OpenSSL Cryptographic Module

version 1.0

FIPS 140-2 Non-Proprietary Security Policy

Version 1.4

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Table of Contents

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1. Cryptographic Module Specification

This document is the non-proprietary FIPS 140-2 Security Policy for version 1.0 of the Ubuntu OpenSSL Cryptographic Module. It contains the security rules under which the module must operate and describes how this module meets the requirements as specified in FIPS PUB 140-2 (Federal Information Processing Standards Publication 140-2) for a Security Level 1 software module.

The following sections describe the cryptographic module and how it conforms to the FIPS 140-2 specification in each of the required areas.

1.1. Module Overview

The Ubuntu OpenSSL Cryptographic Module (hereafter referred to as "the module") is a set of software libraries implementing the Transport Layer Security (TLS) protocol v1.0, v1.1 and v1.2 and Datagram Transport Layer Security (DTLS) protocol v.1.0 and v1.2, as well as general purpose cryptographic algorithms. The module provides cryptographic services to applications running in the user space of the underlying Ubuntu operating system through a C language Application Program Interface (API). The module utilizes processor instructions to optimize and increase performance. The module can act as a TLS server or client, and interacts with other entities via TLS/DTLS network protocols.

For the purpose of the FIPS 140-2 validation, the module is a software-only, multi-chip standalone cryptographic module validated at overall security level 1. The table below shows the security level claimed for each of the eleven sections that comprise the FIPS 140-2 standard:

FIPS 140-2 Section		Security Level
1	Cryptographic Module Specification	1
2	Cryptographic Module Ports and Interfaces	1
3	Roles, Services and Authentication	1
4	Finite State Model	1
5	Physical Security	N/A
6	Operational Environment	1
7	Cryptographic Key Management	1
8	EMI/EMC	1
9	Self-Tests	1
10	Design Assurance	1
11	Mitigation of Other Attacks	1
Overall Level		1

Table 1 - Security Levels

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The cryptographic logical boundary consists of all shared libraries and the integrity check files used for Integrity Tests. The following table enumerates the files that comprise the module:

Component	Description
libssl.so.1.0.0	Shared library for TLS/DTLS network protocols.
libcrypto.so.1.0.0	Shared library for cryptographic implementations.
.libssl.so.1.0.0.hmac	Integrity check signature for libssl shared library.
.libcrypto.so.1.0.0.hmac	Integrity check signature for libcrypto shared library.

Table 2 - Cryptographic Module Components

The software block diagram below shows the module, its interfaces with the operational environment and the delimitation of its logical boundary, comprised of all the components within the **BLUE** box:

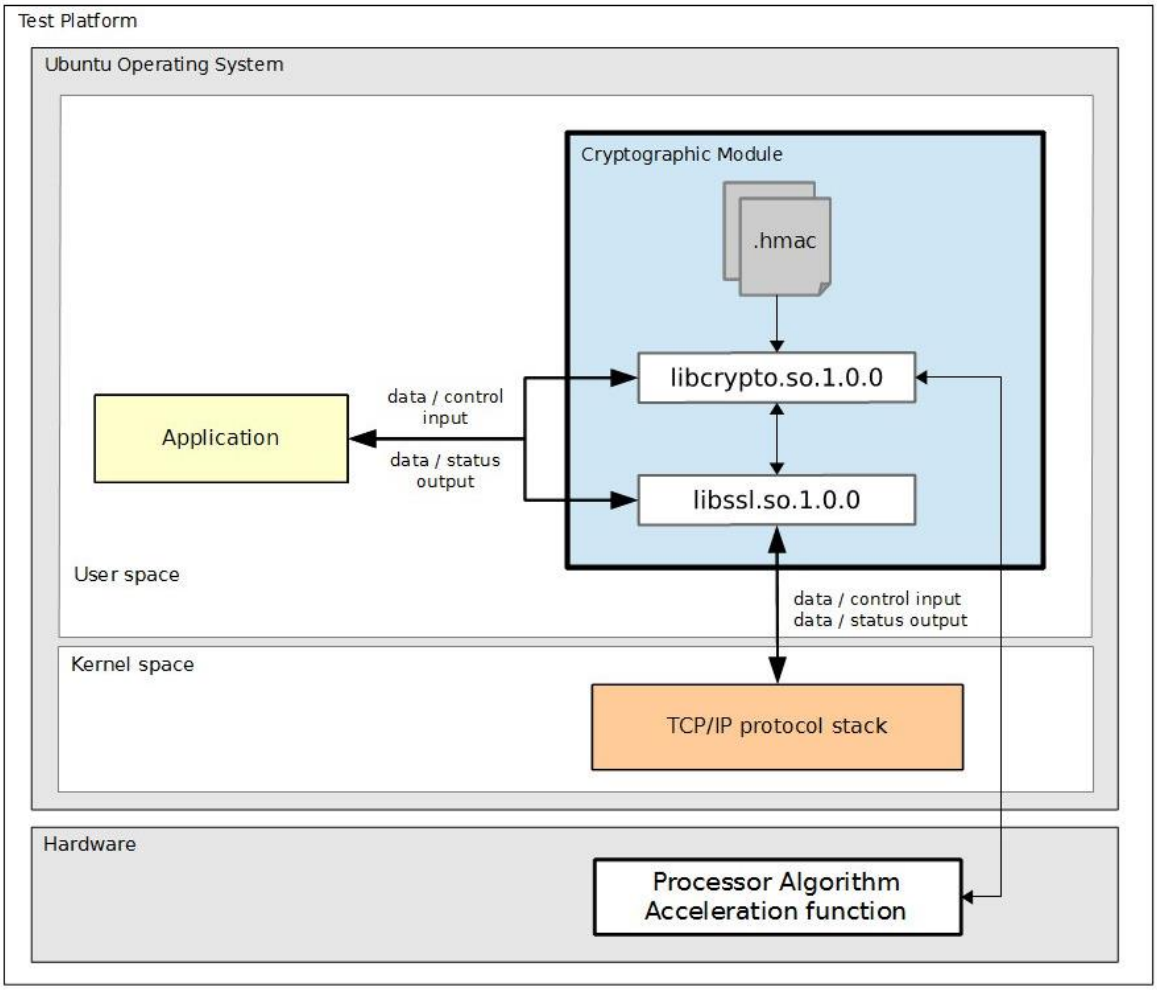

Figure 1 - Software Block Diagram

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The module is aimed to run on a general purpose computer (GPC); the physical boundary of the module is the tested platforms. Figure 2 shows the major components of a GPC:

