



Red Hat

Red Hat Enterprise Linux 7 OpenSSL Cryptographic Module

version rhel7.20190409

FIPS 140-2 Non-proprietary Security Policy

version 1.3

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1. Cryptographic Modules' Specifications

This document is the non-proprietary Security Policy for the Red Hat Enterprise Linux 7 OpenSSL Cryptographic Module version rhel7.20190409 and was prepared as part of the requirements for conformance to Federal Information Processing Standard (FIPS) 140-2, Level 1.

1.1. Description of the Module

The Red Hat Enterprise Linux 7 OpenSSL Cryptographic Module (hereafter referred to as the "Module") is a software libraries supporting FIPS 140-2 Approved cryptographic algorithms. The code base of the Module is formed in a combination of standard OpenSSL shared library, OpenSSL FIPS Object Module and development work by Red Hat. The Module provides a C language application program interface (API) for use by other processes that require cryptographic functionality.

The following table shows the security level for each of the eleven sections of the validation.

Security Component	FIPS 140-2 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	1

Table 1: Security Level of the Module

The Red Hat Enterprise Linux 7 OpenSSL Cryptographic Module has been tested on the following multi-chip standalone platforms:

Manufacturer	Model	O/S & Ver.	Processor
Dell	PowerEdge R630	Red Hat Enterprise Linux 7	Intel(R) Xeon(R) CPU E5

Table 2: Test Platform

The Module has been tested for the following configurations:

- 32-bit library, x86_64 with and without AES-NI enabled
- 64-bit library, x86_64 with and without AES-NI enabled.

To operate the Module, the operating system must be restricted to a single operator mode of operation. (This should not be confused with single user mode which is run level 1 on Red Hat

Enterprise Linux (RHEL). This refers to processes having access to the same cryptographic instance which RHEL ensures this cannot happen by the memory management hardware.)

1.2. Description of the Approved Modes

The Module supports two modes of operation:

- in "FIPS mode" (the FIPS Approved mode of operation) only approved or allowed security functions with sufficient security strength can be used.
- in "non-FIPS mode" (the non-Approved mode of operation) non-approved security functions can also be used.

The Module verifies the integrity of the runtime executable using a HMAC-SHA-256 digest computed at build time. If the digests matched, the power-up self-test is then performed. The module enters FIPS mode after power-up tests succeed. Once the module is operational, the mode of operation is implicitly assumed depending on the security function invoked and the security strength of the cryptographic keys.

The Red Hat Enterprise Linux 7 OpenSSL Cryptographic Module supports the following FIPS 140-2 Approved algorithms in FIPS Approved mode:

Algorithm	Validation Certificate	Standards/Usage	Keys/CSPs
AES	Certs. #C1378, #C1379, #C1380, #C1381, #C1382, #C1383, #C1384, #C1385, #C1386, #C1419	FIPS 197 (AES) SP 800-38A (ECB, CBC, OFB, CFB1, CFB8, CFB128, CTR) SP 800-38B (CMAC) SP 800-38C (CCM) SP 800-38D (GCM, GMAC) SP 800-38E (XTS) SP 800-38F (KW, KWP) ¹ Encryption and Decryption	AES keys 128 bits, 192 bits (except XTS-AES) and 256 bits
Triple-DES	Certs. #C1378, #C1379, #C1385, #C1386	SP 800-67 SP 800-38A (ECB, CBC, OFB, CFB1, CFB8, CFB64, CTR) SP 800-38B (CMAC) Encryption and Decryption	Triple-DES keys 192 bits
DSA	Certs. #C1378, #C1379, #C1385, #C1386	FIPS 186-4 Domain Parameters Generation and Verification, Key Generation,	Hash Algorithms: <ul style="list-style-type: none"> • SHA2-224 • SHA2-256 DSA keys: <ul style="list-style-type: none"> • L=2048, N=224

1 Not all block chaining modes apply to all CAVS certificates.

Algorithm	Validation Certificate	Standards/Usage	Keys/CSPs
		Signature Generation, Signature Verification	<ul style="list-style-type: none"> L=2048, N=256 L=3072, N=256
RSA	Certs. #C1378, #C1379, #C1385, #C1386	FIPS 186-2	RSA keys: <ul style="list-style-type: none"> 4096 bits
		FIPS 186-4 Appendix B.3.3 Key Generation	RSA keys: <ul style="list-style-type: none"> 1024 bits (For SigVer only) 2048 bits 3072 bits <p>Note: 1024-bit RSA signature verification is legacy-use.</p> <p>Hash Algorithms:</p> <ul style="list-style-type: none"> SHA1(For SigVer only) SHA2-224 SHA2-256 SHA2-384 SHA2-512
		Signature Generation and Verification (PKCS#1 v1.5)	
		Signature Generation and Verification (ANSI X9.31)	RSA keys: <ul style="list-style-type: none"> 1024 bits (For SigVer only) 2048 bits 3072 bits <p>Note: 1024-bit RSA signature verification is legacy-use.</p> <p>Hash Algorithms:</p> <ul style="list-style-type: none"> SHA1(For SigVer only) SHA2-256 SHA2-384 SHA2-512
ECDSA	Certs. #C1378, #C1379, #C1385, #C1386	FIPS 186-4 Key Pair Generation and Public Key Verification	ECDSA keys based on P-256, P-384, or P-521 curve Hash Algorithms: <ul style="list-style-type: none"> SHA1 (For SigVer only) SHA2-224
		FIPS 186-4 Signature	

