Nutanix Cryptographic Module for OpenSSH Server

FIPS 140-2 Non-Proprietary Security Policy

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Ref	Full Specification Name
	References used in Approved Algorithms Table
[38A]	NIST SP 800-38A, *Recommendation for Block Cipher Modes of Operation: Methods and Techniques*, Dec 2001
[38C]	NIST SP 800-38C, *Recommendation for Block Cipher Modes of Operation: the CCM Mode for Authentication and Confidentiality*, Jul 2007
[38D]	NIST SP 800-38D, *Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC*, Nov 2007
[56A]	NIST SP 800-56A, *Recommendation for Pair-Wise Key-Establishment Schemes Using Discrete Logarithm Cryptography*, Mar 2007
[57P1]	NIST SP 800-57 Part 1 Rev. 5, *Recommendation for Key Management: Part 1 - General,* May 2020
[90A]	NIST SP 800-90A Rev. 1, *Recommendation for Random Number Generation Using Deterministic Random Bit Generators*, Jun 2015
[135]	NIST SP 800-135 Rev. 1, *Recommendation for Existing Application-Specific Key Derivation Functions*, Dec 2011
[180]	FIPS 180-4, *Secure Hash Standard (SHS)*, Aug 2015
[186]	FIPS 186-4, *Digital Signature Standard (DSS)*, Jul 2013
[197]	FIPS 197, *Advanced Encryption Standard (AES)*, Nov 2001
[198]	FIPS 198-1, *The Keyed Hash Message Authentication Code (HMAC)* , Jul 2008
	Other References
[140]	FIPS 140-2, *Security Requirements for Cryptographic Modules*, May 2001
[140DTR]	FIPS 140-2 *Derived Test Requirements*, Jan 2011
[140IG]	*Implementation Guidance for FIPS 140-2 and the Cryptographic Module Validation Program*, Dec 2019
[131A]	SP 800-131A Rev. 2, *Transitioning the Use of Cryptographic Algorithms and Key Lengths*, Mar 2019

Acronyms and Definitions

Term	Definition
AES	Advanced Encryption Standard [197]
API	Application Programming Interface
CAVP	Cryptographic Algorithm Validation Program
CMVP	Cryptographic Module Validation Program
CO	Cryptographic Officer
DRBG	Deterministic Random Number Generator [90A]
DTR	Derived Test Requirements, see [140DTR]
FIPS	Federal Information Processing Standard
HMAC	Keyed-Hash Message Authentication Code [198]

Term	Definition
IG	Implementation Guidance [140IG]
KAT	Known Answer Test
KDF	Key Derivation Function
NDRNG	Non-Deterministic Random Number Generator
NIST	National Institute of Standards and Technology
RSA	Rivest, Shamir, and Adleman Algorithm [186]
SHA/SHS	Secure Hash Algorithm/Standard [180]
SP	Special Publication
SSH	Secure Shell

1 Overview

This document defines the non-proprietary Security Policy for the Nutanix Cryptographic Module for OpenSSH Server, hereafter denoted the module. The module is a cryptographic software library, designated as multi-chip standalone embodiment in [140] terminology, used in Nutanix, Inc. (Nutanix) solutions to provide FIPS 140-2 Approved SSH server-side secure communication.

The module meets FIPS 140-2 overall Level 1 requirements, with security levels as follows:

Table 1: Security Level of Security Requirements

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	N/A
Operational Environment	1
Cryptographic Key Management	1
EMI/EMC	1
Self-Tests	1
Design Assurance	1
Mitigation of Other Attacks	N/A

In Table 1 above, [140] Section 4.5 *Physical Security* is not applicable, as permitted by [140IG] 1.16 *Software Module* and [140IG] G.3 *Partial Validations and Not Applicable Areas of FIPS 140-2*.

The module design corresponds to the module security rules. Security rules enforced by the module are described in the appropriate context of this document.

