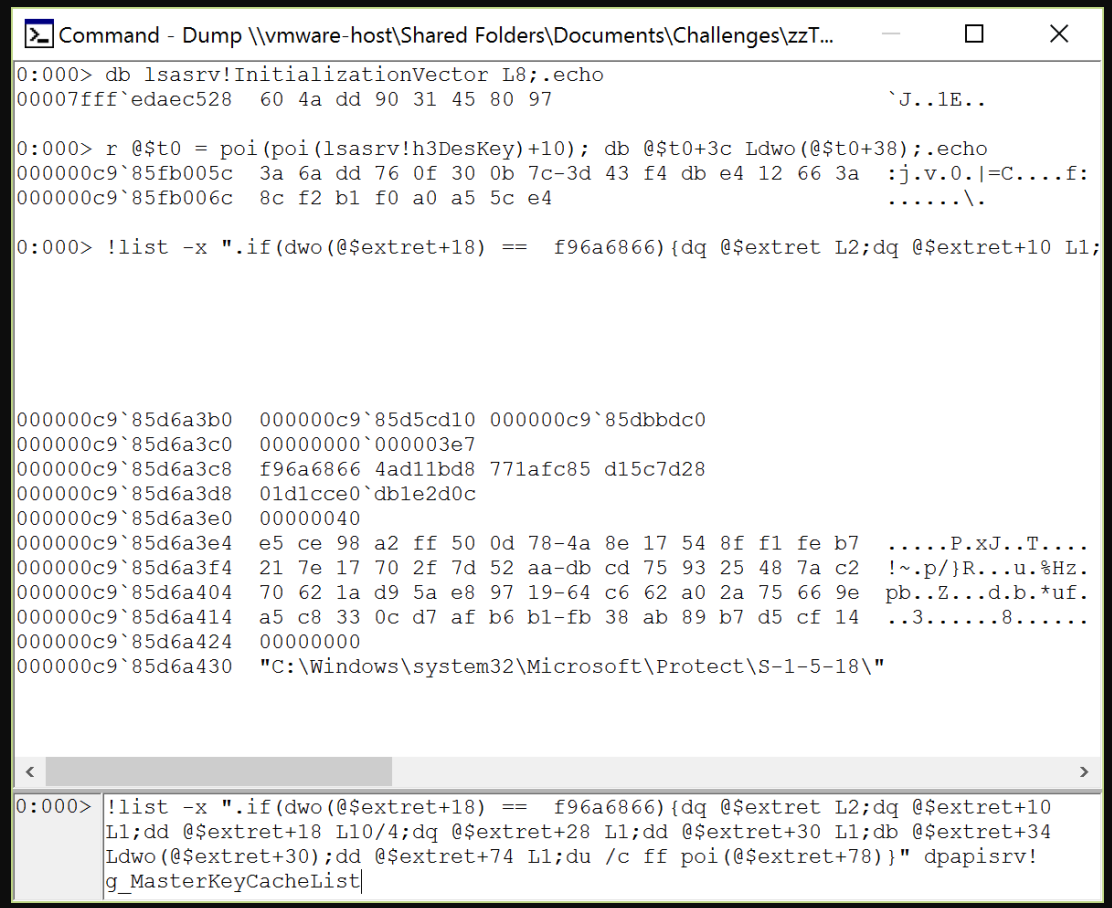


Decrypting Persistent Key - DPAPI

- Can extract the blob from memory and decrypt w/ keys from disk
  - DPAPIck / Mimikatz