Algorithm	Validation Certificate	Standards/Usage	Keys/CSPs
		Generation FIPS 186-4 Signature Verification	<ul style="list-style-type: none"> SHA2-256 SHA2-384 SHA2-512
DRBG	Certs. #C1378, #C1379, #C1380, #C1381, #C1382, #C1383, #C1384, #C1385, #C1386, #C1419	SP 800-90A (Hash_DRBG, HMAC_DRBG, CTR_DRBG) Random Number Generation	Entropy input string, seed, V and Key
SHS	Certs. #C1378, #C1379, #C1380, #C1381, #C1382, #C1383, #C1384, #C1385, #C1386, #C1419	FIPS 180-4 (SHA-1, SHA-224, SHA-256, SHA-384, SHA-512) Hashing	N/A
HMAC	Certs. #C1378, #C1379, #C1380, #C1381, #C1382, #C1383, #C1384, #C1385, #C1386, #C1419	FIPS 198-1 (HMAC-SHA-1, HMAC-SHA-224, HMAC-SHA-256, HMAC-SHA-384, HMAC-SHA-512) Message Integrity	At least 112 bits HMAC Key
SP 800-56A DLC primitive Diffie-Hellman (CVL)	Certs. #C1378, #C1379, #C1385, #C1386	SP 800-56A Key Agreement and Establishment	Public key size 2048 bits, and private key size 224 bits or 256 bits
SP 800-56A DLC primitive EC Diffie-Hellman (CVL)			NIST curves P-256, P-384, P-521
SP 800-135 Section 4.2 Key Derivation in TLS v1.0, v1.1 and v1.2 (CVL)	Certs. #C1378, #C1379, #C1381, #C1382, #C1385, #C1386	SP800-135 Key Derivation in TLS	Hash Algorithms: <ul style="list-style-type: none"> SHA2-256 SHA2-384
CKG (Vendor Affirmed)	N/A	Asymmetric Key Generation	RSA key pair DSA key pair ECDH key pair DH key pair Note: Only approved key sizes for relative algorithms listed in

Algorithm	Validation Certificate	Standards/Usage	Keys/CSPs
			Table 3
KTS	Certs. #C1378, #C1379, #C1380, #C1381, #C1382, #C1383, #C1384, #C1385, #C1386, #C1419	SP800-38F AES KW, KWP AES CCM AES GCM	AES keys 128, 192, 256 bits
	Certs. #C1378, #C1379, #C1380, #C1381, #C1382, #C1383, #C1384, #C1385, #C1386, #C1419	SP800-38F AES CBC and HMAC	AES keys 128, 256 bits
	Certs. #C1378, #C1379, #C1385, #C1386, #C1380, #C1381, #C1382, #C1383, #C1384, #C1419	SP800-38F Triple-DES CBC and HMAC	Triple-DES keys 192 bits

Table 3: Approved Algorithms

The Module supports the following non-Approved algorithms but allowed in FIPS Approved mode:

Algorithm	Usage	Keys/CSPs
RSA (encrypt, decrypt) with key size equal or 2048 bits to 16384 bits	Key Wrapping	RSA private key
Diffie-Hellman with public key size 2048 bits to 10000 bits	Key Agreement	Diffie-Hellman private key
EC Diffie-Hellman with key sizes according to P-256, P-384 and P-521 NIST curves	Key Agreement	EC Diffie-Hellman private key
MD5	Message Digest used only in TLS	N/A
NDRNG	Seeding the module's DRBG	Internal state

Table 4: Non-Approved but allowed Algorithms

The Key Establishment entries for the module are listed below with their strength caveats.

- Diffie-Hellman (CVL Certs. #C1378, #C1379, #C1385 and #C1386 with CVL Certs. #C1378, #C1379, #C1381, #C1382, #C1385 and #C1386, key agreement; key establishment methodology provides between 112 and 219 bits of encryption strength)
- EC Diffie-Hellman (CVL Certs. #C1378, #C1379, #C1385 and #C1386 with CVL Certs. #C1378, #C1379, #C1381, #C1382, #C1385 and #C1386, key agreement; key

establishment methodology provides between 128 and 256 bits of encryption strength)

- RSA (key wrapping; key establishment methodology provides between 112 and 256 bits of encryption strength)

Per FIPS 140-2 IG G.5, the CMVP makes no statement as to the correct operation of the Module or the security strengths of the generated keys when those Module are ported and executed in an operational environment not listed on the validation certificate.

The Module supports the following non-FIPS 140-2 Approved algorithms, which shall not be used in the FIPS Approved mode. Any use of the non-Approved functions will cause the Module to operate in the non-FIPS mode implicitly:

Algorithm	Usage	Keys
RSA (encrypt, decrypt) with key size smaller than 2048 bits	key wrapping	RSA key
RSA with key sizes not listed in Table 3	sign, verify, and key generation	RSA key
DSA with key and hash sizes not listed in Table 3	sign, verify, and key generation	DSA key
Diffie-Hellman with key sizes not listed in Table 4	key agreement and establishment	Diffie-Hellman key
Signature generation using SHA-1	Signature generation	Derived key
TLS 1.2 KDF with SHA-512	Key Derivation in TLS	Derived key
ANSI X9.31 RNG (with AES-128 core)	random number generation	PRNG seed value and seed key 128 bits
Camellia	Encryption/decryption	Symmetric key
CAST	Encryption/decryption	Symmetric key
DES	Encryption/decryption	Symmetric key
IDEA	Encryption/decryption	Symmetric key
MD2	Hash function	Derived key
MD4	Hash function	Derived key
RC2	Encryption/decryption	Symmetric key
RC4	Encryption/decryption	Symmetric key
RC5	Encryption/decryption	Symmetric key
RIPMD	Hash function	Derived key
Whirlpool	Hash function	Derived key

Table 5: Non-Approved Algorithms

1.3. Cryptographic Boundary

The Modules' physical boundaries are the surface of the case of the platform (depicted in the hardware block diagram).

