Microsoft Windows

FIPS 140 Validation

Microsoft Windows 10 (October 2018 Update)

Microsoft Windows Server 2019

Microsoft Azure Data Box Edge

Non-Proprietary

Security Policy Document

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Version History

Version	Date	Summary of changes
1.0	October 22, 2018	Draft sent to NIST CMVP
1.1	September 17, 2019	Updates for Windows version 1809
1.2	December 4, 2019	Updates in response to comments
1.3	April 8, 2022	Updates for Windows Server 2019 (RTM)

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1 Introduction

The Windows Operating System (OS) Loader, which consists of the binary WINLOAD.EFI, is the operating system loader that loads the operating system kernel (ntoskrnl.exe) and other boot stage binary image files. The Windows OS Loader is a part of BitLocker Drive Encryption, which is a data protection feature of the Windows 10 operating system which encrypts data on a storage volume.

1.1 List of Cryptographic Module Binary Executables

The Windows OS Loader module contains the following binary:

- WINLOAD.EFI

The Windows builds covered by this validation are:

- Windows 10 version 1809 and Windows Server 2019 build 10.0.17763
- Windows Server 2019 (RTM) build 10.0.17763.107
- Microsoft Azure Data Box Edge build 10.0.17763

1.2 Validated Platforms

The Windows editions covered by this validation are:

- Microsoft Windows 10 Home Edition (32-bit version)
- Microsoft Windows 10 Pro Edition (64-bit version)
- Microsoft Windows 10 Enterprise Edition (64-bit version)
- Microsoft Windows 10 Education Edition (64-bit version)
- Windows Server 2019 Standard Core
- Windows Server 2019 Datacenter Core
- Microsoft Azure Data Box Edge

The Windows OS Loader components listed in Section 1.1 were validated using the combination of computers and Windows operating system editions specified in the table below. Users who want to operate the Microsoft cryptographic modules validated to the FIPS 140-2 standard by the CMVP on new devices shall operate with a Windows version higher than 10.0.17763 where the Microsoft cryptographic modules have been FIPS 140-2 validated.[1]

All the computers for Windows 10 and Windows Server listed in the table below are all 64-bit Intel architecture and implement the AES-NI instruction set but not the SHA Extensions. The exceptions are:

- Dell Inspiron 660s - Intel Core i3 without AES-NI and SHA Extensions
- HP Slimline Desktop - Intel Pentium with AES-NI and SHA Extensions

[1] For Windows, Microsoft validates a collection of cryptographic modules in addition to the Windows OS Loader.

Table 1 Validated Platforms for Windows 10 version 1809, Windows Server 2019, and Azure Data Box Edge

Computer	Windows 10 Home	Windows 10 Pro	Windows 10 Enterprise	Windows 10 Education	Windows Server 2019	Windows Server 2019 Datacenter	Windows Server 2019 (RTM) Datacenter	Azure Data Box Edge
Microsoft Surface Go – Intel Pentium		√						
Microsoft Surface Book 2 – Intel Core i7		√	√					
Microsoft Surface Pro LTE – Intel Core i5		√	√					
Microsoft Surface Laptop – Intel Core i5		√	√	√				
Microsoft Surface Studio – Intel Core i7			√					
Microsoft Windows Server 2019 Hyper-V[2]					√	√		
Microsoft Windows Server 2016 Hyper-V[3]					√			
Dell Latitude 12 Rugged Tablet – Intel Core i5		√						
Dell Latitude 5290 – Intel Core i7		√						
Dell PowerEdge R740 – Intel Xeon Gold					√	√		

[2] Hardware Platform: Dell Precision Tower 5810MT – Intel Xeon E5
[3] Hardware Platform: Dell PowerEdge R740 Server – Intel Xeon Gold

Dell Inspiron 660s [with x86 Windows] – Intel Core i3	√							
HP Slimline Desktop – Intel Pentium		√						
HP Elite x2 1013 G3 Tablet – Intel Core i7		√						
HP EliteBook x360 1030 G2 – Intel Core i7			√					
HP Edgeline EL8000 / ProLiant e910 Server Blade							√	
Samsung Galaxy Book 10.6” – Intel Core m3		√						
Samsung Galaxy Book 12” – Intel Core i5			√					
Microsoft Azure Data Box Edge – Intel Xeon Silver								√

2 Cryptographic Module Specification

Windows OS Loader is a multi-chip standalone module that operates in FIPS-approved mode during normal operation of the computer and Windows operating system boot sequence.