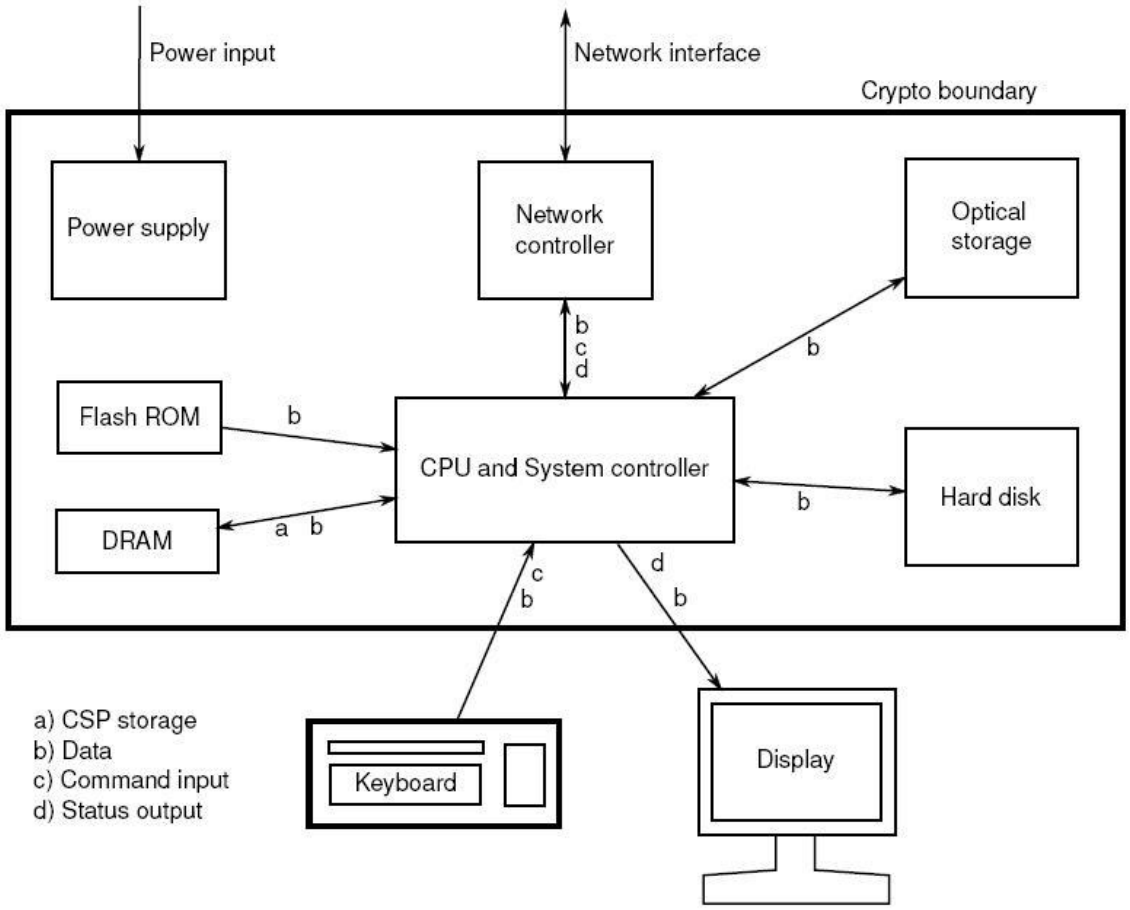

Figure 2 - Cryptographic Module Physical Boundary

The module has been tested on the test platforms shown below:

Test Platform	Processor	Test Configuration
IBM Power System S822L (PowerNV 8247-22L)	POWER8	Ubuntu 16.04 LTS 64-bit Little Endian with/without Power ISA 2.07 (PAA)
IBM Power System S822LC (PowerNV 8001-22C)	POWER8	Ubuntu 16.04 LTS 64-bit Little Endian with/without Power ISA 2.07 (PAA)
IBM Power System S822LC (PowerNV 8335-GTB)	POWER8	Ubuntu 16.04 LTS 64-bit Little Endian with/without Power ISA 2.07 (PAA)
Supermicro SYS-5018R-WR	Intel® Xeon® CPU E5-2620v3	Ubuntu 16.04 LTS 64-bit with/without AES-NI (PAA)
IBM z13	z13	Ubuntu 16.04 LTS 64-bit running on LPAR with/without CPACF (PAI)

Table 3 - Tested Platforms

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Note: Per FIPS 140-2 IG G.5, the Cryptographic Module Validation Program (CMVP) makes no statement as to the correct operation of the module or the security strengths of the generated keys when this module is ported and executed in an operational environment not listed on the validation certificate.

1.2. Modes of Operation

The module supports two modes of operation:

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

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.

Critical security parameters used or stored in FIPS mode are not used in non-FIPS mode, and vice versa.

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2. Cryptographic Module Ports and Interfaces

As a software-only module, the module does not have physical ports. For the purpose of the FIPS 140-2 validation, the physical ports are interpreted to be the physical ports of the hardware platform on which it runs.