The Red Hat Enterprise Linux 7 OpenSSL Cryptographic Module logical cryptographic boundary is the shared library files and their integrity check HMAC files, which are delivered through Red Hat Package Manager (RPM) as listed below.

The `openssl-libs-1.0.2k-19.el7.x86_64.rpm` (64 bits) and `openssl-libs-1.0.2k-19.el7.i686.rpm` (32 bits) file contains the following files that are part of the module boundary:

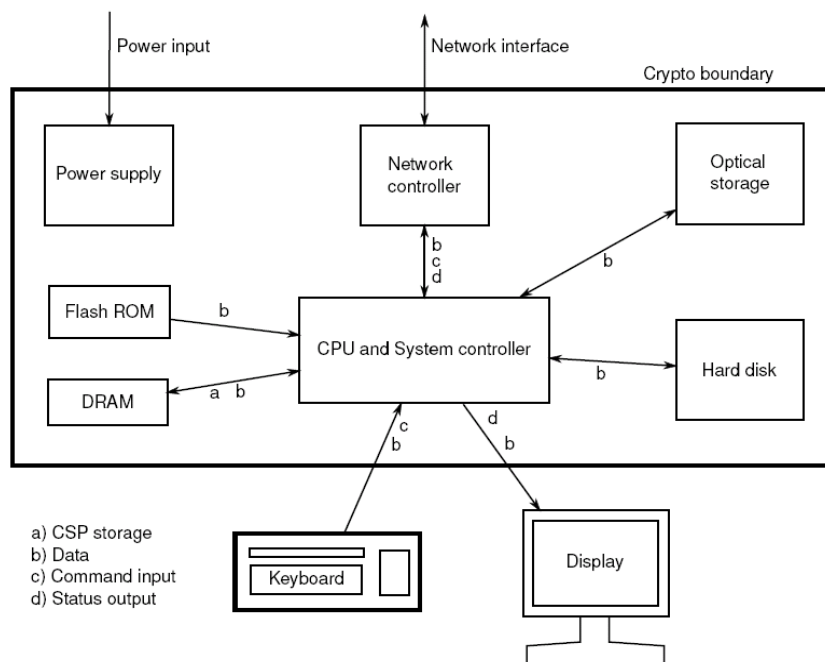
- `/usr/lib{64,}/libcrypto.so.1.0.2k.hmac`
- `/usr/lib{64,}/libssl.so.1.0.2k.hmac`
- `/usr/lib{64,}/libcrypto.so.1.0.2k`
- `/usr/lib{64,}/libssl.so.1.0.2k`

The OpenSSL RPM package of the Module includes the binary files, integrity check HMAC files, Man Pages and the OpenSSL Engines provided by the standard OpenSSL shared library. The OpenSSL Engines and their shared object files are not part of the Module, and therefore they must not be used.

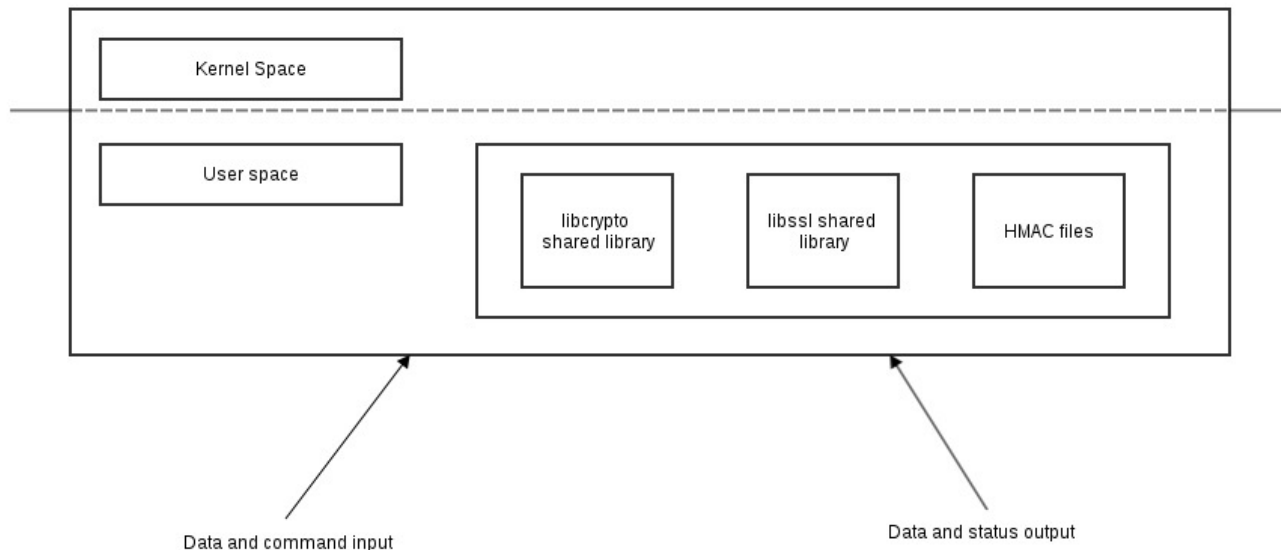
The Module shall be installed and instantiated by the `dracut-fips` package with the RPM file version specified above. The `dracut-fips` RPM package is only used for the installation and instantiation of the Module. This code is not active when the Module is operational and does not provide any services to users interacting with the Module. Therefore the `dracut-fips` RPM package is outside the Modules' logical boundary.