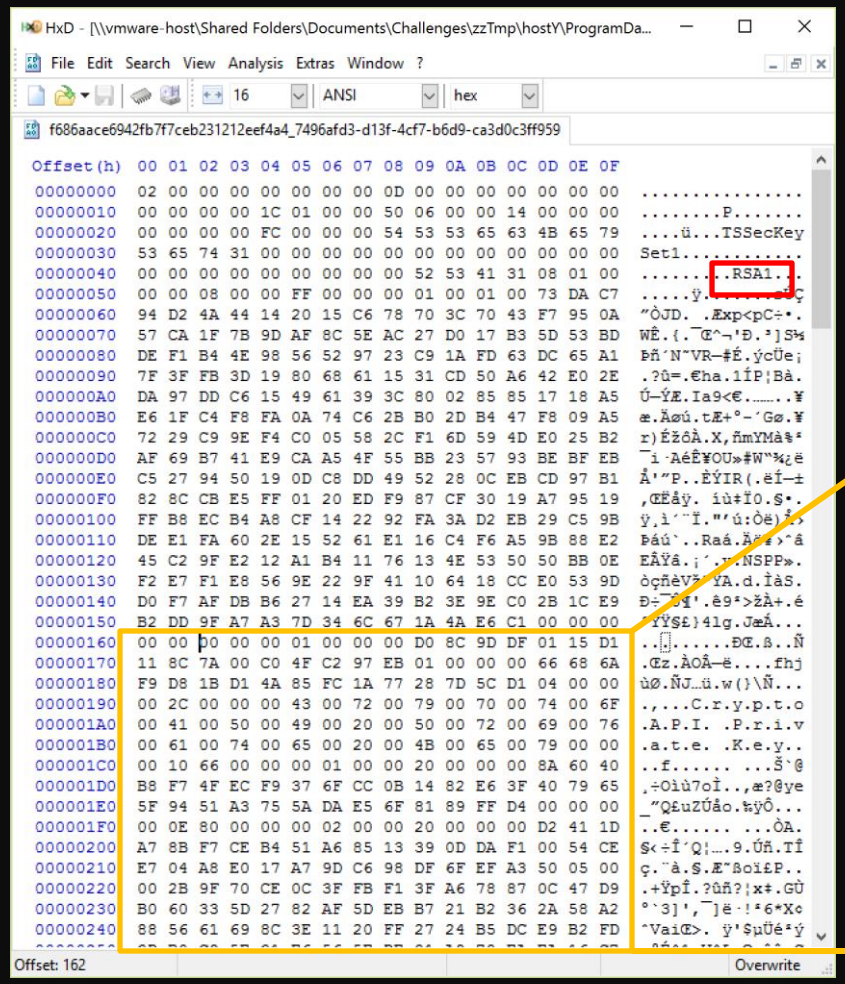
OR

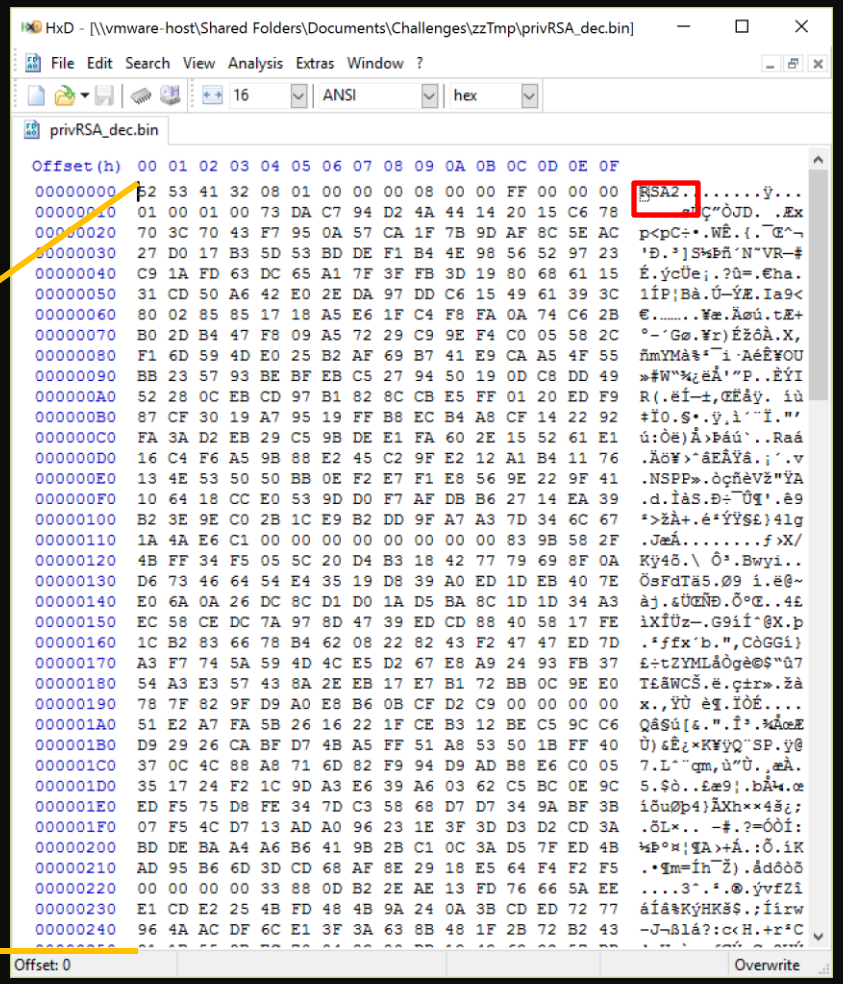
- Can decrypt directly from memory :D
  - MasterKeys get cached in Memory
    - On Win10 in: dpapisrv!g_MasterKeyCacheList
    - See Mimilib for further details
    - Even though symbols are sort of required, we could likely do without them
      - There are only two Bcrypt key pointers in lsasrv's .rdata section (plus one lock)
      - Identifying the IV is more challenging



Cached DPAPI MK + Params to Decrypt

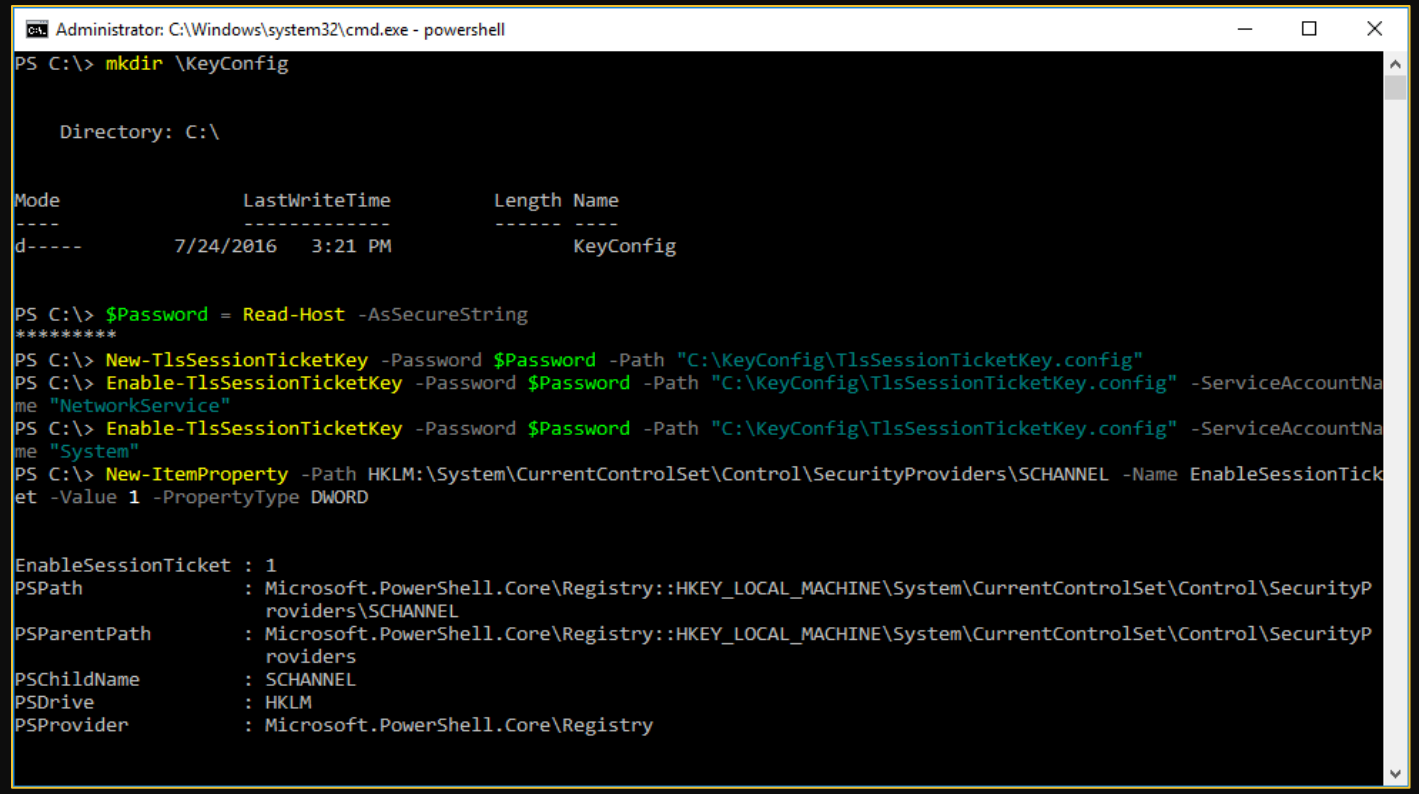
Decrypting Persistent Key - DPAPI





Session Tickets

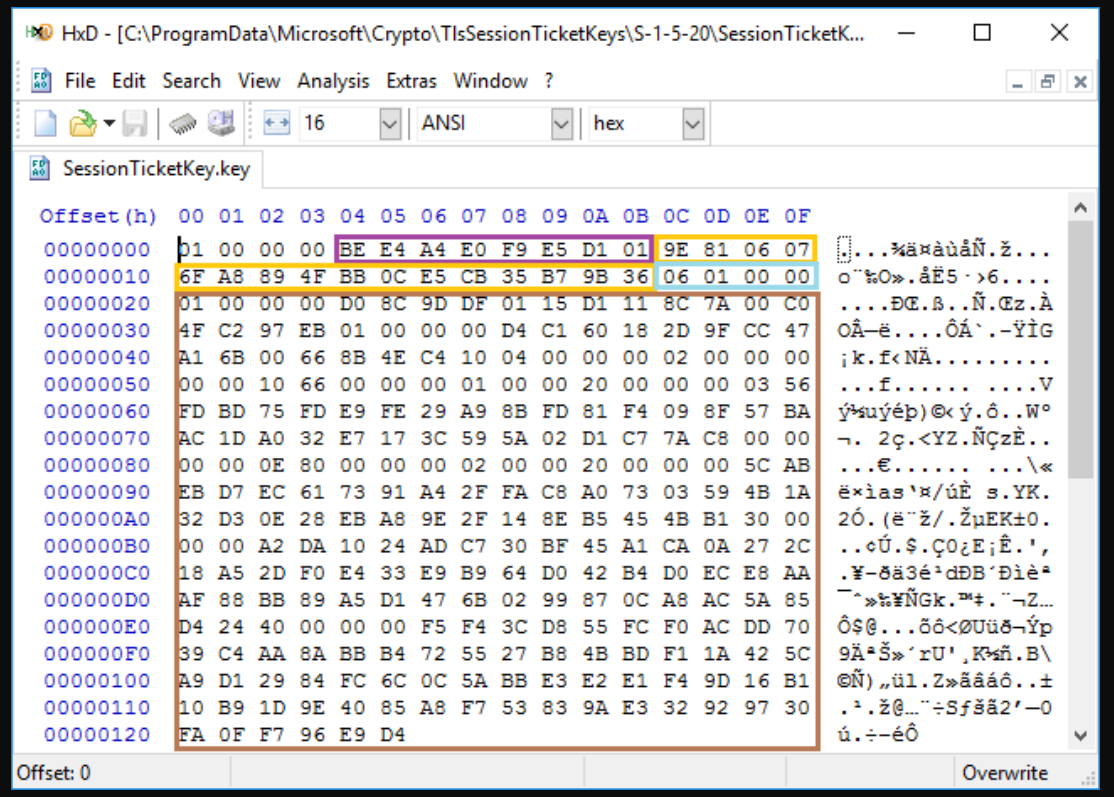
- Not seemingly in widespread use with IIS?
  - Comes around w/ Server 2012 R2
  - Documentation is lacking.
- Enabled via reg key + powershell cmdlets?
  - Creates an “Administrator managed” session ticket key
- Schannel functions related to Session Tickets load the keyfile from disk
- Export-TlsSessionTicketKey :D