The module is bound to FIPS 140-2 Cert. #3460 - *Nutanix Cryptographic Module for OpenSSL*. This security policy represents the complete, composite functionality of this module: the SSHv2 service implemented using the cryptographic primitives of Cert. #3460. Unlike Cert. #3460, the module does not offer a set of cryptographic primitives, rather it provides only the SSHv2 subsystem. Specifically:

- The logical boundary of this module is shown below; the logical boundary of the bound (Cert. #3460) module is not within the boundary of this module.
- Table 4 lists all approved cryptographic algorithms used by this module, inclusive of those implemented in Cert. #3460.
- Table 5 lists the non-approved algorithms that are possible by configuring the SSH subsystem using non-approved SSH parameters.
- The CSPs and public keys listed in this security policy are those accessed by this module.
- The module provides the software integrity test described in Section 6.

The module operates within a general-purpose computer. Figure 1 depicts the module operational environment, with the logical boundary highlighted in red inclusive of all module entry points (API calls), conformant with [140IG] 14.3 *Logical Diagram for Software, Firmware and Hybrid Modules*.

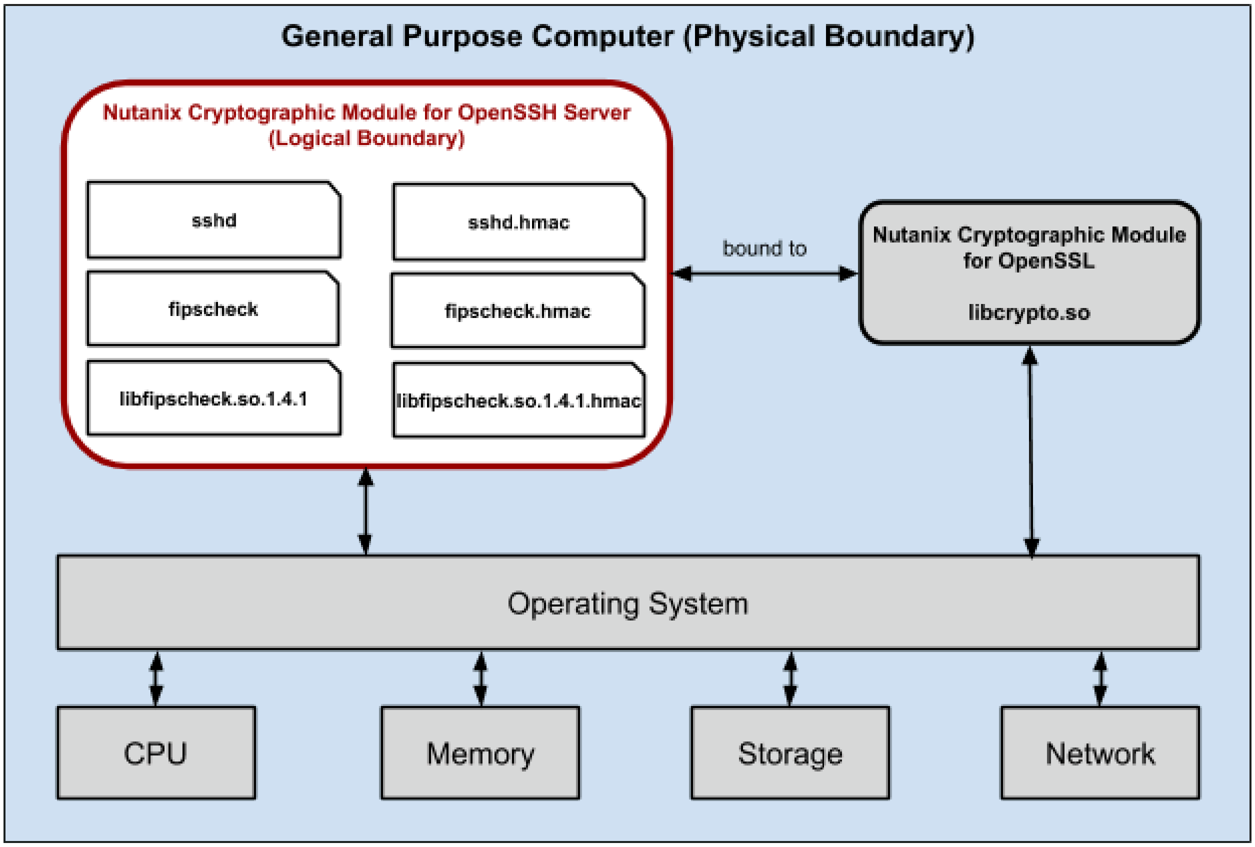
General Purpose Computer (Physical Boundary)
Nutanix Cryptographic Module for OpenSSH Server (Logical Boundary)
sshd
sshd.hmac
fipscheck
fipscheck.hmac
libfipscheck.so.1.4.1
libfipscheck.so.1.4.1.hmac
bound to
Nutanix Cryptographic Module for OpenSSL
libcrypto.so
Operating System
CPU
Memory
Storage
Network