The following configurations and modes of operation will cause Windows OS Loader to operate in a non-approved mode of operation:

- Boot Windows in Debug mode
- Boot Windows with Driver Signing disabled
- Windows enters the ACPI S4 power state

2.1 Cryptographic Boundary

The software cryptographic boundary for Windows OS Loader is defined as the binaries WINLOAD.EFI.

2.2 FIPS 140-2 Approved Algorithms

Windows OS Loader implements the following FIPS 140-2 Approved algorithms:[4]

Algorithm	Windows 10 and Windows Server version 1809	Windows Server 2019 (RTM)	Azure Data Box Edge
FIPS 186-4 RSA PKCS#1 (v1.5) digital signature verification with 1024, 2048, and 3072 moduli; supporting SHA-1, SHA-256, SHA-384, and SHA-512	#C349	#C2058	#C349
FIPS 180-4 SHS SHA-1, SHA-256, SHA-384, and SHA-512	#C211	#C2047	#C211
FIPS 197 AES CBC 128 and 256	#C211	#C2047	#C211
NIST SP 800-38E AES XTS 128 and 256	#C211	#C2047	#C211
NIST SP 800-38C AES CCM 256	#C346	#C2055	#C346
NIST SP 800-38D AES-256 GCM	#C211	#C2047	#C211
NIST SP 800-90A AES-256 counter mode DRBG	#C211	#C2047	#C211
NIST SP 800-133 Cryptographic Key Generation	Vendor affirmed	Vendor affirmed	Vendor affirmed

2.3 Non-Approved Algorithms

Windows OS Loader implements the following non-approved algorithms:

- IEEE 1619-2007 AES-XTS 128 and 256
- A non-determinic random number generator for entropy that is a not a FIPS Approved algorithm but is allowed by FIPS 140. See **Collecting Initial Entropy for the OS** in Services.

2.4 FIPS 140-2 Approved Algorithms from Bounded Modules

A bounded module is a FIPS 140 module which provides cryptographic functionality that is relied on by a downstream module. As described in the Integrity Chain of Trust section, the Windows OS Loader depends on the following algorithms:

The Boot Manager (module certificate #3089) provides:

- CAVP certificates #C349 for FIPS 186-4 RSA PKCS#1 (v1.5) digital signature verification with 2048 moduli; supporting SHA-256
- CAVP certificates #C211 for FIPS 180-4 SHS SHA-256

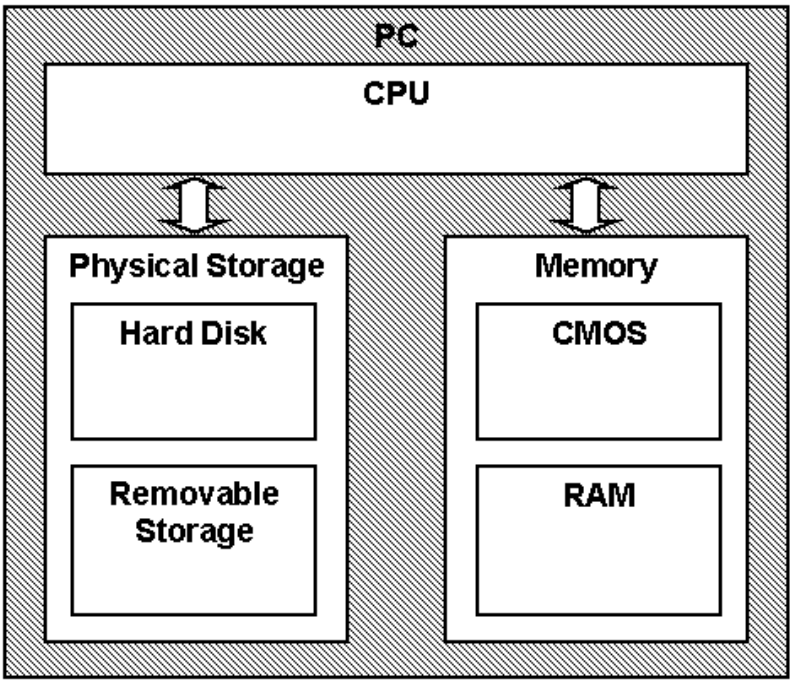
2.5 Cryptographic Bypass

Cryptographic bypass is not supported by Windows OS Loader.