The logical interfaces are the API through which applications request services, and the TLS protocol internal state and messages sent and received from the TCP/IP protocol. The following table summarizes the four logical interfaces:

FIPS Interface	Physical Port	Logical Interface
Data Input	Ethernet ports	API input parameters, kernel I/O – network or files on file system, TLS protocol input messages.
Data Output	Ethernet ports	API output parameters, kernel I/O – network or files on file system, TLS protocol output messages.
Control Input	Keyboard, Serial port, Ethernet port, Network	API function calls, API input parameters for control, TLS protocol internal state.
Status Output	Serial port, Ethernet port, Network	API return codes, TLS protocol internal state.
Power Input	PC Power Supply Port	N/A

Table 4 - Ports and Interfaces

Note: The module is an implementation of the TLS protocol as defined in the RFC standards. The TLS protocol provides confidentiality and data integrity between communicating applications. When an application calls into the module's API, the data passed will be securely passed to the peer.

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3. Roles, Services and Authentication

3.1. Roles

The module supports the following roles:

- **User role**: performs cryptographic services (in both FIPS mode and non-FIPS mode), TLS network protocol, key zeroization, get status, and on-demand self-test.
- **Crypto Officer role**: performs module installation and initialization, and certificates management.

The User and Crypto Officer roles are implicitly assumed by the entity accessing the module services.

3.2. Services

The module provides services to users that assume one of the available roles. All services are shown in Table 5 and Table 6, and described in detail in the user documentation (i.e., man pages) referenced in section 9.1.

The table below shows the services available in FIPS mode. For each service, the associated cryptographic algorithms, the roles to perform the service, and the cryptographic keys or Critical Security Parameters and their access right are listed. If the services involve the use of the cryptographic algorithms, the corresponding Cryptographic Algorithm Validation System (CAVS) certificate numbers of the cryptographic algorithms can be found in Table 7, Table 8, Table 9 and Table 11 of this security policy. Notice that the algorithms mentioned in the Network Protocol Services correspond to the same implementation of the algorithms described in the Cryptographic Library Services.

Service	Algorithms	Role	Access	Keys/CSP
Cryptographic Library Services				
Symmetric Encryption and Decryption	AES	User	Read	AES key
	Triple-DES	User	Read	Triple-DES key
RSA key generation	RSA, DRBG	User	Create	RSA public-private key
RSA digital signature generation and verification	RSA	User	Read	RSA public-private key
DSA key generation	DSA, DRBG	User	Create	DSA public-private key
DSA domain parameter generation	DSA	User	Read	DSA domain parameters
DSA digital signature generation and verification	DSA	User	Read	DSA public-private key
ECDSA key generation	ECDSA, DRBG	User	Create	ECDSA public-private key

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Service	Algorithms	Role	Access	Keys/CSP
ECDSA public key validation	ECDSA	User	Read	ECDSA public key
ECDSA signature generation and verification	ECDSA	User	Read	ECDSA public-private key
Random number generation	DRBG	User	Read, Update	Entropy input string, Internal state
Message digest	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512	User	n/a	n/a
Message authentication code (MAC)	HMAC	User	Read	HMAC key
	CMAC with AES	User	Read	AES key
	CMAC with Triple-DES	User	Read	Triple-DES key
Key wrapping	AES	User	Read	AES key
Key encapsulation	RSA	User	Read	RSA public-private key
Diffie-Hellman Key Agreement	KAS FFC	User	Create, Read	Diffie-Hellman domain parameters
EC Diffie-Hellman Key Agreement	KAS ECC, ECC CDH primitive	User	Create, Read	EC Diffie-Hellman public-private keys
Network Protocols Services				
Transport Layer Security (TLS) network protocol v1.0, v1.1 and v1.2	See Appendix A for the complete list of supported cipher suites.	User	Read	AES or Triple-DES key, RSA, DSA or ECDSA public-private key, HMAC Key, Shared Secret, Diffie-Hellman domain parameters or EC Diffie-Hellman public-private keys
TLS extensions	n/a	User	Read	RSA, DSA or ECDSA public-private key
Certificates management	n/a	Crypto Officer	Read	RSA, DSA or ECDSA public-private key
Other FIPS-Related Services				
Show status	n/a	User	n/a	None
Zeroization	n/a	User	Zeroize	All CSPs

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Service	Algorithms	Role	Access	Keys/CSP
Self-Tests	AES, Triple-DES, SHS, HMAC, DSA, RSA, ECDSA, DRBG, Diffie-Hellman, EC Diffie-Hellman, TLS KDF	User	n/a	None
Module installation	n/a	Crypto Officer	n/a	None
Module initialization	n/a	Crypto Officer	n/a	None

Table 5 - Services in FIPS mode of operation

The table below lists the services only available in non-FIPS mode of operation.

Service	Algorithms / Key sizes	Role	Access	Keys/CSPs
Symmetric encryption and decryption	2-key Triple-DES listed in Table 12	User	Read	2-key Triple-DES key
Authenticated Encryption cipher for encryption and decryption	AES and SHA from multi-buffer or stitch implementation listed in Table 12	User	Read	AES key, HMAC key
Asymmetric key generation using keys disallowed by [SP800-131A]	RSA, DSA listed in Table 12	User	Create	RSA, DSA or ECDSA public-private keys
Digital signature generation using keys disallowed by [SP800-131A].	RSA, DSA listed in Table 12	User	Read	RSA or DSA public-private keys
Key establishment using keys disallowed by [SP800-131A].	Diffie-Hellman, RSA listed in Table 12	User	Read	Diffie-Hellman domain parameters or RSA public-private keys
Message digest	MD5	User	n/a	none
Message authentication code (MAC) using keys disallowed by [SP800-131A]	HMAC listed in Table 12, CMAC with 2-key Triple-DES	User	Read	HMAC key, 2-key Triple-DES key
X9.31 RSA Key Generation	ANSI X9.31 RSA Key Generation	User	Create	RSA public-private keys

Table 6 – Services in non-FIPS mode of operation

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3.3. Algorithms

The algorithms implemented in the module are tested and validated by CAVP for the following operating environment:

- Ubuntu 16.04 LTS 64-bit Little Endian running on POWER system
- Ubuntu 16.04 LTS 64-bit running on Intel® Xeon® processor
- Ubuntu 16.04 LTS 64-bit running on z system

The Ubuntu OpenSSL Cryptographic Module is compiled to use the support from the processor and assembly code for AES, SHA and GHASH operations to enhance the performance of the module. Different implementations can be invoked by setting the environment variable in the operational environment. Please note that only one AES, SHA and/or GHASH implementation can be executed in runtime.