1.3.1. Hardware Block Diagram

Figure 1: Hardware Block Diagram



1.3.2. Software Block Diagram



*Figure 2: Software Block Diagram
(the cryptographic boundary includes the HMAC integrity files)*

2. Cryptographic Modules' Ports and Interfaces

The physical ports of the Module are the same as the computer system on which it executes. The logical interface is a C-language Application Program Interface (API).

The Data Input interface consists of the input parameters of the API functions. The Data Output interface consists of the output parameters of the API functions. The Control Input interface consists of the actual API functions. The Status Output interface includes the return values of the API functions. The ports and interfaces are shown in the following table.

FIPS Interface	Physical Port	Modules' Interfaces
Data Input	Ethernet ports	API input parameters, kernel I/O - network or files on filesystem
Data Output	Ethernet ports	API output parameters, kernel I/O - network or files on filesystem
Control Input	Keyboard, Serial port, Ethernet port, Network	API function calls, or configuration files on filesystem
Status Output	Serial port, Ethernet port, Network	API
Power Input	PC Power Supply Port	N/A

Table 6: Ports and Interfaces

3. Roles, Services and Authentication

This section defines the roles, services, and authentication mechanisms and methods with respect to the applicable FIPS 140-2 requirements.

3.1. Roles

There are two users of the Module:

- User
- Crypto Officer

The User and Crypto Officer roles are implicitly assumed by the entity accessing services implemented by the Module. For User documentation, please refer to the man pages of `ssl(3)`, `crypto(3)` as an entry into the Modules' API documentation for SSL/TLS and generic crypto support. Installation of the Module is only done by the Crypto Officer.

3.2. Services

The Module supports services that are available to users in the various roles. All of the services are described in detail in the Modules' user documentation. The following tables show the services available to the various roles and the access to cryptographic keys and CSPs resulting from services.

The following table lists the Approved services available in FIPS Approved mode. Please refer to Table 4 and 5 for the Approval key size of each algorithm used in the services.

Service	Role	Keys/CSPs	Access
Symmetric encryption/decryption	User	AES and Triple-DES key	read
Asymmetric key generation	User	RSA, DSA, ECDSA public and private key	read/write
Digital signature generation and verification	User	RSA, DSA, ECDSA public and private key	read
TLS network protocol	User	AES or Triple-DES key, HMAC Key	read/write
TLS key agreement	User	AES or Triple-DES key, RSA, DSA or ECDSA public and private key, HMAC Key, Premaster Secret, Master Secret, Diffie-Hellman Public and Private Components and EC Diffie-Hellman Public and Private Components	read/write
RSA key wrapping	User	RSA public and private keys	read
Certificate Management/ Handling	User	RSA, DSA or ECDSA public and private key parts of certificates	read
Keyed Hash (HMAC)	User	HMAC Key	read
Keyed Hash (CMAC)	User	CMAC key	read
Message digest (SHS)	User	none	N/A

Service	Role	Keys/CSPs	Access
Random number generation (SP800-90A DRBG)	User	Entropy input string and seed (C, K and V values)	read/write
Show status	User	none	N/A
Module initialization	User	none	N/A
Self-test	User	none	N/A
Zeroize	User	All aforementioned CSPs	write
Module installation	Crypto Officer	none	N/A

Table 7: Approved Service Details

The following table lists the non-Approved services available in non-FIPS mode. Please refer to Table 6 for the non-Approved key size of each algorithm.

Service	Role	Access
Asymmetric encryption/decryption using non-Approved RSA key size	User	read
Symmetric encryption/decryption using non-Approved algorithms	User	read
Hash operation using non-Approved algorithms	User	read
Digital signature generation and verification using non-Approved RSA and DSA private key	User	read
DSA with key and hash sizes not listed in table 3	User	read
TLS 1.2 KDF with SHA-512	User	read/write
TLS connection using keys established by Diffie-Hellman with non-Approved key sizes	User	read/write
Signature generation using SHA-1	User	read
Asymmetric key generation using non-Approved RSA and DSA key size or ECDSA P-224, P-192	User	read/write
Random number generation using ANSI X9.31 RNG	User	read/write

Table 8: Non-Approved Service Details

Note:

The Module does not share CSPs between an Approved mode of operation and a non-Approved mode of operation. All cryptographic keys used in the FIPS-Approved mode of operation must be generated in the FIPS-Approved mode or imported while running in the FIPS-Approved mode. If the DRBG is used for key generation for non-Approved services in non-FIPS mode, reseeding the DRBG before and after the key generation is mandatory.

More information about the services and their associated APIs can be found in the Man Pages included in the rpm packages. The `evp(3)` is the starting point of the Man Pages.

3.3. Operator Authentication

At security level 1, authentication is neither required nor employed. The role is implicitly assumed on entry.

3.4. Mechanism and Strength of Authentication

At security level 1, authentication is not required.

4. Physical Security

The Module is comprised of software only and thus does not claim any physical security.

5. Operational Environment

5.1. Applicability

The Red Hat Enterprise Linux operating system is used as the basis of other products which include but are not limited to:

- Red Hat Enterprise Linux Atomic Host
- Red Hat Virtualization (RHV)
- Red Hat OpenStack Platform
- OpenShift Container Platform
- Red Hat Gluster Storage
- Red Hat Ceph Storage
- Red Hat CloudForms
- Red Hat Satellite.

Compliance is maintained for these products whenever the binary is found unchanged.

The module operates in a modifiable operational environment per FIPS 140-2 level 1 specifications. The module runs on a commercially available general-purpose operating system executing on the hardware specified in section 1.2.

5.2. Policy

The operating system is restricted to a single operator (concurrent operators are explicitly excluded). The application that request cryptographic services is the single user of the module, even when the application is serving multiple clients.

In the operational mode, the `ptrace(2)` system call, the debugger (`gdb(1)`), and `strace(1)` shall be not used.