[4] This module may not use some of the capabilities described in each CAVP certificate.

2.6 Hardware Components of the Cryptographic Module

The physical boundary of the module is the physical boundary of the computer that contains the module. The following diagram illustrates the hardware components used by the Windows OS Loader module:



3 Cryptographic Module Ports and Interfaces

3.1 Control Input Interface

The Windows OS Loader Control Input Interface is the set of internal functions responsible for intercepting control input. These functions are:

1. OslMain (WINLOAD) – This function receives and parses the Boot Application parameters, which are passed to the module when execution is passed from Boot Manager.
2. BlBdInitialize – Reads the system status to determine if a boot debugger is attached.
3. BlInitializeLibrary – Performs the parsing Boot Application parameters.
4. BlXmiRead – Reads the operator selection from the Windows OS Loader user interface.

3.2 Status Output Interface

The Status Output Interface is the BlXmiWrite function that is responsible for displaying any integrity verification errors to the display. The Status Output Interface is also defined as the BlLogData responsible for writing the name of the corrupt driver to the bootlog.

3.3 Data Output Interface

The Data Output Interface is represented by the AhCreateLoadOptionsString function. OslArchTransferToKernel is responsible for transferring the execution from Windows OS Loader to the initial execution point of the Windows 10 kernel. Data exits the module in the form of the initial instruction address of the Windows 10 kernel.

Data exits the module from the AhCreateLoadOptionsString function in the form of boot application parameters passed to the Windows 10 kernel, and for computers with a TPM running in Virtual Secure Mode, keys sealed by the TPM.

3.4 Data Input Interface

The Data Input Interface is represented by the BlFileReadEx function and the BlDeviceRead function. BlFileReadEx is responsible for reading the binary data of unverified components from the computer hard drive. In addition the BitLocker Full Volume Encryption Key (FVEK) can also be entered into the module over the module's data input interface. BlDeviceRead is responsible for reading data directly from devices.

4 Roles, Services and Authentication

4.1 Roles

In Windows 10 , authentication and assignment of roles happens after the OS boots. Since Windows OS Loader functions only during the period between power-on and OS initialization, the module's functions are fully automatic and not configurable. FIPS 140 validations define formal "User" and "Cryptographic Officer" roles. Both roles can use any Windows OS Loader service.

4.2 Services

Windows OS Loader services are described below. It does not export any cryptographic functions.

1. **Loading the OS (Trusted Boot)** - The main service is to load the Windows 10 operating system kernel (ntoskrnl.exe), the Windows hypervisor (hvix64.exe for Intel processors and hvax64.exe for AMD processors), and other boot stage binary image files, including Code Integrity (ci.dll), Secure Kernel Code Integrity (skci.dll), and Kernel Mode Cryptographic Primitives Library (cng.sys) after it validates their integrity using the FIPS 140-2 Approved cryptographic algorithm implementations described below. After the verified kernel and boot stage binary image files are loaded, Windows OS Loader passes the execution control to the NT operating system kernel, and the Virtual Secure Mode kernel, and it terminates its own execution. If the integrity of any module is not verified, Windows OS Loader does not transfer the execution to the kernel and displays the boot failure page.
2. **Show Status** – If Windows OS Loader fails any of the checks specified in the Finite State Model then it reports a boot failure status on the computer monitor.
3. **Perform Self-Tests** - The module provides a power-up self-tests service that is automatically executed when the module is loaded into memory. See Self-Tests.