Notice that for the Transport Layer Security (TLS) protocol, no parts of this protocol, other than the key derivation function (KDF), have been tested by the CAVP.

3.3.1. Ubuntu 16.04 LTS 64-bit Little Endian Running on POWER System

On the platform that runs POWER system, the module supports the use of Power ISA 2.07 and strict assembler for AES, SHA and GHASH implementation, and the use of SSSE3 with Altivec for AES implementation. Each implementation is determined by the environment variable `OPENSSL_ppccap`.

The following table shows the CAVS certificates and their associated information of the cryptographic implementation in FIPS mode.

CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Strict AES assembler: #4354 Using the support from POWER ISA 2.07: #4355 Using the support from SSSE3 with Altivec: #4356	AES	[FIPS197], [SP800-38A]	ECB, CBC, OFB, CFB1, CFB8, CFB128, CTR	128, 192, 256	Data Encryption and Decryption
		[SP800-38B]	CMAC	128, 192, 256	MAC Generation and Verification
		[SP800-38C]	CCM	128, 192, 256	Data Encryption and Decryption
		[SP800-38D]	GCM	128, 192, 256	Data Encryption and Decryption
		[SP800-38E]	XTS	128, 256	Data Encryption and Decryption for Data Storage
Strict AES assembler: #4354	AES	[SP800-38F]	KW	128, 192, 256	Key Wrapping and Unwrapping

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Strict SHA assembler: CVL #1054 Using the support from POWER ISA 2.07[1]: CVL #1057	ECC CDH Primitive	[SP800-56A] Section 5.7.1.2	n/a	P-224, P-256, P-384, P-521 K-233, K-283, K-409, K-571 B-233, B-283, B-409, B-571	EC Diffie-Hellman Key Agreement
Strict SHA assembler: CVL #1053 Using the support from POWER ISA 2.07[1]: CVL #1056	Partial EC Diffie-Hellman	[SP800-56A]	ECC Ephemeral Unified scheme	P-224, P-256, P-384, P-521	EC Diffie-Hellman Key Agreement
Strict SHA assembler: CVL #1053 Using the support from POWER ISA 2.07[1]: CVL #1056	Partial Diffie-Hellman	[SP800-56A]	FCC dhEphem scheme	p=2048, q=224; p=2048, q=256	Diffie-Hellman Key Agreement
Strict SHA assembler: CVL #1055 Using the support from POWER ISA 2.07[1]: CVL #1058	TLS v1.0, v1.1 and v1.2 KDF	[SP800-135rev1]	n/a	n/a	Key Derivation

[1] The module uses the support from Power ISA 2.07 for SHA-224, SHA-256, SHA-384 and SHA-512. The SHA-1 is not supported.

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Strict SHA assembler: #1156 Using the support from POWER ISA 2.07[1]: #1157	DSA	[FIPS186-4]	SHA-1[2], SHA-224, SHA-256, SHA-384, SHA-512	L=1024, N=160[3]; L=2048, N=224; L=2048, N=256; L=3072, N=256	Key Pair Generation, Domain Parameter Generation and Verification, Digital Signature Generation and Verification
Strict SHA assembler: #1390 Using the support from POWER ISA 2.07[1]: #1391	DRBG	[SP800-90A]	**Hash_DRBG:** SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 without PR	n/a	Deterministic Random Bit Generation
			HMAC_DRBG: SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 without PR		
Strict AES assembler: #1390			**CTR_DRBG:** AES-128, AES-192, AES-256 with/without DF, without PR		

[2] SHA-1 is only allowed and CAVS tested in DSA Domain Parameter Verification and DSA Signature Verification for legacy use.

[3] 1024-bit key is only allowed and CAVS tested in DSA Domain Parameter Verification and DSA Signature Verification for legacy use.

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Strict SHA assembler: #1031 Using the support from POWER ISA 2.07[1]: #1032	ECDSA	[FIPS186-4]	SHA-1[4], SHA-224, SHA-256, SHA-384, SHA-512	P-192[5], P-224, P-256, P-384, P-521, K-163[5], K-233, K-283, K-409, K-571, B-163[5], B-233, B-283, B-409, B-571	Key Pair Generation, Public Key Verification, Digital Signature Generation and Verification
Strict SHA assembler: #2895 Using the support from POWER ISA 2.07[1]: #2896	HMAC	[FIPS198-1]	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512	112 or greater	Message authentication code
Strict SHA assembler: #2351 Using the support from POWER ISA 2.07[1]: #2352	RSA	[FIPS186-4]	**X9.31** SHA-1[6], SHA-256, SHA-384, SHA-512 **PKCS#1v1.5** SHA-1[6], SHA-224, SHA-256, SHA-384, SHA-512	1024[7], 2048, 3072, 4096[8]	Key Pair Generation, Digital Signature Generation and Verification

[4] SHA-1 is only allowed and CAVS tested in ECDSA Public Key Validation and ECDSA Signature Verification for legacy use.

[5] P-192, K-163 and B-163 curves are only allowed and CAVS tested in ECDSA Public Key Validation and ECDSA Signature Verification for legacy use.

[6] SHA-1 is only allowed and CAVS tested in RSA Signature Verification for legacy use.

[7] 1024-bit key is only allowed and CAVS tested in RSA Signature Verification for legacy use.

[8] 4096-bit key is only CAVS tested for RSA Signature Generation.