Figure 1: Module Physical and Logical Boundary

The module conforms to [140IG] 1.16 *Software Module*:

- The physical cryptographic boundary is the general-purpose computer which wholly contains the module and operating system.
- The logical cryptographic boundary is the set of shared library files and associated HMAC files:
  - sshd, .sshd.hmac
  - fipscheck, .fipscheck.hmac
  - libfipscheck.so.1.4.1, .libfipscheck.so.1.4.1.hmac
- All components are defined in accordance with [140DTR] AS01.08; no components are excluded from [140] requirements.
- The power-up approved integrity test is performed over all components within the logical boundary.
- Updates to the module are provided as a complete replacement in accordance with [140IG] 9.7 *Software/Firmware Load Test*.
- Table 2 defines the module's [140] logical interfaces.

Table 2: Ports and Interfaces

Description	Logical Interface Type
Terminal I/O (command line in, display out)	Control input, status output
File I/O (Configuration, key and log files)	Control input, data input, status output
TLS module API (calls to libcrypto.so services)	Control input, data input, data output, Status output
Network traffic	Control input, data input, data output, Status output

Software versions:

- OpenSSH server RPM package 7.4p1-16.el7
- fipscheck RPM package 1.4.1-6.el7

Operational testing was performed on the Operating Environments listed in Table 3.

Table 3: Tested Operating Environments

Operating System	Processor	Platform
CentOS 7.5	Intel Xeon Silver-4116 with PAA	Nutanix NX-3360-G6
CentOS 7.5	Intel Xeon Silver-4116 without PAA	Nutanix NX-3360-G6

The module conforms to [140IG] 6.1 *Single Operator Mode and Concurrent Operators*. The tested environments place user processes into segregated spaces. A process is logically removed from all other processes by the hardware and Operating System. Since the module exists inside the process space of the application this environment implicitly satisfies requirement for a single user mode.

2 Cryptographic Functionality

The module implements the FIPS Approved cryptographic functions listed in Table 4. [57P1] notation is used throughout this document to describe key sizes and security strength. Items in curly brackets { } are tested but not used by the module.

Table 4: Approved CAVP Validated Cryptographic Functions

Cert	Algorithm	Mode	Description	Functions, Caveats
Implemented by this module (Nutanix Cryptographic Module for OpenSSH Server)				
1998	CVL: SSH KDF [135]	SSHv2 key derivation		Key derivation
Implemented by Cert. #3460 (Nutanix Cryptographic Module for OpenSSL)				
5562, C661	AES [197]	CBC [38A]	Key sizes: 128, 192, 256	Encryption, Decryption
		CCM [38C]	Key sizes: 128, 192, 256	Authenticated Encryption, Authenticated Decryption
		GCM [38D]	Key sizes: 128, {192}, 256	Authenticated Encryption, Authenticated Decryption, Message Authentication
1994	CVL: KAS [56A] Primitive	FFC	FB $L \geq 2048$ $N = 224$ FC $L \geq 2048$ $N = 256$[1]	Key Agreement: All KAS Initiator and Responder functions except KDF
		ECC	P-256, P-384, P-521[2]	

2216	DRBG [90A]	CTR_DRBG
		{Hash_DRBG}
		{HMAC_DRBG}
			AES: {128, 192}, 256 (bits)
			{Other DRBG variants and strengths are tested on the bound module cert but are not used by this module}
				Random bit generation.