Reference to DISABLING session tickets in Win8.1 Preview release notes: https://technet.microsoft.com/en-us/library/dn303404.aspx

Session Ticket Key

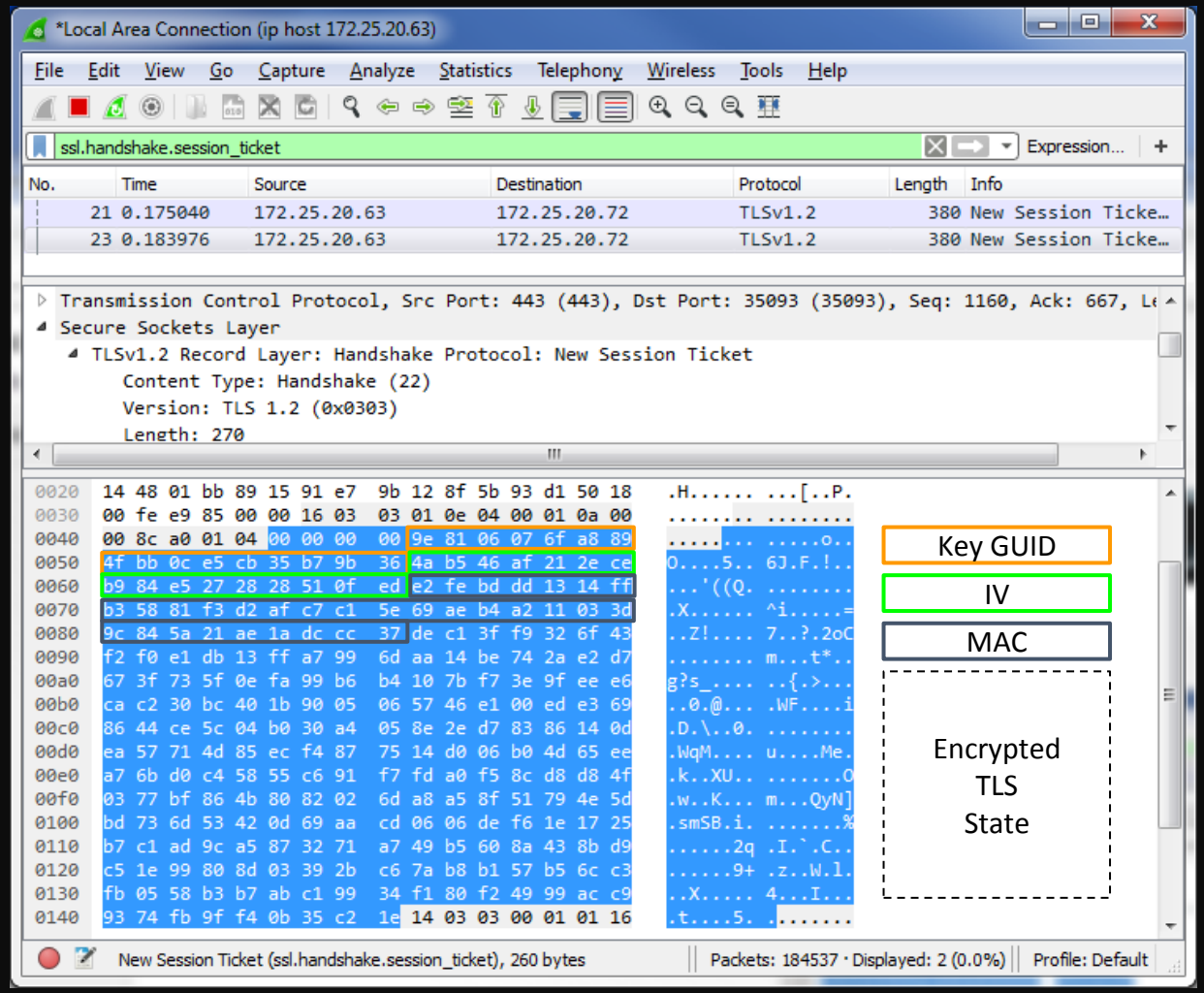
- Keyfile contains a DPAPI blob, preceded by a SessionTicketKey GUID + 8 byte value
- Key gets loaded via schannel
  - The heavy lifting (at least in Win10) is done via mskeyprotect
- AES key derived from decrypted blob via BCryptKeyDerivation()
- Key gets cached inside mskeyprotect!
  - No symbols for cache : /
  - No bother, we can just find the Key GUID that's cached with it :D