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
			PSS SHA-1[6], SHA-224, SHA-256, SHA-384, SHA-512		
Strict SHA assembler: #3593 Using the support from POWER ISA 2.07[1]: #3594	SHS	[FIPS180-4]	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512	n/a	Message Digest
#2355	Triple-DES	[SP800-67], [SP800-38A]	ECB, CBC, CFB1, CFB8, CFB64, OFB	192	Data Encryption and Decryption
		[SP800-67], [SP800-38B]	CMAC	192	MAC Generation and Verification

Table 7 – Cryptographic Algorithms for POWER system

3.3.2. Ubuntu 16.04 LTS 64-bit Running on Intel® Xeon® Processor

On the platform that runs Intel Xeon processor, the module supports the use of AES-NI, SSSE3 and strict assembler for AES implementation, the use of AVX2, SSSE3 and strict assembler for SHA implementation, and the use of CLMUL instruction set and strict assembler for GHASH that is used for GCM mode. Each implementation is determined by the environment variable `OPENSSL_ia32cap`.

The following table shows the CAVS certificates and their associated information of the cryptographic implementation in FIPS mode.

CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Using the support from AES-NI					
#4359	AES	[FIPS197], [SP800-38A]	ECB, CBC, OFB, CFB1, CFB8, CFB128, CTR	128, 192, 256	Data Encryption and Decryption

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
		[SP800-38B]	CMAC	128, 192, 256	MAC Generation and Verification
		[SP800-38C]	CCM	128, 192, 256	Data Encryption and Decryption
		[SP800-38E]	XTS	128, 256	Data Encryption and Decryption for Data Storage
Using the support from AES-NI and CLMUL: #4370	AES	[SP800-38D]	GCM	128, 192, 256	Data Encryption and Decryption
Using the support from AES-NI and strict GHASH assembler: #4371	AES	[SP800-38D]	GCM	128, 192, 256	Data Encryption and Decryption
Using the strict AES assembler					
#4360	AES	[FIPS197], [SP800-38A]	ECB, CBC, OFB, CFB1, CFB8, CFB128, CTR	128, 192, 256	Data Encryption and Decryption
		[SP800-38B]	CMAC	128, 192, 256	MAC Generation and Verification
		[SP800-38C]	CCM	128, 192, 256	Data Encryption and Decryption
		[SP800-38E]	XTS	128, 256	Data Encryption and Decryption for Data Storage
		[SP800-38F]	KW	128, 192, 256	Key Wrapping and Unwrapping
Using strict AES assembler and the support from CLMUL: #4372	AES	[SP800-38D]	GCM	128, 192, 256	Data Encryption and Decryption

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Using strict AES and GHASH assembler: #4373	AES	[SP800-38D]	GCM	128, 192, 256	Data Encryption and Decryption
Using the support from SSSE3 for Bit Slice AES/Constant Time assembler					
#4361	AES	[FIPS197], [SP800-38A]	ECB, CBC, OFB, CFB1, CFB8, CFB128, CTR	128, 192, 256	Data Encryption and Decryption
		[SP800-38B]	CMAC	128, 192, 256	MAC Generation and Verification
		[SP800-38C]	CCM	128, 192, 256	Data Encryption and Decryption
		[SP800-38E]	XTS	128, 256	Data Encryption and Decryption for Data Storage
Using the support from SSSE3 for Bit Slice AES and CLMUL: #4374	AES	[SP800-38D]	GCM	128, 192, 256	Data Encryption and Decryption
Using the support from SSSE3 for Bit Slice AES and strict GHASH assembler: #4375	AES	[SP800-38D]	GCM	128, 192, 256	Data Encryption and Decryption

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Other algorithms					
Using the support from AVX2: CVL #1065 Using the support from SSSE3: CVL #1067 Strict SHA assembler: CVL #1069	ECC CDH Primitive	[SP800-56A] Section 5.7.1.2	n/a	P-224, P-256, P-384, P-521 K-233, K-283, K-409, K-571 B-233, B-283, B-409, B-571	EC Diffie-Hellman Key Agreement
Using the support from AVX2: CVL #1065 Using the support from SSSE3: CVL #1068 Strict SHA assembler: CVL #1069	Partial EC Diffie-Hellman	[SP800-56A]	ECC Ephemeral Unified scheme	P-224, P-256, P-384, P-521	EC Diffie-Hellman Key Agreement
Using the support from AVX2: CVL #1065 Using the support from SSSE3: CVL #1067 Strict SHA assembler: CVL #1069	Partial Diffie-Hellman	[SP800-56A]	FCC dhEphem scheme	p=2048, q=224; p=2048, q=256	Diffie-Hellman Key Agreement

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Using the support from AVX2: CVL #1066 Using the support from SSSE3: CVL #1068 Strict SHA assembler: CVL #1070	TLS v1.0, v1.1 and v1.2 KDF	[SP800-135rev1]	n/a	n/a	Key Derivation
Using the support from AVX2: #1160 Using the support from SSSE3: #1161 Strict SHA assembler: #1162	DSA	[FIPS186-4]	SHA-1[2], SHA-224, SHA-256, SHA-384, SHA-512	L=1024, N=160[3]; L=2048, N=224; L=2048, N=256; L=3072, N=256	Key Pair Generation, Domain Parameter Generation and Verification, and Digital Signature Generation and Verification
Using the support from AVX2: #1395 Using the support from SSSE3[9]: #1396 Strict SHA assembler: #1397	DRBG	[SP800-90A]	**Hash_DRBG:** SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 without PR **HMAC_DRBG:** SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 without PR	n/a	Deterministic Random Bit Generation

[9] The module only supports SHA-1, SHA-224 and SHA-256 when it uses the support of SSSE3.