1499	ECDSA [186]	P-256, P-384, P-521 with SHA-2 {Other curves and SHA combinations are tested on the bound module cert but are not used by this module}		Signature Generation, Signature Verification {Key generation and key verification are not used}
3708	HMAC [198]	SHA-1, SHA-256, SHA-384 {Other SHA sizes are tested on the bound module cert but are not used by this module}		Generation, Verification, (Message Authentication)
N/A	NDRNG	Entropy sourced by the NDRNG is used to seed the SP800-90A default AES-256 CTR_DRBG		Non-approved but allowed
4465	SHS [180]	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512		Message Digest

The module conforms to [140IG] D.11 *References to the Support of Industry Protocols* (Resolution scenario 2) by providing CAVP validated [56A] components along with the CAVP validated [135] Section 4.2 KDF for

[1] Diffie-Hellman: key establishment methodology provides 112 bits of encryption strength

[2] EC Diffie-Hellman: key establishment methodology provides between 128 and 256 bits of encryption strength.

SSHv2. In accordance with [140IG] D.11, the remainder of the SSHv2 protocol has not been reviewed or tested by the CAVP and CMVP.

The module implements the non-Approved but allowed cryptographic functions listed in Table 5.

Table 5: Non-Approved but Allowed Cryptographic Functions

Cryptographic Function	Description / Usage
Diffie-Hellman	Key Agreement: FB $L \geq 2048$ $N = 224$; FC $L \geq 2048$ $N = 256$
EC Diffie-Hellman	Key Agreement: P-256, P-384, P-521

3 Modes of Operation, Security Rules and Guidance

The module supports a FIPS Approved mode of operation and a non-FIPS Approved mode of operation, and conforms to [140IG] 1.2 *FIPS Approved Mode of Operation* and 1.19 *non-Approved Mode of Operation*.

The conditions for using module cryptographic primitives in the [140] Approved mode of operation are:

1. Only the sshd parameters listed in Table 6 are to be used. Key pairs generated external to the module for use with key exchange and server authentication must comply to the Table 6 parameters.
2. SSH protocol version 1 is not usable in the approved mode; SSH protocol version 2 must be enabled.
3. GSS API authentication is not allowed.
4. If module power is lost and restored, a new key for use with AES GCM cipher is established.
5. Data output is inhibited during self-tests, zeroization, and error states.
6. Status information does not contain CSPs or sensitive data that if misused could lead to module compromise.

Table 6: SSH Parameters Used in the Approved Mode of Operation

Key exchange	Client authentication	Cipher	MAC
diffie-hellman-group14-sha1	ecdsa-sha2-nistp256	aes256-cbc	hmac-sha1
diffie-hellman-group14-sha256	ecdsa-sha2-nistp384	aes192-cbc	hmac-sha2-256
ecdh-sha2-nistp256	ecdsa-sha2-nistp521	aes128-cbc	aes-128-gcm[3]
ecdh-sha2-nistp384		aes128-ctr	aes-256-gcm[3]
ecdh-sha2-nistp521		aes192-ctr	hmac-sha2-256-etm[4]
		aes256-ctr	hmac-sha1-etm
		aes128-gcm[3]	
		aes256-gcm[3]	

The SSH parameters are set as described in the corresponding Nutanix User Guide. To confirm the settings for the above SSH parameters, query the running instance of ssh as follows:

- Key exchange algorithms: ssh -Q kex
- Host key algorithms: ssh -Q key
- Cipher algorithms: ssh -Q cipher
- MAC (message integrity) algorithms: ssh -Q mac

[3] For GCM integrity, GMAC is not explicitly named in configuration or negotiated; integrity is accomplished as a facet of the GCM authenticated cipher functionality.

[4] *etm* refers to "encrypt then MAC" - the HMAC is performed on the ciphertext message content

Table 7 lists ciphersuites available in the non-approved mode of operation.

Table 7: SSH Parameters Used in the Non-Approved Mode of Operation

Key exchange	Client authentication	Cipher	Digest
diffie-hellman-group1-sha1	sha-rsa	rijndael-cbc	All are approved
diffie-hellman-group-exchange-sha1		3des-cbc	
diffie-hellman-group-exchange-sha256			
curve25519-sha256			
diffie-hellman-group16-sha512[5]			
diffie-hellman-group18-sha512[6]			

4 Critical Security Parameters and Public Keys

All CSPs and public keys used by the module are described in this section. The module does not implement random number generation or key pair generation, instead using those provided by the bound OpenSSL libcrypto.so services. The module and an external ssh client perform the SSH protocol, the module calls the libcrypto shared secret generation primitive, then calls its SSHv2 KDF to derive the session keys from the shared secret. The session keys are provided to libcrypto.so for message cipher (encrypt/decrypt) and integrity functions. Table 8 summarizes the CSPs and public keys implemented by the module.