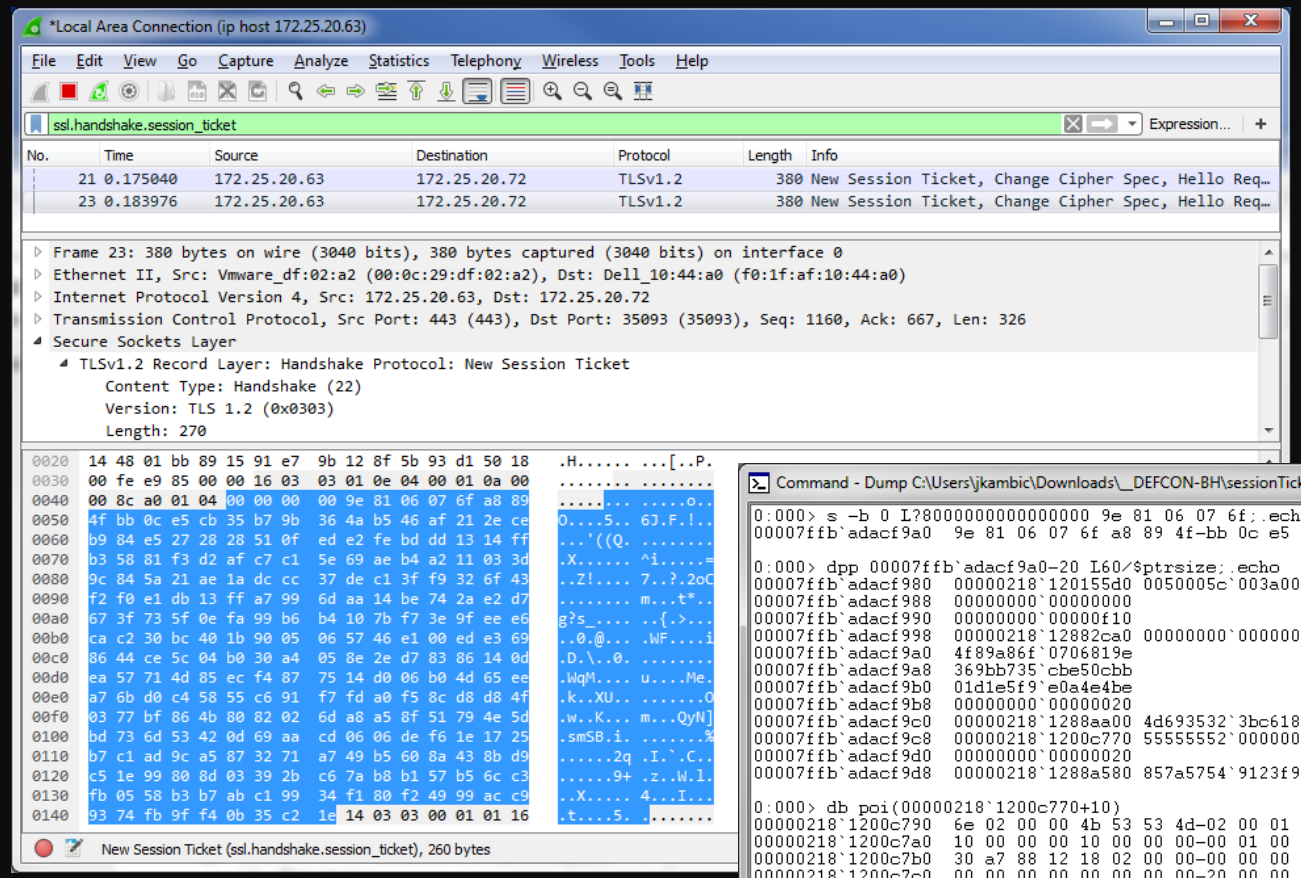
- Possibly Salt or MAC?
- Session Ticket Key GUID
- Size of ensuing DPAPI Blob
- DPAPI Blob (contains it's own fields)

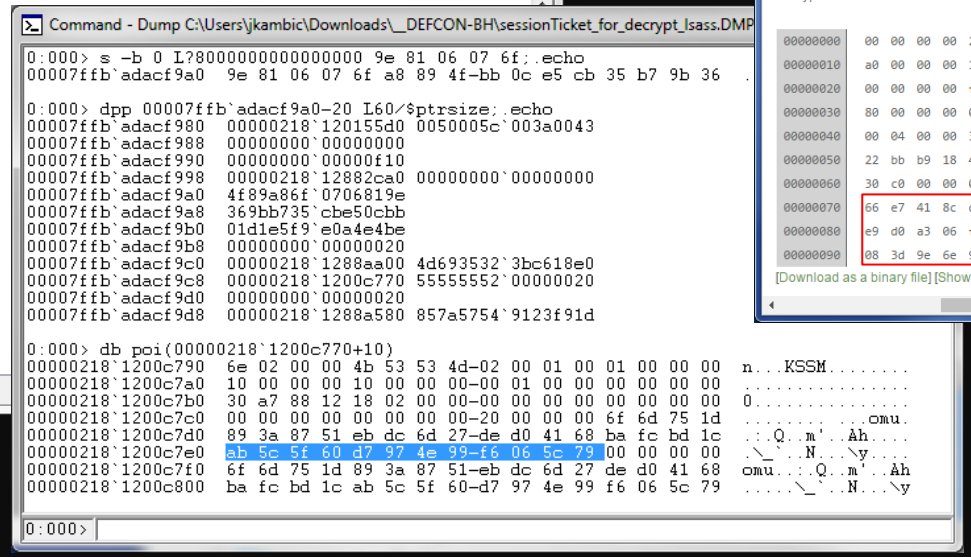
Decrypting Session Tickets

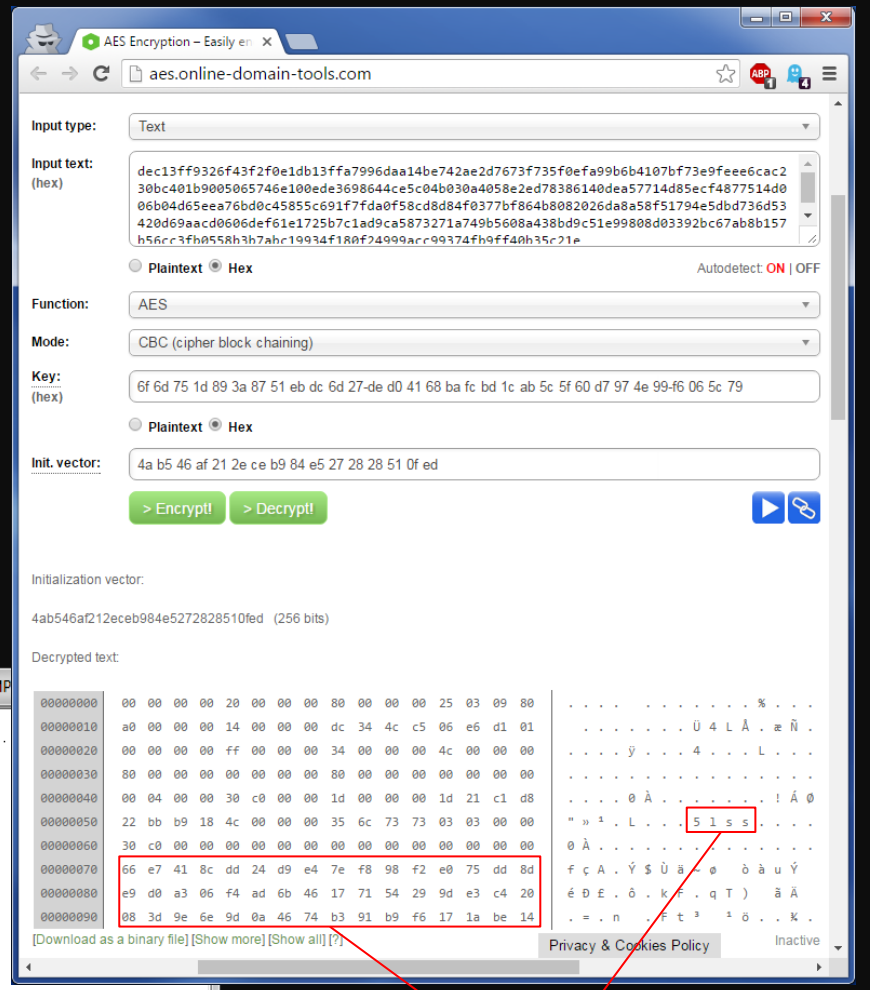
- Session Ticket structure pretty much follows the RFC (5077), except:
  - MAC & Encrypted State are flipped (makes a lot of sense)
- After extracting/deriving the Symm key, it's just straight AES 256
- Contents of the State are what you'd expect:
  - Timestamp
  - Protocol/Ciphersuite info
  - MS struct



Decrypting Session Tickets







Master Secret

Secrets are cool and all...