6. Cryptographic Key Management

6.1. Random Number and Key Generation

The Module provides an SP800-90A-compliant Deterministic Random Bit Generator (DRBG) for creation of key components of asymmetric keys, and random number generation.

The NDRNG used to seed the DRBG is provided by the operational environment (i.e., Linux RNG) which is within the module's physical boundary but outside of the module's logical boundary. The DRBG is seeded from the NDRNG via `getrandom()` call.

The Module performs continuous self-tests on the output of SP800-90A DRBG to ensure that consecutive random numbers do not repeat. Moreover, the module performs the health tests for the SP800-90A DRBG as defined per section 11.3 of SP800-90A.

The Key Generation methods implemented in the module for Approved services in FIPS mode is compliant with [SP800-133].

For generating RSA, DSA and ECDSA keys the module implements asymmetric key generation services compliant with [FIPS186-4]. A seed (i.e. the random value) used in asymmetric key generation is directly obtained from the [SP800-90A] DRBG.

The public and private key pairs used in the Diffie-Hellman and EC Diffie-Hellman KAS are generated internally by the module using the same DSA and ECDSA key generation compliant with [FIPS186-4] which is compliant with [SP800-56A].

The NDRNG provides 128 bits of entropy to the DRBG. Therefore, the following caveat applies: *The module generates cryptographic keys whose strengths are modified by available entropy.*

6.2. Key Establishment

The module provides Diffie-Hellman and EC Diffie-Hellman key agreement. In addition, the module offers AES key wrapping per [SP800-38F] (using GCM, CCM, and a combination of any approved block chaining modes with HMAC for authentication), Triple-DES key wrapping per [SP800-38F] (using a combination of any approved block chaining modes with HMAC for authentication), and RSA key wrapping (encapsulation) using public key encryption and private key decryption primitives as allowed by [FIPS140-2_IG] D.9.

AES, RSA, Diffie-Hellman and EC Diffie-Hellman provide the following security strengths:

- AES: key wrapping KW, KWP, AES-CCM and AES-GCM provides between 128 and 256 bits of encryption strength.
- AES: key wrapping using AES in CBC mode and HMAC, provides 128 or 256 bits of encryption strength.
- Triple-DES: key wrapping using HMAC provides 112 bits of encryption strength.

- RSA: key wrapping provides between 112 and 256 bits of encryption strength.
- Diffie-Hellman: key agreement provides between 112 and 219 bits of encryption strength.
- EC Diffie-Hellman: key agreement provides between 128 and 256 bits of encryption strength.

6.3. Key/Critical Security Parameter (CSP)

An authorized application as user (i.e., the User role) has access to all key data generated during the operation of the Module. The following table summarizes the Critical Security Parameters (CSPs) that are used by the cryptographic services implemented in the module:

Key/CSP	Generation	Storage	Zeroization
AES Symmetric Key	N/A(passed in as API input parameter) Alternatively, key can be established during a TLS handshake	RAM	EVP_CIPHER_CTX_cleanup()
Triple-DES Symmetric Key			
HMAC Key			HMAC_CTX_cleanup()
CMAC Key			CMAC_CTX_cleanup()
RSA Private Key	Generated using FIPS 186-4 key generation method and the random value used in the key generation is generated using SP800-90A DRBG.	RAM	RSA_free()
DSA Private Key			DSA_free()
ECDSA Private Key			EC_GROUP_clear_free() and EC_POINT_clear_free()
Diffie-Hellman Private Components	Generated as specified in SP800-56A and the random value used in the key generation is generated using SP800-90A DRBG.	RAM	DH_free()
EC Diffie-Hellman Private Components			EC_GROUP_clear_free() and EC_POINT_clear_free()
SP 800-90A DRBG seed and entropy input (C, K, V values)	Obtained from NDRNG	RAM	FIPS_drbg_free()
TLS Pre-Master Secret and Master Secret	Established during the TLS handshake	RAM	SSL_free() and SSL_clear()
Diffie-Hellman Public Components	Generated as specified in SP800-56A and the random value used in the key generation is generated using SP800-90A DRBG.	RAM	DH_free()
RSA public key for signature generation verification or for Key	Generated using FIPS 186-4 key generation method and the random value used in the	RAM	RSA_free()

Key/CSP	Generation	Storage	Zeroization
Wrapping	key generation is generated using SP800-90A DRBG.		
DSA public key for signature generation verification			DSA_free()
ECDSA public key for signature generation verification			EC_GROUP_clear_free() and EC_POINT_clear_free()
EC Diffie-Hellman Public Components	Generated as specified in SP800-56A and the random value used in the key generation is generated using SP800-90A DRBG.	RAM	EC_GROUP_clear_free() and EC_POINT_clear_free()

Table 9: Key Life Cycle

6.4. Key/CSP Storage

Public and private keys are provided to the Module by the calling process, and are destroyed when released by the appropriate API function calls. The Module does not perform persistent storage of CSPs.

6.5. Key/CSP Zeroization

The memory occupied by keys is allocated by regular libc malloc/calloc() calls. The application is responsible for calling the appropriate destruction functions from the OpenSSL API. The destruction functions then overwrite the memory occupied by keys with pre-defined values and deallocates the memory with the free() call. In case of abnormal termination, or swap in/out of a physical memory page of a process, the keys in physical memory are overwritten by the Linux kernel before the physical memory is allocated to another process.

The application that uses the Module is responsible for appropriate destruction and zeroization of the key material. The library provides functions for key allocation and destruction, which overwrites the memory that is occupied by the key information with “zeros” before it is deallocated.

7. Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC)

MARKETING NAME..... PowerEdge R630
REGULATORY MODEL..... E26S
REGULATORY TYPE..... E26S001
EFFECTIVE DATE..... September 03, 2014
EMC EMISSIONS CLASS..... Class A

7.1. Statement of compliance

This product has been determined to be compliant with the applicable standards, regulations, and directives for the countries where the product is marketed. The product is affixed with regulatory marking and text as necessary for the country/agency. Generally, Information Technology Equipment (ITE) product compliance is based on IEC and CISPR standards and their national equivalent such as Product Safety, IEC 60950-1 and European Norm EN 60950-1 or EMC, CISPR 22/CISPR 24 and EN 55022/55024. Dell products have been verified to comply with the EU RoHS Directive 2011/65/EU. Dell products do not contain any of the restricted substances in concentrations and applications not permitted by the RoHS Directive.

8. Self-Tests

FIPS 140-2 requires that the Module performs self-tests to ensure the integrity of the Module, and the correctness of the cryptographic functionality at start up. In addition, some functions require continuous verification of function, such as the Random Number Generator. All of these tests are listed and described in this section. No operator intervention is required during the running of the self-tests.

See section 9.3 for descriptions of possible self-test errors and recovery procedures.

8.1. Power-Up Tests

The Module performs both power-up self-tests (at module initialization) and continuous conditional tests (during operation). The power-up self test start with the integrity test, where the `FIPS_mode_set()` function verifies the integrity of the runtime executable using a HMAC SHA-256 digest, which is computed at build time. If this computed HMAC SHA-256 digest matches the stored, known digest, then the rest of the power-up self-test (consisting of the algorithm-specific Pairwise Consistency and Known Answer Tests) is performed. Input, output, and cryptographic functions cannot be performed while the Module is in a self-test or error state because the Module is single-threaded and will not return to the calling application until the power-up self-tests are complete. After successful completion of the power-up tests, the module is loaded and cryptographic functions are available for use. If the power-up self-tests fail, subsequent calls to the Module will also fail - thus no further cryptographic operations are possible.

Algorithm	Test
AES	KAT, encryption and decryption are tested separately
Triple-DES	KAT, encryption and decryption are tested separately
DSA	Pairwise consistency test (PCT), sign and verify
RSA	KAT, signature generation and verification are tested separately
ECDSA	PCT, sign and verify
Diffie-Hellman	Primitive "Z" Computation KAT
EC Diffie-Hellman	Primitive "Z" Computation KAT
SP 800-90A CTR_DRBG	KAT
SP 800-90A Hash_DRBG	KAT
SP 800-90A DRBG_HMAC	KAT
HMAC-SHA-1, -224, -256, -384, -512	KAT
SHA-1, -224, -256, -384, -512	KAT
CMACAES128, 192, 256, and TDES	KAT
Module integrity	HMAC-SHA-256

Table 10: Modules' Self-Tests

8.2. Conditional Tests

Algorithm	Test
DSA	PCT: signature generation and verification
ECDSA	PCT: signature generation and verification
RSA	PCT: signature generation and verification, encryption and decryption

Table 11: Modules' Conditional Tests

9. Guidance

9.1. Crypto Officer Guidance

The version of the RPM containing the FIPS validated Module is stated in section 1. The RPM package of the Module can be installed by standard tools recommended for the installation of RPM packages on a Red Hat Enterprise Linux system (for example, yum, rpm, and the RHN remote management tool). The integrity of the RPM is automatically verified during the installation of the Module and the Crypto Officer shall not install the RPM file if the RPM tool indicates an integrity error.

The OpenSSL static libraries libcrypto.a and libssl.a in openssl-static package are not approved to be used. The applications must be dynamically linked to run the OpenSSL.

The RPM package of the Module can be installed by standard tools recommended for the installation of RPM packages on a Red Hat Enterprise Linux system (for example, yum, rpm, and the RHN remote management tool). For proper operation of the in-module integrity verification, the prelink has to be disabled.

1 Disable the prelink:

```
# sed -i 's/PRELINKING=yes/PRELINKING=no/g' /etc/sysconfig/prelink
```

2 Run following command to return binaries to a non-prelink state:

```
# /usr/sbin/prelink -ua
```

Crypto officer should perform the following for Module installation:

1. Install the dracut-fips package:

```
# yum install dracut-fips
```

2. Recreate the INITRAMFS image:

```
# dracut -f
```

After regenerating the initramfs, the Crypto Officer has to append the following string to the kernel command line by changing the setting in the boot loader:

```
fips=1
```

If /boot or /boot/efi resides on a separate partition, the kernel parameter boot=<partition of /boot or /boot/efi> must be supplied. The partition can be identified with the command

```
"df /boot"
```

or

```
"df /boot/efi"
```

respectively. For example:

```
$ df /boot
```

Filesystem	1K-blocks	Used	Available	Use%	Mounted on
/dev/sda1	233191	30454	190296	14%	/boot

The partition of /boot is located on /dev/sda1 in this example. Therefore, the following string needs to be appended to the kernel command line:

```
"boot=/dev/sda1"
```

Reboot to apply these settings.

The next step is to check the presence of the configuration file `/proc/sys/crypto/fips_enabled` and make sure it contains value 1.

The version of the RPM containing the validated Module is the version listed in chapter 1. The integrity of the RPM is automatically verified during the installation of the Module and the Crypto Officer shall not install the RPM file if the RPM tool indicates an integrity error.

9.2. User Guidance

To operate the Module in FIPS Approved mode, the user should use services and security functions listed in Table 6. Any use of non-approved services will put the module in the non-FIPS mode implicitly.

Interpretation of the return code is the responsibility of the host application.

`ENGINE_register_*`, `ENGINE_set_default_*` and `FIPS_mode_set(0)` function calls are prohibited.