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Strict AES assembler: #1394			**CTR_DRBG:** AES-128, AES-192, AES-256 with/without DF, without PR		
Using the support from AVX2: #1035 Using the support from SSSE3[9]: #1036 Strict SHA assembler: #1037	ECDSA	[FIPS186-4]	SHA-1[4], SHA-224, SHA-256, SHA-384, SHA-512	P-192[5], P-224, P-256, P-384, P-521, K-163[5], K-233, K-283, K-409, K-571, B-163[5], B-233, B-283, B-409, B-571	Key Pair Generation, Public Key Verification, Digital Signature Generation and Verification
Using the support from AVX2: #2899 Using the support from SSSE3[9]: #2900 Strict SHA assembler: #2901	HMAC	[FIPS198-1]	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512	112 or greater	Message authentication code
Using the support from AVX2: #2355 Using the support from SSSE3[9]: #2356 Strict SHA	RSA	[FIPS186-4]	**X9.31** SHA-1[6], SHA-256, SHA-384, SHA-512 **PKCS#1v1.5** SHA-1[6], SHA-224, SHA-256, SHA-384, SHA-512	1024[7], 2048, 3072, 4096[8]	Key Pair Generation, Digital Signature Generation and Verification

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
assembler: #2357			**PSS** SHA-1[6], SHA-224, SHA-256, SHA-384, SHA-512		
Using the support from AVX2: #3597 Using the support from SSSE3[9]: #3598 Strict SHA assembler: #3599	SHS	[FIPS180-4]	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512	n/a	Message Digest
#2357	Triple-DES	[SP800-67], [SP800-38A]	ECB, CBC, CFB1, CFB8, CFB64, OFB	192	Data Encryption and Decryption
		[SP800-67], [SP800-38B]	CMAC	192	MAC Generation and Verification

Table 8 – Cryptographic Algorithms for Intel® Xeon® Processor

3.3.3. Ubuntu 16.04 LTS 64-bit Running on z System

On the platform that runs z system, the module supports the use of CPACF or strict assembler for AES, SHA and GHASH implementations. If the CPACF is available in the operational environment, the module uses the support from the CPACF automatically; if CPACF is unavailable in the operational environment, the module uses the strict assembler implemented in the module.

The following table shows the CAVS certificates and their associated information of the cryptographic implementation in FIPS mode.

CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Strict AES assembler: #4357	AES	[FIPS197], [SP800-38A]	ECB, CBC, OFB, CFB1, CFB8, CFB128, CTR	128, 192, 256	Data Encryption and Decryption

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Using the support from CPACF: #4358		[SP800-38B]	CMAC	128, 192, 256	MAC Generation and Verification
		[SP800-38C]	CCM	128, 192, 256	Data Encryption and Decryption
		[SP800-38D]	GCM	128, 192, 256	Data Encryption and Decryption
		[SP800-38E]	XTS	128, 256	Data Encryption and Decryption for Data Storage
		[SP800-38F]	KW	128, 192, 256	Key Wrapping and Unwrapping
Strict SHA assembler: CVL #1060 Using the support from CPACF: CVL #1063	ECC CDH Primitive	[SP800-56A] Section 5.7.1.2	n/a	P-224, P-256, P-384, P-521 K-233, K-283, K-409, K-571 B-233, B-283, B-409, B-571	EC Diffie-Hellman Key Agreement
Strict SHA assembler: CVL #1059 Using the support from CPACF: CVL #1063	Partial EC Diffie-Hellman	[SP800-56A]	ECC Ephemeral Unified scheme	P-224, P-256, P-384, P-521	EC Diffie-Hellman Key Agreement
Strict SHA assembler: CVL #1059 Using the support from CPACF: CVL #1062	Partial Diffie-Hellman	[SP800-56A]	FCC dhEphem scheme	p=2048, q=224; p=2048, q=256	Diffie-Hellman Key Agreement

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Strict SHA assembler: CVL #1061 Using the support from CPACF: CVL #1064	TLS v1.0, v1.1 and v1.2 KDF	[SP800-135rev1]	n/a	n/a	Key Derivation
Strict SHA assembler: #1158 Using the support from CPACF: #1159	DSA	[FIPS186-4]	SHA-1[2], SHA-224, SHA-256, SHA-384, SHA-512	L=1024, N=160[3]; L=2048, N=224; L=2048, N=256; L=3072, N=256	Key Pair Generation, Domain Parameter Generation and Verification, and Digital Signature Generation and Verification
Strict SHA assembler: #1392 Using the support from CPACF: #1393	DRBG	[SP800-90A]	**Hash_DRBG:** SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 without PR	n/a	Deterministic Random Bit Generation
			HMAC_DRBG: SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 without PR		
Strict AES assembler: #1392 Using the support from CPACF: #1393			**CTR_DRBG:** AES-128, AES-192, AES-256 with/without DF, without PR		

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
Strict SHA assembler: #1033 Using the support from CPACF: #1034	ECDSA	[FIPS186-4]	SHA-1[4], SHA-224, SHA-256, SHA-384, SHA-512	P-192[5], P-224, P-256, P-384, P-521, K-163[5], K-233, K-283, K-409, K-571, B-163[5], B-233, B-283, B-409, B-571	Key Pair Generation, Public Key Verification, Digital Signature Generation and Verification
Strict SHA assembler: #2897 Using the support from CPACF: #2898	HMAC	[FIPS198-1]	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512	112 or greater	Message authentication code
Strict SHA assembler: #2353 Using the support from CPACF: #2354	RSA	[FIPS186-4]	**X9.31** SHA-1[6], SHA-256, SHA-384, SHA-512 **PKCS#1v1.5** SHA-1[6], SHA-224, SHA-256, SHA-384, SHA-512 **PSS** SHA-1[6], SHA-224, SHA-256, SHA-384, SHA-512	1024[7], 2048, 3072, 4096[8]	Key Pair Generation, Digital Signature Generation and Verification
Strict SHA assembler: #3595 Using the support from CPACF: #3596	SHS	[FIPS180-4]	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512	n/a	Message Digest

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CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
#2356	Triple-DES	[SP800-67], [SP800-38A]	ECB, CBC, CFB1, CFB8, CFB64, OFB	192	Data Encryption and Decryption
		[SP800-67], [SP800-38B]	CMAC	192	MAC Generation and Verification