4. **Zeroizing Cryptographic Material -** see Cryptographic Key Management.
5. **Collecting Initial Entropy** for the OS - Windows OS Loader also implements an entropy source for the operating system. Entropy is gathered from the following sources, when they are available on the computer:
   a. The contents of the registry value HKLM\System\RNG\Seed, which is written by the Kernel Mode Cryptographic Primitives Library (cng.sys) during its normal operation.
   b. The contents of the registry value HKLM\System\RNG\ExternalEntropy, which can be populated by system administrators. This value is overwritten after reading, to ensure that it is not reused.
   c. If a Trusted Platform Module (TPM) is available, the output of a TPM_GetRandom call to the TPM.
   d. The current system time.
   e. The contents of the OEM0 ACPI table in the machine firmware.
   f. If the CPU supports instructions for the RDSEED (used when available) or RDRAND (used if RDSEED is not available), the output from RDSEED or RDRAND.
   g. The output of the UEFI random number generator.
   h. The CPU timings.

   These inputs are then combined using SHA-512, and the entropy source is conditioned using a non-Approved RNG. From this NDRNG, a block of output bytes is passed to the Windows kernel at boot time. This block of output bytes is used by CNG.SYS as one of its entropy sources.

   This service is considered a “Non-Approved, but Allowed” service. It is only “Allowed” in the context that it is being used by another FIPS 140-2 Approved module, i.e., the Kernel Mode Cryptographic Primitives Library (cng.sys), in order to provide entropy to one of the FIPS-approved DRBGs.

6. **System Integrity During Hibernation (Random Number Generation)** to generate keys for system integrity during OS hibernation.
7. **Measured Boot** – The combination of Windows 10 and the computer’s firmware logs measurements from the boot process that can be sent to a remote trusted attestation server which objectively assesses the health of early boot stage components.

The following table maps the services to their corresponding algorithms and critical security parameters (CSPs) as described in Cryptographic Key Management.

Service	Algorithms	CSPs	Invocation
Loading the OS (Trusted Boot)	FIPS 186-4 RSA PKCS#1 (v1.5) FIPS 180-4 SHS: SHA-256 hash SHA-384 hash SHA-512 hash	RSA public key to verify the integrity of components mentioned in Integrity Chain of Trust Full Volume Encryption Key (FVEK) (to load the	This service is fully automatic.

Service	Algorithms	CSPs	Invocation
	AES CBC 128 and 256 bits AES XTS 128 and 256 bits[5] AES CCM 256 bits AES GCM 256 bits (IEEE 1619-2007 XTS-AES which cannot be used in FIPS mode)	BitLocker encrypted data containing the OS) VSM Key (to load the encrypted data used by Virtual Secure Mode)	
Show Status	None	None	This service is fully automatic.
Perform Self-Tests	FIPS 186-4 RSA PKCS#1 (v1.5) verify with public key KAT and signature verification KAT FIPS 180-4 SHS: SHA-1 KAT SHA-256 KAT SHA-512 KAT FIPS 197 AES: AES CBC KAT AES CCM KAT AES GCM KAT AES XTS KAT NIST SP 800-90A AES-256 counter mode DRBG Known Answer Tests (instantiate, generate and reseed)	None	This service is fully automatic.
Zeroizing Cryptographic Material	None	Full Volume Encryption Key (FVEK)	See Zeroization.
Collecting Initial Entropy	SHA-512	None	This service is fully automatic.
System Integrity During Hibernation (Random Number Generation)	AES-256 CTR DRBG NDRNG (allowed, used to provide entropy to DRBG)	AES-CTR DRBG Seed AES-CTR DRBG Entropy Input AES-CTR DRBG V AES-CTR DRBG Key	This service is fully automatic.

[5] The length of the data unit does not exceed 2^{20} AES blocks for storage applications such as BitLocker..

Service	Algorithms	CSPs	Invocation
Measured Boot	SHA-1 SHA-256	None	This service is fully automatic after Measured Boot has been enabled.