9.2.1. TLS and Diffie-Hellman

The TLS protocol implementation provides both, the server and the client sides. As required by SP800-131A, Diffie-Hellman with keys smaller than 2048 bits must not be used any more. The TLS protocol cannot enforce the support of FIPS Approved Diffie-Hellman key sizes. To ensure full support for all TLS protocol versions, the TLS client implementation of the cryptographic module must accept Diffie-Hellman key sizes smaller than 2048 bits offered by the TLS server.

The TLS server implementation of the cryptographic Module allows the application to set the Diffie-Hellman key size. The server side must always set the DH parameters with the API call of:

```
SSL_CTX_set_tmp_dh(ctx, dh)
```

To comply with the FIPS 140-2 standard the requirement to not allow Diffie-Hellman key sizes smaller than 2048 bits must be met, to do this the Crypto Officer must ensure that:

- in case the Module is used as TLS server, the Diffie-Hellman parameters (dh argument) of the aforementioned API call must be 2048 bits or larger;
- in case the Module is used as TLS client, the TLS server must be configured to only offer Diffie-Hellman keys of 2048 bits or larger.

Using DH parameters and keys smaller than 2048 bits will implicitly place the module into non-FIPS mode, as specified in section 1.2 of the Security Policy.

9.2.2. AES-XTS Guidance

The length of a single data unit encrypted or decrypted with the XTS-AES shall not exceed 2^{20} AES blocks that is 16MB of data per AES-XTS instance. An XTS instance is defined in section 4 of SP 800-38E.

The AES-XTS mode shall only be used for the cryptographic protection of data on storage devices. The AES-XTS shall not be used for other purposes, such as the encryption of data in transit. The module implements the check to ensure that the two AES keys used in XTS-AES algorithm are not identical

9.2.3. Random Number Generator

The OpenSSL API call of RAND_cleanup must not be used. This call will cleanup the internal DRBG state. This call also replaces the DRBG instance with the non-FIPS Approved SSLey Deterministic Random Number Generator when using the RAND_* API calls.

9.2.4. AES-GCM IV

In case the Modules' power is lost and then restored, the key used for the AES GCM encryption/decryption shall be re-distributed.

The nonce_explicit part of the IV does not exhaust the maximum number of possible values for a given session key. The design of the TLS protocol in this module implicitly ensures that the nonce_explicit, or counter portion of the IV will not exhaust all of its possible values.

The module complies with IG A.5, provision 1 ("TLS protocol IV generation"). The GCM IV is generated as part of the TLS protocol handshake and key derivation. AES-GCM can only be used in the context of TLSv1.2. The module complies with bullet ii) of this provision: the entire TLS protocol is implemented within the module boundary. The module supports the TLS GCM ciphersuites from SP800-52 Rev1, section 3.3.1.

9.2.5. Triple-DES Keys

According to IG A.13, the same Triple-DES key shall not be used to encrypt more than 2^{16} 64-bit blocks of data. It is the user's responsibility to make sure that the module complies with this requirement and that the module does not exceed this limit.

9.2.6. RSA and DSA Keys

The Module allows the use of 1024 bit RSA and DSA keys for legacy purposes, including signature generation.

RSA and DSA must be used with either 2048 bit keys or 3072 bit keys because larger key sizes have not been CAVS tested. To comply with the requirements of FIPS 140-2, a user must therefore only use keys with 2048 bits or 3072 bits in FIPS Approved mode.

Application can enforce the key generation bit length restriction for RSA and DSA keys by setting the environment variable OPENSSL_ENFORCE_MODULUS_BITS. This environment variable ensures that 1024 bit keys cannot be generated.

9.2.7. Handling Self-Test Errors

The effects of self-test failures in the Module differ depending on the type of self-test that failed.

self-test errors transition the Module into an error state. The application must be restarted to recover from these errors. The self-test errors are:

- FIPS_R_FINGERPRINT_DOES_NOT_MATCH - The integrity verification check failed
- FIPS_R_FIPS_SELFTEST_FAILED - a known answer test failed
- FIPS_R_SELFTEST_FAILED - a known answer test failed
- FIPS_R_TEST_FAILURE - a known answer test failed (RSA); pairwise consistency test failed (DSA)
- FIPS_R_PAIRWISE_TEST_FAILED - a pairwise consistency test during DSA or RSA key generation failed
-

These errors are reported through the regular ERR interface of the Module and can be queried by functions such as `ERR_get_error()`. See the OpenSSL manual page for the function description.

When a error occurs (a self-test or conditional test has failed), the Module enters an error state. Any calls to a crypto function of the Module returns an error with the error message: 'FATAL FIPS SELFTTEST FAILURE' printed to `stderr` and the Module is terminated with the `abort()` call.

The only way to recover from an error is to restart the Module. If failures persist, the Module must be reinstalled. If downloading the software, make sure to verify the package hash to confirm a proper download.

10. Mitigation of Other Attacks

RSA is vulnerable to timing attacks. In a setup where attackers can measure the time of RSA decryption or signature operations, blinding must be used to protect the RSA operation from that attack.

The API function of `RSA_blinding_on` turns blinding on for key `rsa` and generates a random blinding factor. The random number generator must be seeded prior to calling `RSA_blinding_on`.