Table 9 – Cryptographic Algorithms for z system

The CPACF provided by the IBM z system contains the completed AES and SHA implementations. The following table shows the CAVS certificates and their associated information of the AES and SHA implementation tested directly from the CPACF:

CAVP Cert	Algorithm	Standard	Mode / Method	Key Lengths, Curves or Moduli (in bits)	Use
#3958	AES	[FIPS197], [SP800-38A]	ECB, CBC, CTR	128, 192, 256	Data Encryption and Decryption
#3196	SHS	[FIPS180-4]	SHA-1, SHA-224, SHA-256, SHA-384, SHA-512	n/a	Message Digest

Table 10 – Cryptographic Algorithms from CPACF

3.3.4. Non-Approved Algorithms

The following table describes the non-Approved but allowed algorithms in FIPS mode:

Algorithm	Caveat	Use
RSA Key Encapsulation with Encryption and Decryption Primitives and at least 2048 bits key size	Provides between 112 and 256 bits of encryption strength.	Key Establishment; allowed in [FIPS140-2_IG] D.9
Diffie-Hellman with at least 2048 bit key size (CVL certs #1053, #1056, #1059, #1062, #1065, #1067, #1069)	Provides between 112 and 256 bits of encryption strength.	Key Agreement; allowed in [FIPS140-2_IG] D.8

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Algorithm	Caveat	Use
EC Diffie-Hellman with P-224, P-256, P-384, P-521 curves (CVL certs #1053, #1054, #1056, #1057, #1059, #1060, #1063, #1065, #1067, #1068, #1069)	Provides between 112 and 256 bits of encryption strength.	Key Agreement; allowed in [FIPS140-2_IG] D.8
RSA Key Generation and Digital Signature Verification with at least 3072 bit key size, and Digital Signature Generation with at least 4096 bits key size	n/a	Digital Signature; allowed in [SP800-131A]
DSA Key Generation, Domain Parameter Generation and Verification, Digital Signature Generation and Verification with at least 3072 bits key size	n/a	Digital Signature; allowed in [SP800-131A]
MD5[10]	n/a	Pseudo-random function (PRF) in TLS v1.0 and v1.1; allowed in [SP800-52]
SHA-1 used in the Digital Signature Generation[11]	n/a	Digital Signature Generation in TLS; allowed in [SP800-52]
NDRNG	n/a	The module obtains the entropy data from NDRNG to seed the DRBG.

Table 11 – FIPS-Allowed Cryptographic Algorithms

The table below shows the non-Approved cryptographic algorithms implemented in the module that are only available in non-FIPS mode.

Algorithm	Use
RSA with key size greater than 1024 bits but smaller than 2048 bits	Key Pair Generation, Digital Signature Generation, Key Encapsulation
DSA with key size greater than 1024 bits but smaller than 2048 bits	Key Pair Generation, Domain Parameters Generation, Digital Signature Generation
Diffie-Hellman with key size greater than 1024 bits but smaller than 2048 bits	Key Agreement

[10] According [SP800-52], MD5 is allowed to be used in TLS versions 1.0 and 1.1 as the hash function used in the PRF, as defined in [RFC2246] and [RFC4346].

[11] According [SP800-52], SHA-1 is disallowed for Key Pair Generation and Digital Signature Generation, with the exception of digital signatures on ephemeral parameters in TLS.

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MD5	Message Digest
HMAC with less than 112 bits key	Message Authentication Code
2-key Triple-DES	Data Encryption / Decryption
AES from multi-buffer AES-NI	Authenticated Encryption cipher for Data Encryption and Decryption
AES from AESNI-CBC+SHA-1 "stitch" implementation	Authenticated Encryption cipher for Data Encryption and Decryption
AES from AESNI-CBC+SHA-256 "stitch" implementation	Authenticated Encryption cipher for Data Encryption and Decryption
SHA-1 from AESNI-CBC+SHA-1 "stitch" implementation	Authenticated Encryption cipher for Data Encryption and Decryption
SHA-256 from AESNI-CBC+SHA-256 "stitch" implementation	Authenticated Encryption cipher for Data Encryption and Decryption
SHA-1 from multi-buffer SHA-1	Authenticated Encryption cipher for Data Encryption and Decryption
SHA-256 from multi-buffer SHA-256	Authenticated Encryption cipher for Data Encryption and Decryption
SHA-512 from multi-buffer SHA-512	Authenticated Encryption cipher for Data Encryption and Decryption
ANSI X9.31 RSA Key Generation	Key Pair Generation
SSLeay Deterministic Random Number Generator (PRNG)	Random Number Generation

Table 12 - Non-Approved Cryptographic Algorithms

3.4. Operator Authentication

The module does not implement user authentication. The role of the user is implicitly assumed based on the service requested.

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4. Physical Security

The module is comprised of software only and therefore this security policy does not make any claims on physical security.

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5. Operational Environment

5.1. Applicability

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 Table 3 - Tested Platforms.

5.2. Policy

The operating system is restricted to a single operator; concurrent operators are explicitly excluded.

The application that requests cryptographic services is the single user of the module.