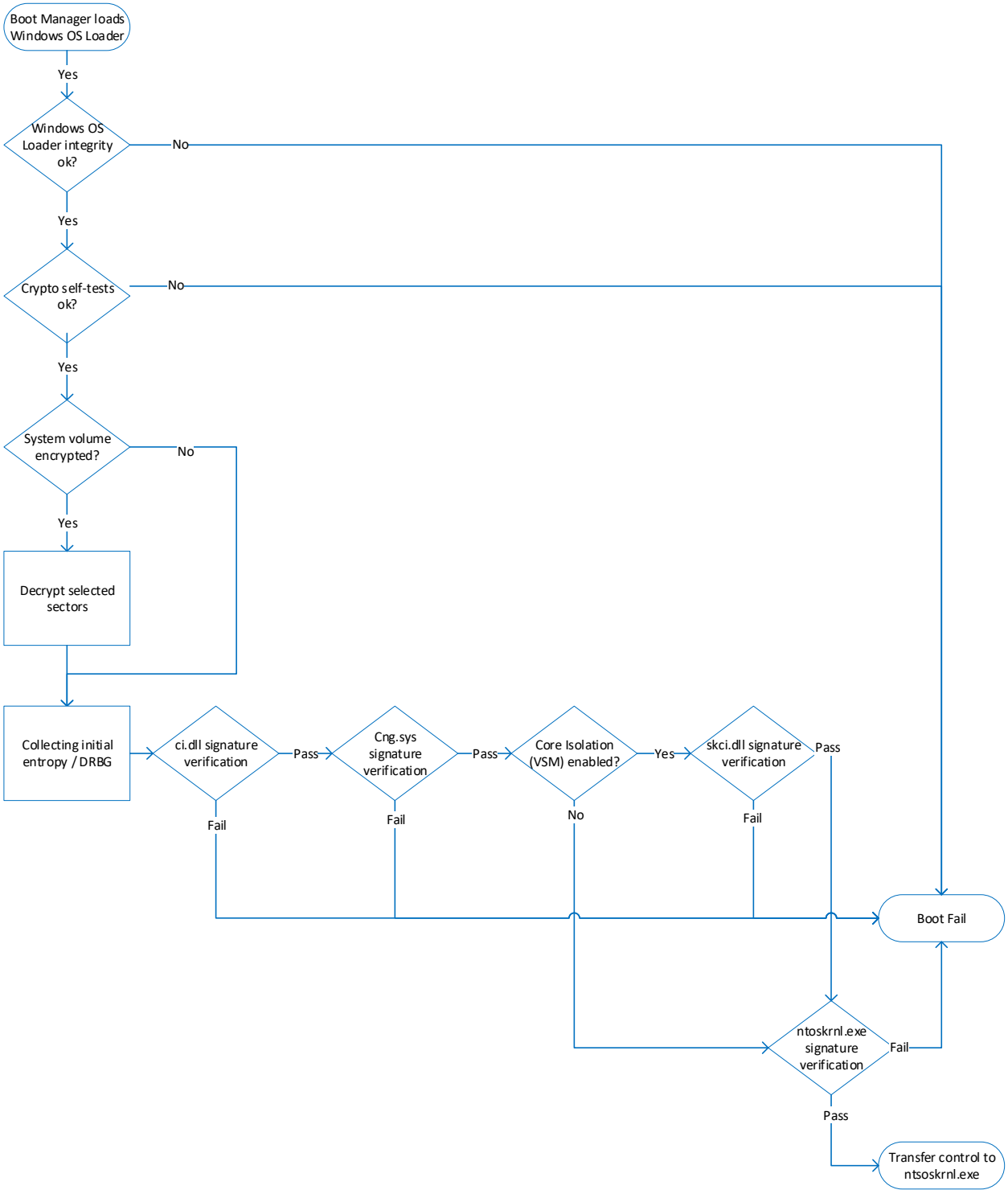
4.3 Authentication

The Windows OS Loader does not implement any authentication services.

5 Finite State Model

5.1 Specification

The following diagram shows the finite state model for Windows OS Loader:



6 Operational Environment

The operational environment for Windows OS Loader is the Windows operating system running on a supported hardware platform.

6.1 Single Operator

During the operating system boot process there is no logged on user, so the single operator requirement is met.