Table 8: Critical Security Parameters (CSPs) and Public Keys

CSP	Description/Usage	Key generation	Key storage	Key entry/output*	Key Zeroization
Shared secret	Secure communications shared secret, used to derive session keys	Obtained from call to libcrypto.so	Module memory	Entry: N/A Output: N/A	Zeroized by sshd
Session keys	Secure communications session keys used for message ciphering and integrity	Derived by the module using the SSHv2 KDF	Module memory	Entry: N/A Output: N/A	Zeroized by sshd
Server key pairs	ECC or FFC key pair used for key exchange; ECC key pair used key for server authentication	N/A	Module memory	Entry: N/A Output: public key to peer	Module removal
Client public key	ECC or FFC key used for key exchange	N/A	Module memory	Entry: From peer* Output: N/A	N/A
Software integrity key	Verification of software file integrity	N/A	Module binary	Entry: N/A Output: N/A	Module removal

Session message cipher key: AES-128, AES-192, or AES-256 key.
Session message integrity key: HMAC-SHA-1, HMAC-SHA-256, HMAC-SHA-512, or AES-128 or AES-256 (GCM). HMAC message authentication key lengths are equal to the digest size.
Server key pairs and client public key: ECC (P-256, P-384, P-521).
Software integrity key: HMAC-SHA-256 (128-bit key).

**Key entry/output* is interpreted based on [140IG] 7.7; no CSPs cross the physical boundary, rather, local private and public keys are obtained from files within the boundary; and the shared secret is obtained by API interaction with the libcrypto.so within the boundary. Public keys are exchanged over the network port in the SSH handshake.

[5] Uses a 4096-bit modulus: sizes over 2048 bits are allowed but are not defined by [56A]

[6] Uses a 8192-bit modulus: sizes over 2048 bits are allowed but are not defined by [56A]

5 Roles and Services

The module supports two distinct operator roles, User and Cryptographic Officer (CO), and does not support a maintenance role or bypass capability. The CO and the User roles are implicitly identified by the service requested.

All services implemented by the module are listed in Table 9. This table describes module service access to CSPs and public keys, where I indicates *input*, O indicates *output*, G indicates *generate* (use of the SSHv2 KDF), X indicates *execute* (use of the CSP or public key by a function), and Z indicates *zeroize*. Note that I and O are relative to the logical interfaces; the module does not output any CSP over the physical boundary, and the guidance of [140IG] 7.7 applies where entry and output are considered N/A between software components internal to the general-purpose computer. The peer public is marked I as it crosses the physical boundary via the network port.

Table 9: Authorized Services Available in FIPS Mode

Service	Description	Role	CSP and public key access
Install	Install the module	CO	N/A
Configure	Configure the module	CO	N/A
Launch (Self-Test)	Launch the sshd application (includes self-test)	User	Software integrity key: X
Secure communications	Establish and use sshd secure communications channel	User	Server private key: X Server public key: O Peer public key: I, X Shared secret: X, Z Session keys: G, X
Close	Close sshd secure communications channel	User	Session keys: Z
Show status	Show sshd status	User	N/A
Terminate (Zeroize)	Shut down the sshd application	User	Shared secret: Z Session keys: Z

6 Self-test

The module performs the software integrity check using HMAC-SHA-256 on initialization of the sshd executable. The sshd application calls the fipscheck utility via the fipscheck.so library, which tests the fipscheck binary, the fipscheck shared library and the calling application binary (sshd). The fipscheck utility returns a non-zero error code on failure, with a corresponding error log message “FIPS Integrity verification test failed”, and on successful completion “FIPS mode initialized”.

All algorithms provided by the Nutanix Cryptographic Module for OpenSSL (the cryptographic primitives library this module is bound to) are self-tested when the library (libcrypto.so) is loaded.

The module returns an error code and enters the error state if any of the power-on self-tests fail.

The fipscheck utility exit value indicates the comparison result, either zero if the integrity tests succeed, or an error code if any of the integrity tests fail (resulting in termination of the sshd application).