But Jake, what if I don’t have a packet capture?
(And I don’t care about future connections?)

THE CONTEXT



Inherent Metadata TLS Provides

Core SSL/TLS functionality

- Timestamps
  - The random values *typically* start with a 4-byte timestamp (if you play by the RFCs)
- Identity / fingerprinting
  - Public Key
  - Session ID*
  - Offered Cipher Suites / Extensions
- Session ID's are arbitrary, but are not always random -> Schannel is a perfect example
  - uses `MaximumCacheEntries` parameter when creating the first dword of the random, leading to a(n imperfect) fingerprint of two zero bytes in 3/4th byte*

TLS Extensions

- Server Name Indication (SNI)
  - Virtual hosts
- Application-Layer Protocol Negotiation (ALPN)
  - Limited, but what protocol comes next
    - fingerprinting?
- Session Tickets
  - Key GUID

*Referenced in this paper: http://dualec.org/DualECTLS.pdf

Schannel Caching Parameters

Parameters:

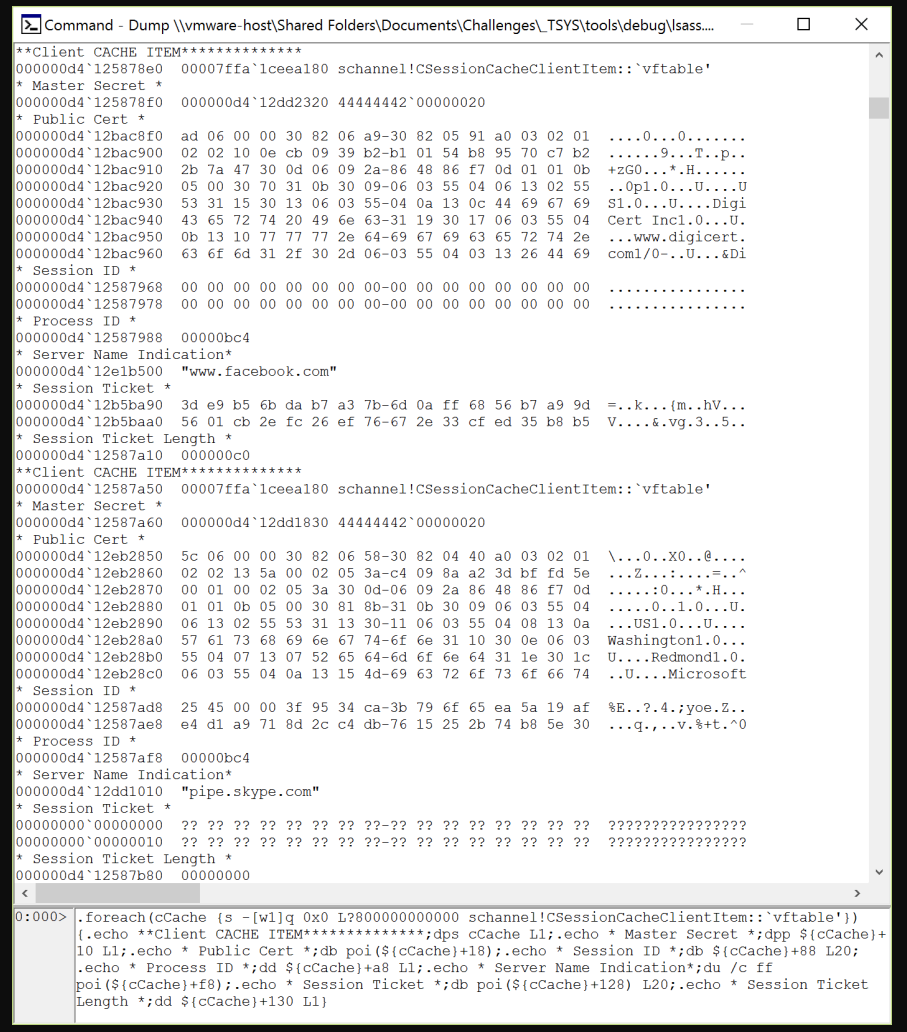
- The following control upper-limit of cache time:
  - `m_dwClientLifespan`
  - `m_dwServerLifespan`
  - `m_dwSessionTicketLifespan`
- All of which:
  are set to `0x02255100` (**10hrs** in ms)
- Also of Interest:
  - `m_dwMaximumEntries` (set to `0x4e20` or **20,000 entries** by default)
  - `m_dwEnableSessionTicket` controls use of session tickets (e.g. `0, 1, 2`)
  - `m_dwSessionCleanupIntervalInSeconds` (set to `0x012c` or **300 seconds** by default)

HOWEVER!

- Schannel is the library, the ***process*** has control
- Proc can purge its own cache at will
  - For example, IIS reportedly* purges after around two hours
- Schannel maintains track of process, frees cache items after client proc terminates : <
  - Haven't looked at the exact mechanism
  - As you'll see, the upside is that the Process ID is stored in the Cache

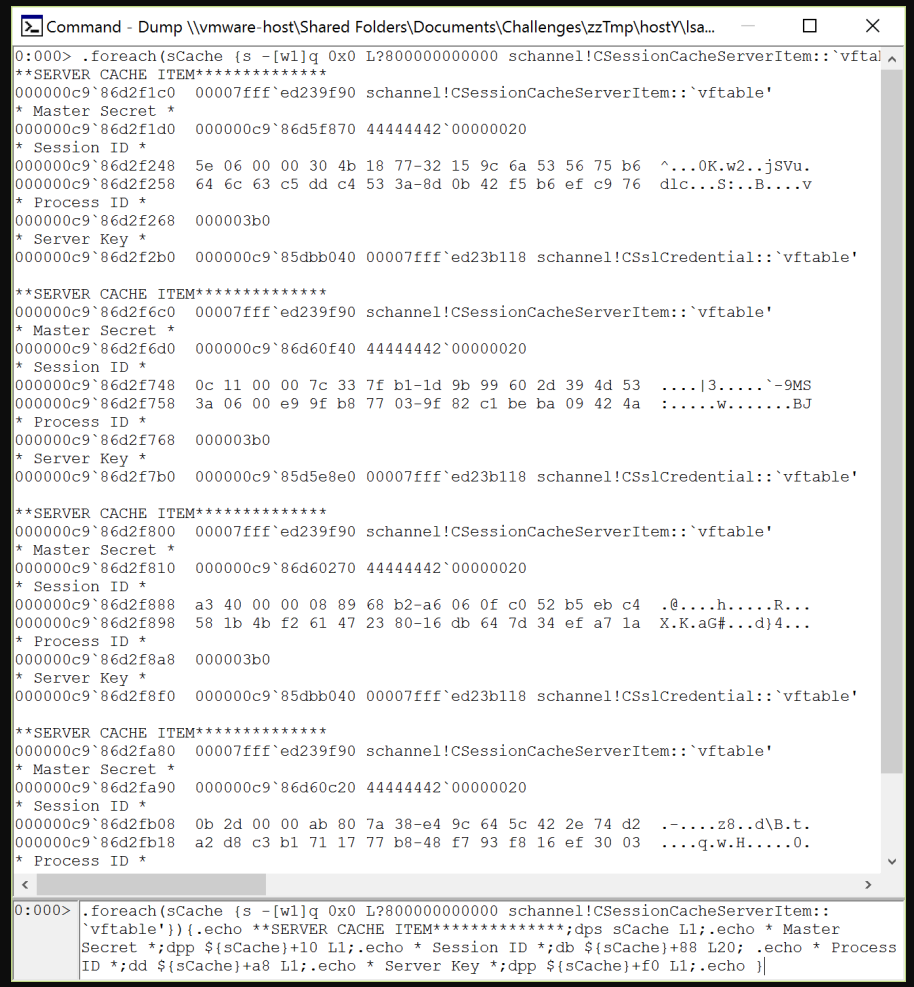
This is your Schannel Cache (x64)

```
'_SSL_SESSION_CACHE_CLIENT_ITEM': [ 0x148, {
    'Vftable': [0x0, ['pointer64', ['void']]],
    'MasterKey': [0x10, ['pointer64', ['void']]],
    'PublicCertificate': [0x18, ['pointer64', ['void']]],
    'PublicKey': [0x28, ['pointer64', ['void']]],
    'NcryptSslProv': [0x60, ['pointer64', ['void']]],
    'SessionIdLen': [0x86, ['short short']],
    'SessionId': [0x88, ['array', 0x20, ['unsigned char']]],
    'ProcessId': [0xa8, ['unsigned long']],
    'MaxLifeTime': [0xB0, ['unsigned long']],
    'CertSerializedCertificateChain': [0xB0, ['pointer64', ['void']]],
    'UnkList1Flink': [0xB8, ['pointer64', ['void']]],
    'UnkList1Blink': [0xC0, ['pointer64', ['void']]],
    'UnkCacheList2Flink': [0xC8, ['pointer64', ['void']]],
    'UnkCacheList2Blink': [0xD0, ['pointer64', ['void']]],
    'ServerName': [0x108, ['pointer64', ['void']]],
    'LogonSessionUID': [0x110, ['pointer64', ['void']]],
    'CSessCacheManager': [0x120, ['pointer64', ['void']]],
    'SessionTicket': [0x138, ['pointer64', ['void']]],
    'SessionTicketLen': [0x140, ['int']],
    }],
```