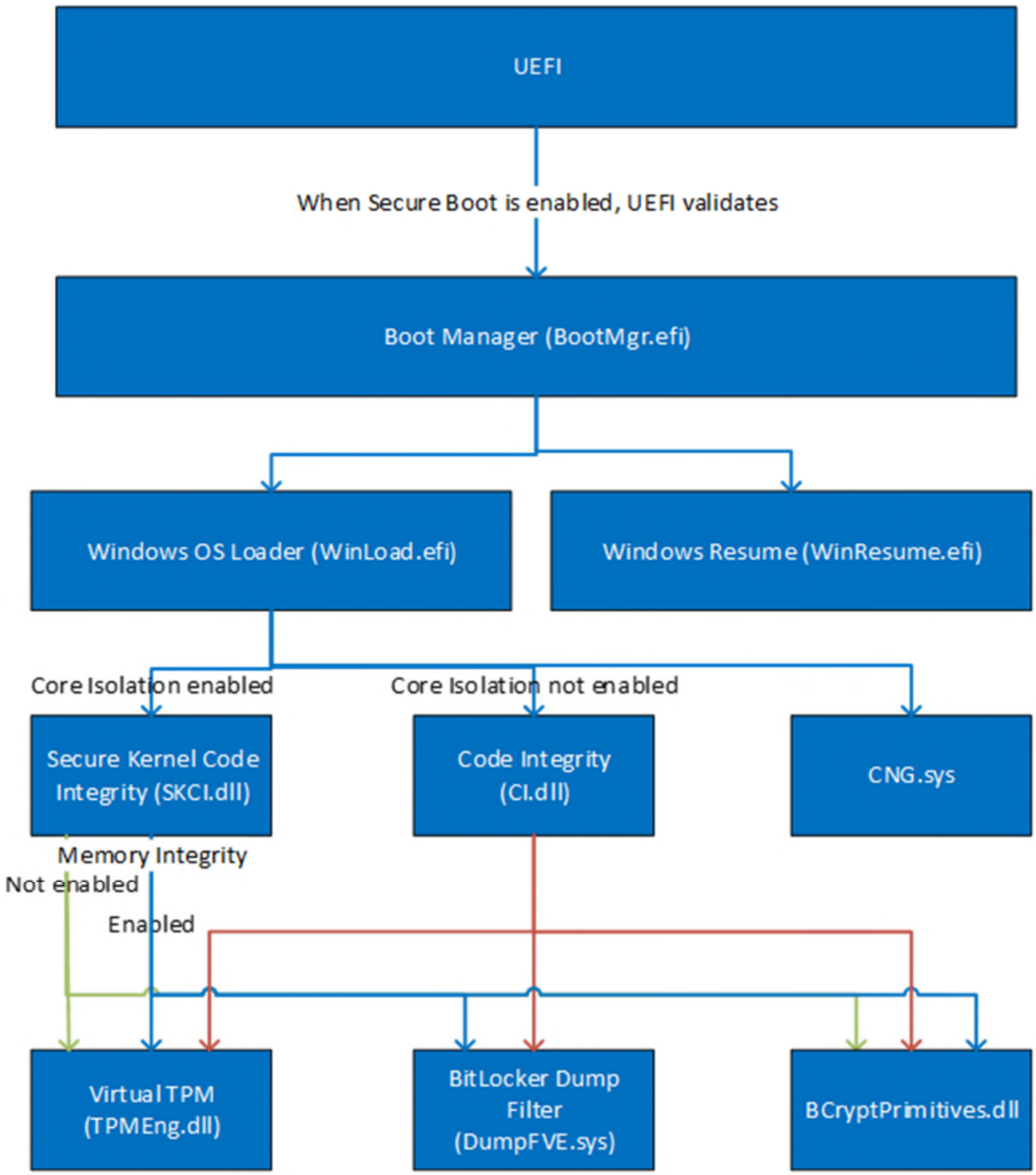
6.2 Cryptographic Isolation

While it is running, Windows OS Loader is the only process running on the computer.

6.3 Integrity Chain of Trust

Windows uses several mechanisms to provide integrity verification depending on the stage in the boot sequence and also on the hardware and configuration. The following diagram describes the Integrity Chain of trust for each supported configuration for the following versions:

- Windows 10 version 1809 and Windows Server 2019 build 10.0.17763
- Windows Server 2019 (RTM) build 10.0.17763.107
- Microsoft Azure Data Box Edge build 10.0.17763



Boot Manager checks the integrity of the WINLOAD.EFI component of the Windows OS Loader before it is loaded.