Weak Triple-DES keys are detected as follows:

```
/* Weak and semi weak keys as taken from
 * %A D.W. Davies
 * %A W.L. Price
 * %T Security for Computer Networks
 * %I John Wiley & Sons
 * %D 1984
 * Many thanks to smb@ulysses.att.com (Steven Bellovin) for the reference
 * (and actual cblock values).
 */
#define NUM_WEAK_KEY 16
static const DES_cblock weak_keys[NUM_WEAK_KEY]={
    /* weak keys */
    {0x01,0x01,0x01,0x01,0x01,0x01,0x01,0x01},
    {0xFE,0xFE,0xFE,0xFE,0xFE,0xFE,0xFE,0xFE},
    {0x1F,0x1F,0x1F,0x1F,0x0E,0x0E,0x0E,0x0E},
    {0xE0,0xE0,0xE0,0xE0,0xF1,0xF1,0xF1,0xF1},
    /* semi-weak keys */
    {0x01,0xFE,0x01,0xFE,0x01,0xFE,0x01,0xFE},
    {0xFE,0x01,0xFE,0x01,0xFE,0x01,0xFE,0x01},
    {0x1F,0xE0,0x1F,0xE0,0x0E,0xF1,0x0E,0xF1},
    {0xE0,0x1F,0xE0,0x1F,0xF1,0x0E,0xF1,0x0E},
    {0x01,0xE0,0x01,0xE0,0x01,0xF1,0x01,0xF1},
    {0xE0,0x01,0xE0,0x01,0xF1,0x01,0xF1,0x01},
    {0x1F,0xFE,0x1F,0xFE,0x0E,0xFE,0x0E,0xFE},
    {0xFE,0x1F,0xFE,0x1F,0xFE,0x0E,0xFE,0x0E},
    {0x01,0x1F,0x01,0x1F,0x01,0x0E,0x01,0x0E},
    {0x1F,0x01,0x1F,0x01,0x0E,0x01,0x0E,0x01},
    {0xE0,0xFE,0xE0,0xFE,0xF1,0xFE,0xF1,0xFE},
    {0xFE,0xE0,0xFE,0xE0,0xFE,0xF1,0xFE,0xF1}};
```

Please note that there is no weak key detection by default. The caller can explicitly set the `DES_check_key` to 1 or call `DES_check_key_parity()` and/or `DES_is_weak_key()` functions on its own.

11. Glossary and Abbreviations

AES	Advanced Encryption Specification
CAVP	Cryptographic Algorithm Validation Program
CBC	Cypher Block Chaining
CCM	Counter with Cipher Block Chaining-Message Authentication Code
CFB	Cypher Feedback
CMVP	Cryptographic Module Validation Program
CSP	Critical Security Parameter
DES	Data Encryption Standard
DRBG	Deterministic Random Bit Generator
DSA	Digital Signature Algorithm
ECB	Electronic Code Book
FSM	Finite State Model
HMAC	Hash Message Authentication Code
MAC	Message Authentication Code
NIST	National Institute of Science and Technology
NVLAP	National Voluntary Laboratory Accreditation Program
OFB	Output Feedback
OS	Operating System
PRNG	Pseudo Random Number Generator
RHEL	Red Hat Enterprise Linux
RNG	Random Number Generator
RSA	Rivest, Shamir, Addleman
SHA	Secure Hash Algorithm
SHS	Secure Hash Standard

12. References

- [1] OpenSSL man pages where `crypto(3)` provides the introduction and link to all OpenSSL APIs regarding the cryptographic operation and `ssl(3)` to all OpenSSL APIs regarding the SSL/TLS protocol family
- [2] FIPS 140-2 Standard, <http://csrc.nist.gov/groups/STM/cmvp/standards.html>
- [3] FIPS 140-2 Implementation Guidance, <http://csrc.nist.gov/groups/STM/cmvp/standards.html>
- [4] FIPS 140-2 Derived Test Requirements, <http://csrc.nist.gov/groups/STM/cmvp/standards.html>
- [5] FIPS 197 Advanced Encryption Standard, <http://csrc.nist.gov/publications/PubsFIPS.html>
- [6] FIPS 180-4 Secure Hash Standard, <http://csrc.nist.gov/publications/PubsFIPS.html>
- [7] FIPS 198-1 The Keyed-Hash Message Authentication Code (HMAC), <http://csrc.nist.gov/publications/PubsFIPS.html>
- [8] FIPS 186-4 Digital Signature Standard (DSS), <http://csrc.nist.gov/publications/PubsFIPS.html>
- [9] ANSI X9.52:1998 Triple Data Encryption Algorithm Modes of Operation, <http://webstore.ansi.org/FindStandards.aspx?Action=displaydept&DeptID=80&Acro=X9&DpName=X9,%20Inc>.
- [10] NIST SP 800-67 Revision 2, Recommendation for the Triple Data Encryption Algorithm (TDEA) Block Cipher, <http://csrc.nist.gov/publications/PubsFIPS.html>
- [11] NIST SP 800-38B, Recommendation for Block Cipher Modes of Operation: The CMAC Mode for Authentication, <http://csrc.nist.gov/publications/PubsFIPS.html>
- [12] NIST SP 800-38C, Recommendation for Block Cipher Modes of Operation: The CCM Mode for Authentication and Confidentiality, <http://csrc.nist.gov/publications/PubsFIPS.html>
- [13] NIST SP 800-38D, Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC, <http://csrc.nist.gov/publications/PubsFIPS.html>
- [14] NIST SP 800-38E, Recommendation for Block Cipher Modes of Operation: The XTS-AES Mode for Confidentiality on Storage Devices, <http://csrc.nist.gov/publications/PubsFIPS.html>
- [15] NIST SP 800-56A Revision 3, Recommendation for Pair-Wise Key Establishment Schemes using Discrete Logarithm Cryptography (Revised), <http://csrc.nist.gov/publications/PubsFIPS.html>
- [16] NIST SP 800-90A Revision 1, Recommendation for Random Number Generation Using Deterministic Random Bit Generators, <http://csrc.nist.gov/publications/PubsFIPS.html>