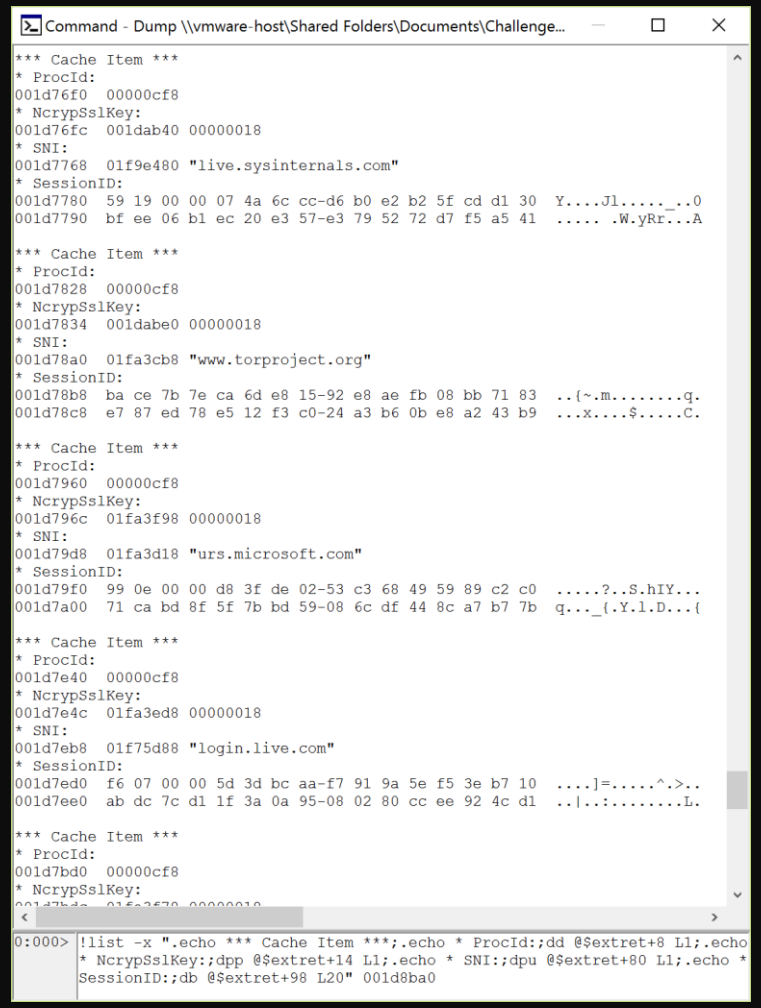
This is your Schannel Cache (x64)

```
'_SSL_SESSION_CACHE_SERVER_ITEM': [ 0x110, {
    'Vftable': [0x0, ['pointer64', ['void']]],
    'NcryptKey': [0x10, ['pointer64', ['void']]],
    'NcryptSslProv': [0x60, ['pointer64', ['void']]],
    'SessionId': [0x88, ['array', 0x20, ['unsigned char']]],
    'ProcessId': [0xa8, ['unsigned long']],
    'MaxLifeTime': [0xB0, ['unsigned long']],
    'LastError?': [0xE8, ['unsigned long']],
    'CSslCredential': [0xF0, ['pointer64', ['void']]],
    }],
```



This is your Schannel Cache on ~~Drugs~~ VISTA

```
'_SSL_SESSION_CACHE_CLIENT_ITEM': [ 0xf0, {
    'Flink': [0x0, ['pointer', ['void']]],
    'Blink': [0x4, ['pointer', ['void']]],
    'ProcessId': [0x8, [['unsigned long']],
    'MasterKey': [0x14, ['pointer', ['NcryptSslKey']]],
    'CipherSuiteId': [0x1C, ['pointer', ['void']]],
    'ECCurveParam': [0x20, ['pointer', ['void']]],
    'NcryptSslProv': [0x28, ['pointer', ['void']]],
    'PublicCertificate': [0x2C, ['pointer', ['void']]],
    'PublicCert2': [0x34, ['pointer', ['void']]],
    'PublicKeyStruct': [0x3C, ['pointer', ['void']]],
    'PublicCertStruct3': [0x44, ['pointer', ['void']]],
    'ServerName': [0x80, ['pointer', ['void']]],
    'SessionIdSize': [0x94, ['short short']],
    'SessionId': [0x98, ['array', 0x20, ['unsigned char']]],
    'ErrorCode': [0xEC, ['pointer64', ['void']]],
    }],
```