Windows binaries include a SHA-256 hash of the binary signed with the 2048 bit Microsoft RSA code-signing key (i.e., the key associated with the Microsoft code-signing certificate). The integrity check uses the public key component of the Microsoft code signing certificate to verify the signed hash of the binary.

The Windows OS Loader component verifies the integrity of multiple kernel mode cryptographic modules using the same process described above. The following binaries are verified:

- CNG.SYS
- CI.DLL
- SKCI.DLL (When VSM is enabled)

Windows OS Loader also verifies the integrity of other early boot kernel mode drivers that are not cryptographic modules.

7 Cryptographic Key Management

7.1 Critical Security Parameters

When the System Volume is encrypted with Bitlocker, the WINLOAD.EFI component of the Windows OS Loader uses these critical security parameters (CSP):

- Full Volume Encryption Key (FVEK) – 128 or 256-bit AES key that is used to decrypt data on disk sectors of the hard drive.
- VSM Key (VSMK) – 256-bit AES key that is directly generated from a DRBG for protecting data used by the secure kernel during hibernation.
- AES-CTR DRBG Entropy Input – A 384 bit secret value that is at least 256 bits of entropy and maintained internal to the module that provides the entropy material for AES-CTR DRBG output
- AES-CTR DRBG Seed – A 384 bit secret value maintained internal to the module that provides the seed material for AES-CTR DRBG output
- AES-CTR DRBG V – A 128 bit secret value maintained internal to the module that provides the entropy material for AES-CTR DRBG output
- AES-CTR DRBG Key – A 256 bit secret value maintained internal to the module that provides the entropy material for AES-CTR DRBG output

The FVEK is provided to the WINLOAD.EFI component of the Windows OS Loader by Boot Manager and the VSMK is generated by the WINLOAD.EFI component using the RBG in the Windows OS Loader.

Windows OS Loader also uses as a CSP the public key component of the Microsoft code signing certificate as described in Integrity Chain of Trust.

Keys generated while not operating in the FIPS mode of operation cannot be used in FIPS mode, and vice versa.

7.2 Zeroization

7.2.1 Volatile Keys

The FVEK, VSMK, and and DRBG CSPs are zeroized when the module component WINLOAD.EFI is unloaded from memory after control is transferred to ntoskrnl.exe.

7.2.2 Persistent Keys

Windows OS Loader will use the TPM to seal keys generated by the RBG; if the computer does not have a TPM, the Windows OS Loader will not persist any keys.

To zeroize a key that has been sealed by the TPM the operator should reformat the computer's storage volume to overwrite any preexisting data.

7.3 Access Control Policy

The Windows OS Loader does not allow access to the cryptographic keys contained within it, so an access control table is not included in this document.

The FVEK is received from outside the Windows OS and then managed appropriately once received, the critical security parameters for the RBG are generated and accessed only within the module, and a protected representation of the VSMK is persisted for other Windows components to use if the system hibernates.

Windows OS Loader prevents access to volatile keys and CSPs by zeroizing them after use.

8 Self-Tests

8.1 Power-On Self-Tests

The WINLOAD.EFI component of the Windows OS Loader performs the following power-on (startup) self-tests:

- RSA PKCS#1 (v1.5) verify with public key Known Answer Test
  - RSA signature verification Known Answer Test with 1024-bit key and SHA-1 message digest
  - RSA signature verification Known Answer Test with 2048-bit key and SHA-256 message digest
- SHS (SHA-1) Known Answer Test
- SHS (SHA-256) Known Answer Test
- SHS (SHA-512) Known Answer Test
- AES-CCM Encrypt/Decrypt Known Answer Tests
- AES-CBC Encrypt/Decrypt Known Answer Tests
- XTS-AES Encrypt/Decrypt Known Answer Tests
- AES-GCM Encrypt/Decrypt Known Answer Tests
- SP 800-90A AES-256 counter mode DRBG Known Answer Tests (instantiate, generate and reseed)

If the self-test fails, the module will not load and status will be returned. If the status is not STATUS_SUCCESS, then that is the indicator a self-test failed.

8.2 Conditional Self-Tests

Windows OS Loader performs the following conditional self-tests:

- A Continuous Random Number Generator Test (CRNGT) is performed for SP 800-90A AES-256 CTR DRBG.
- A CRNGT is performed for the non-approved NDRNG per FIPS 140-2 IG 9.8.

9 Design Assurance

The secure installation, generation, and startup procedures of this cryptographic module are part of the overall operating system secure installation, configuration, and startup procedures for the Windows 10 operating system.

The Windows 10 operating system must be pre-installed on a computer by an OEM, installed by the end-user, by an organization's IT administrator, or updated from a previous Windows 10 version downloaded from Windows Update.

An inspection of authenticity of the physical medium can be made by following the guidance at this Microsoft web site: https://www.microsoft.com/en-us/howtotell/default.aspx

The installed version of Windows 10 must be checked to match the version that was validated. See Appendix A for details on how to do this.

For Windows Updates, the client only accepts binaries signed with Microsoft certificates. The Windows Update client only accepts content whose signed SHA-2 hash matches the SHA-2 hash specified in the metadata. All metadata communication is done over a Secure Sockets Layer (SSL) port. Using SSL ensures that the client is communicating with the real server and so prevents a spoof server from sending the client harmful requests. The version and digital signature of new cryptographic module releases must be verified to match the version that was validated. See Appendix A for details on how to do this.

10 Mitigation of Other Attacks

The following table lists the mitigations of other attacks for this cryptographic module:

Algorithm	Protected Against	Mitigation
SHA1	Timing Analysis Attack	Constant time implementation
	Cache Attack	Memory access pattern is independent of any confidential data
SHA2	Timing Analysis Attack	Constant time implementation
	Cache Attack	Memory access pattern is independent of any confidential data
AES	Timing Analysis Attack	Constant time implementation

	Cache Attack	Memory access pattern is independent of any confidential data
		Protected against cache attacks only when running on a processor that implements AES-NI

11 Security Levels

The security level for each FIPS 140-2 security requirement is given in the following table.

Security Requirement	Security Level
Cryptographic Module Specification	1
Cryptographic Module Ports and Interfaces	1
Roles, Services, and Authentication	1
Finite State Model	1
Physical Security	NA
Operational Environment	1
Cryptographic Key Management	1
EMI/EMC	1
Self-Tests	1
Design Assurance	2
Mitigation of Other Attacks	1

12 Additional Details

For the latest information on Microsoft Windows, check out the Microsoft web site at:

https://www.microsoft.com/en-us/windows

For more information about FIPS 140 validations of Microsoft products, please see:

https://docs.microsoft.com/en-us/windows/security/threat-protection/fips-140-validation

13 Appendix A – How to Verify Windows Versions and Digital Signatures

13.1 How to Verify Windows Versions

The installed version of Windows 10 must be verified to match the version that was validated using the following method:

1. In the Search box type "cmd" and open the Command Prompt desktop app.
2. The command window will open.
3. At the prompt, enter "ver".
4. The version information will be displayed in a format like this:
   `Microsoft Windows [Version 10.0.xxxxx]`

If the version number reported by the utility matches the expected output, then the installed version has been validated to be correct.

13.2 How to Verify Windows Digital Signatures

After performing a Windows Update that includes changes to a cryptographic module, the digital signature and file version of the binary executable file must be verified. This is done like so:

1. Open a new window in Windows Explorer.
2. Type "C:\Windows\" in the file path field at the top of the window.
3. Type the cryptographic module binary executable file name (for example, "CNG.SYS") in the search field at the top right of the window, then press the Enter key.
4. The file will appear in the window.
5. Right click on the file's icon.
6. Select Properties from the menu and the Properties window opens.
7. Select the Details tab.
8. Note the File version Property and its value, which has a number in this format: xx.x.xxxxx.xxxx.
9. If the file version number matches one of the version numbers that appear at the start of this security policy document, then the version number has been verified.
10. Select the Digital Signatures tab.
11. In the Signature list, select the Microsoft Windows signer.
12. Click the Details button.
13. Under the Digital Signature Information, you should see: "This digital signature is OK." If that condition is true, then the digital signature has been verified.