AUTOMATION



Volatility / Rekall

- Plugins for both – by default (no args) they:
  - Find LSASS
  - Scan Writeable VADs / Heap for Master Key signature (Volatility) or directly for SessionCacheItems (Rekall)
  - Dump out the wireshark format shown earlier
- Hoping to have functional powershell module or maybe incorporation into mimikatz? (Benjamin Delphy is kinda the man for LSASS)

```
      % vol.py --plugins=./plugins --profile=Win10x64 -f ./Win10-Test-c2a4a77d.vm
em lsasslkey
Volatility Foundation Volatility Framework 2.5
RSA Session-ID:b93c0000a110690b4ae9111bce5725c6c47a037b3c39c49c75ce51e1c2eb79ee M
aster-Key:bc28467999b99fd3fdf3a24642c5d93b9ab43e51627f6e0145ef120ba98a1c3223f3dbe
0154e30d7869bdb7ab66f5318
RSA Session-ID:173300000f84a86aebb2c5de0af20e6d5c2cab95ab65043e14c6e19cee54ee17 M
aster-Key:9dd750e12e6e4439b08326d4a1f9eba2d2fe65c2a26c2088e7cec22ce1d91e9f219b704
547a2b2eccb9a81d557d5ae1a
RSA Session-ID:3c2c000024b8f70dd2613d8b13d0c4ac4daaefbe53ab4b7cb9763e80feccb4f1 M
aster-Key:2d119c64695ffc9c143c136471f5625d8cde92d35721f5f2849b92639603799a45e1e60
1786cbf89b00c186969d44983
RSA Session-ID:d4170000da09f8596739215e216c496568fa66e42ac32b974d440949dff33d2b M
aster-Key:44b503bef7842ea9a416fbf8b63b932b23b7b687fbf5297b253eac427877c8e11595e14
c3f00c40bf2a0f4688de0b7aa
RSA Session-ID:432a0000bf4f622f0fc119974a0ef30cd838c3a025b83abbdcdbce7b2325d2d9 M
aster-Key:552699d61e21d1b871af4b05a54003bf03eade60666dd1e54b94c3b5ec98f296db4ae99
baed4e23882175e5ffd88be31
RSA Session-ID:6f230000a021aac48d15544524c1454e4ec01d5adb305d8d9d57ab2b991dd597 M
aster-Key:8bc9e9df653e3cbf533be84c6897787bd453b8cee9d5389e9c3659ebf997d9c8d0666aa
dca5be2258f30b9251215a717
```

LIMITATIONS

We're working with internal, undocumented structures

- They change over time -- sometime around April 2016, an element appears to have been inserted in cache after the Session ID and before the SNI
  - Not a huge deal, except when differences amongst instances of same OS (e.g. ones that have and have not been updated)

Relying on symbols for some of this

- MS giveth and can taketh away.
- Still, can be done without them, just slightly less efficiently.

You need to be able to read LSASS memory

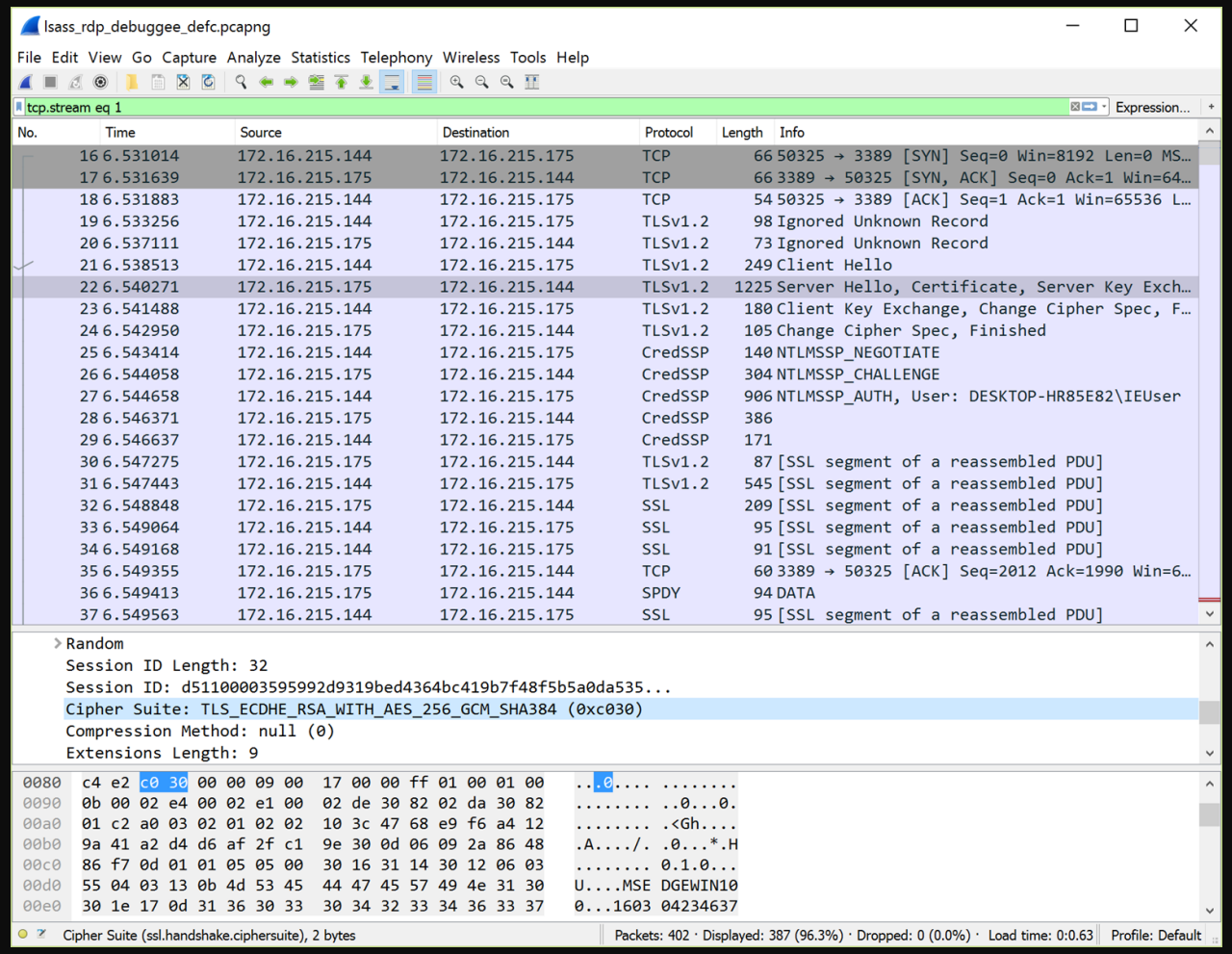
- Not a huge deal in 2016, but still merits mention -- you need to own the system
- If you own the system, you can already do bad stuff (keylog / tap net interface)
- This is why it's probably most useful in a forensic context

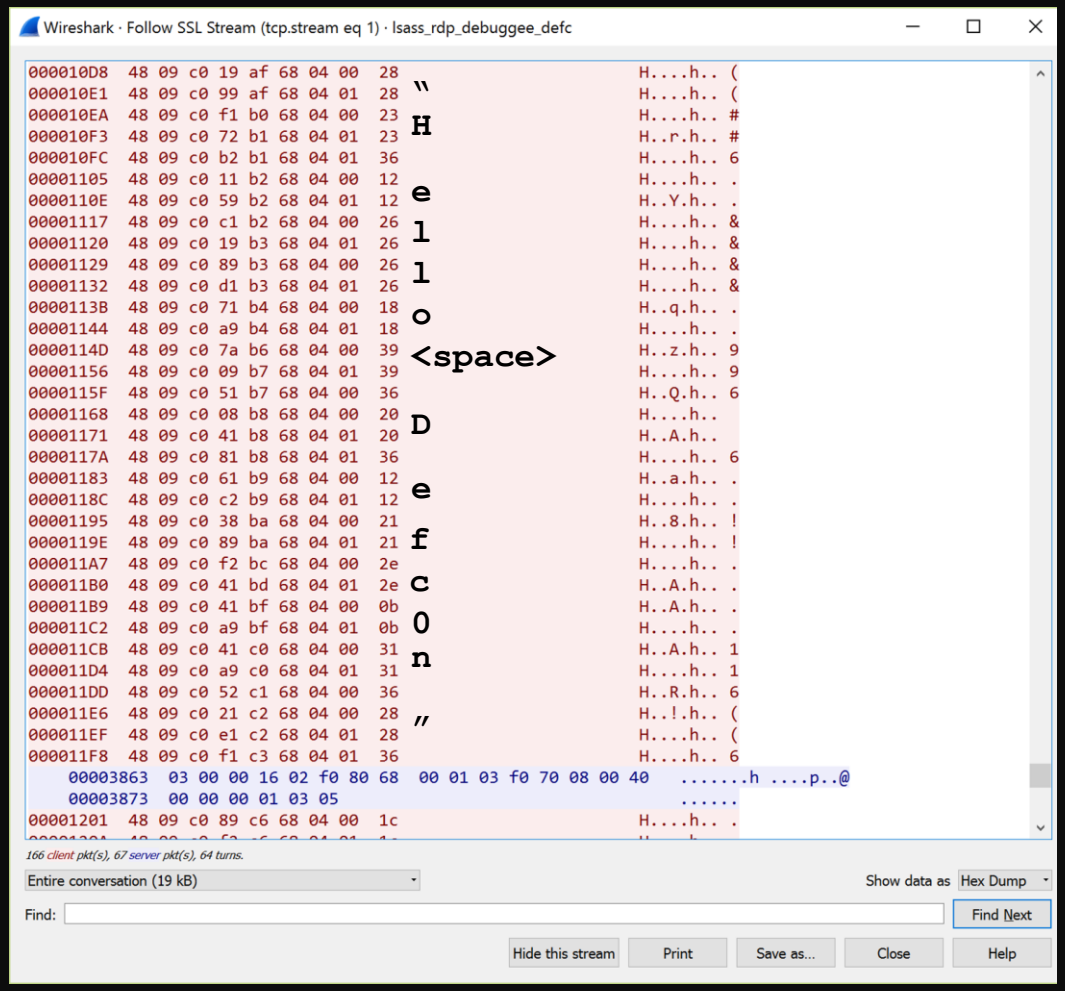
Decrypting an RDP Session (Ephemeral XCHG)

DEMO TIME

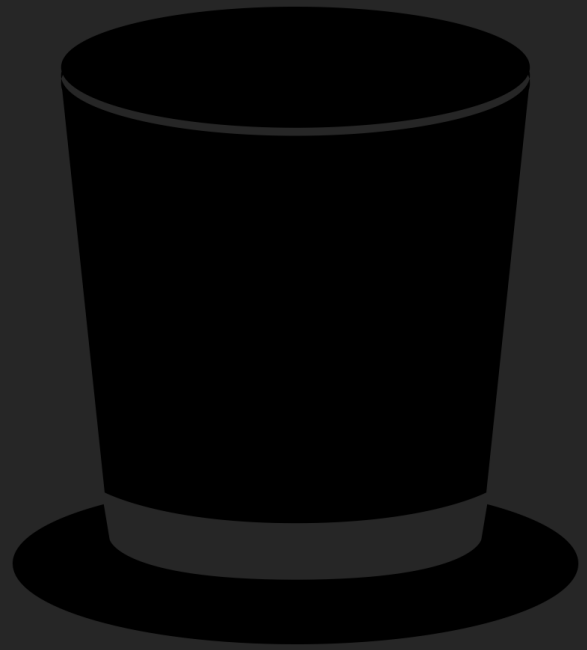


Decrypting an RDP Session (Ephemeral ? XCHG)

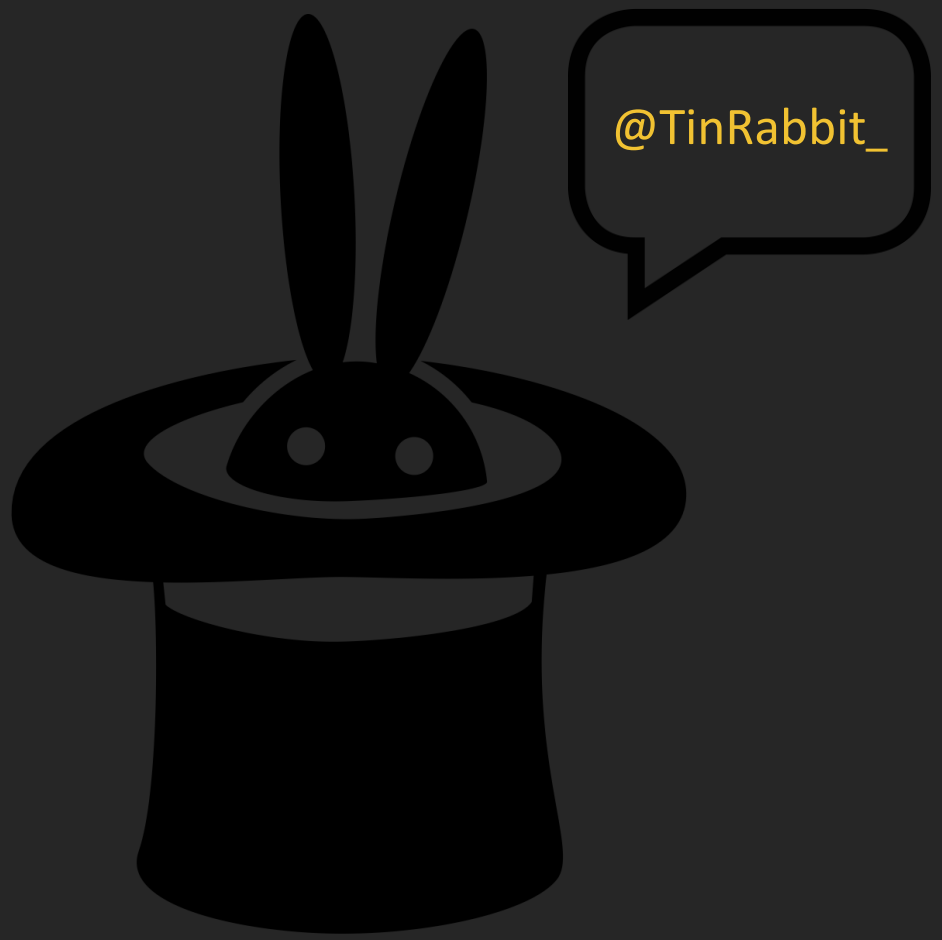




Keycodes from: https://msdn.microsoft.com/en-us/library/aa299374.aspx



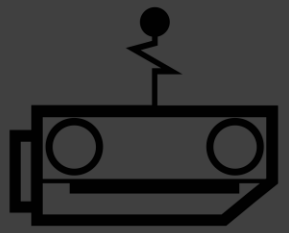
FIN.



QUESTIONS?

SP3CIAL THANKS

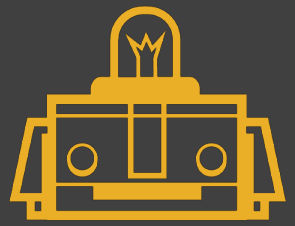
For general support, helpful comments, their time, and encouragement.



Áine Doyle

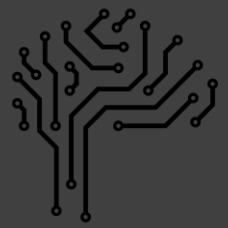
Badass Extraordinaire

(OCSC)



Dr. John-Ross Wallrabenstein

Sypris Electronics



Dr. Marcus Rogers

Purdue Cyber Forensics Laboratory



Michael Hale Ligh (MHL)

Volexity



Tatiana Ringenberg

Sypris Electronics