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6. Cryptographic Key Management

The following table summarizes the Critical Security Parameters (CSPs) that are used by the cryptographic services implemented in the module:

Name	Generation	Entry and Output	Zeroization
AES keys	Not Applicable. The key material may be generated by the SP800-90A DRBG, or generated during the Diffie-Hellman or EC Diffie-Hellman key agreement.	The key is passed into the module via API input parameters in plaintext.	`EVP_CIPHER_CTX_cleanup()`
Triple-DES keys			`EVP_CIPHER_CTX_cleanup()`
HMAC key			`HMAC_CTX_cleanup()`
RSA public-private keys	The public-private keys are generated using FIPS 86-4 Key Generation method, and the random value used in the key generation is generated using SP800-90A DRBG.	The key is passed into the module via API input parameters in plaintext. The key is passed out of the module via API output parameters in plaintext.	`RSA_free()`
DSA public-private keys			`DSA_free()`
ECDSA public-private keys			`EC_KEY_free()`
Diffie-Hellman domain parameters	The domain parameters used in Diffie-Hellman and the components to generate the public-private keys used in EC Diffie-Hellman is generated using SP800-90A DRBG.	The key is passed into the module via API input parameters in plaintext. The key is passed out of the module via API output parameters in plaintext.	`DH_free()`
EC Diffie-Hellman public-private keys			`EC_KEY_free()`
Shared secret	Generated during the Diffie-Hellman or EC Diffie-Hellman key agreement.	None	`EC_KEY_free()`
Entropy input string	Obtained from NDRNG.	None	`FIPS_drbg_free()`
DRBG internal state (V, C, Key)	During DRBG initialization.	None	`FIPS_drbg_free()`

Table 13 - Life cycle of Critical Security Parameters (CSP)

The following sections describe how CSPs, in particular cryptographic keys, are managed during its life cycle.

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6.1. Random Number Generation

The module employs a Deterministic Random Bit Generator (DRBG) based on [SP800-90A] for the creation of HMAC keys, key components of asymmetric keys, symmetric keys, server and client random numbers for the TLS protocol, and internal CSPs. In addition, the module provides a Random Number Generation service to calling applications.

The DRBG supports the Hash_DRBG, HMAC_DRBG and CTR_DRBG mechanisms. The DRBG is initialized during module initialization; the module loads by default the DRBG using the CTR_DRBG mechanism with AES-256 and derivation function without prediction resistance. A different DRBG mechanism can be chosen through an API function call.

The module uses a Non-Deterministic Random Number Generator (NDRNG), `getrandom()` system call, as the entropy source for seeding the DRBG. The NDRNG 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 NDRNG provides at least 128 bits of entropy to the DRBG during initialization (seed) and reseeding (reseed).

The module performs conditional self-tests on the output of NDRNG to ensure that consecutive random numbers do not repeat, and performs DRBG health tests as defined in section 11.3 of [SP800-90A].

Note: According to Linux man pages [LMAN] `random`(4) and `getrandom`(2), the `getrandom()` system call is prohibited until the Linux kernel has initialized its NDRNG during the kernel boot-up. This blocking behavior is only observed during boot time. When defining systemd units using OpenSSL, the Crypto Officer should ensure that these systemd units do not block the general systemd operation as otherwise the entire boot process may be blocked based on the getrandom blocking behavior.

CAVEAT: The module generates cryptographic keys whose strengths are modified by available entropy.

6.2. Key Generation

For generating HMAC keys and symmetric keys, the module does not provide any dedicated key generation service. However, the Random Number Generation service can be called by the user to obtain random numbers which can be used as key material for symmetric algorithms or HMAC. The key material of HMAC keys and symmetric keys may also be generated during the Diffie-Hellman or EC Diffie-Hellman key agreement.

For generating RSA, DSA and ECDSA keys, the module implements asymmetric key generation services compliant with [FIPS186-4], and using DRBG compliant with [SP800-90A].

6.3. Key Agreement / Key Transport / Key Derivation

The module provides Diffie-Hellman and EC Diffie-Hellman key agreement schemes. These key agreement schemes are also used as part of the TLS protocol key exchange.

The module also provides key wrapping using the AES with KW mode and RSA key encapsulation using private key encryption and public key decryption primitives. RSA key encapsulation is also used as part of the TLS protocol key exchange.

According to Table 2: Comparable strengths in [SP 800-57], the key sizes of AES, RSA, Diffie-Hellman and EC Diffie-Hellman provides the following security strength in FIPS mode of operation:

- AES key wrapping provides between 128 and 256 bits of encryption strength.

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- RSA key encapsulation provides between 112 and 256 bits of encryption strength.
- Diffie-Hellman key agreement provides between 112 and 256 bits of encryption strength.
- EC Diffie-Hellman key agreement provides between 112 and 256 bits of encryption strength.

The module supports key derivation for the TLS protocol. The module implements the pseudo-random functions (PRF) for TLSv1.0/1.1 and TLSv1.2.

Note: As the module supports the size of RSA key pair and Diffie-Hellman domain parameters with 15360 bits or more, the encryption strength 256 bits is claimed for RSA key encapsulations and Diffie-Hellman key agreement.

6.4. Key Entry / Output

The module does not support manual key entry or intermediate key generation key output. The keys are provided to the module via API input parameters in plaintext form and output via API output parameters in plaintext form. This is allowed by [FIPS140-2_IG] IG 7.7, according to the “CM Software to/from App Software via GPC INT Path” entry on the Key Establishment Table.

6.5. Key / CSP Storage

Symmetric keys, HMAC keys, public and private keys are provided to the module by the calling application via API input parameters, and are destroyed by the module when invoking the appropriate API function calls.

The module does not perform persistent storage of keys. The keys and CSPs are stored as plaintext in the RAM. The only exception is the HMAC key used for the Integrity Test, which is stored in the module and relies on the operating system for protection.

6.6. Key / CSP Zeroization

The memory occupied by keys is allocated by regular memory allocation operating system calls. The application is responsible for calling the appropriate zeroization functions provided in the module's API listed in Table 13. Calling the `SSL_free()` and `SSL_clear()` will zeroize the keys and CSPs stored in the TLS protocol internal state and also invoke the module’s API listed in Table 13 automatically to zeroize the keys and CSPs. The zeroization functions overwrite the memory occupied by keys with “zeros” and deallocate the memory with the regular memory deallocation operating system call.

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

The test platforms listed in Table 3 - Tested Platforms have been tested and found to conform to the EMI/EMC requirements specified by 47 Code of Federal Regulations, FCC PART 15, Subpart B, Unintentional Radiators, Digital Devices, Class A (i.e., Business use). These devices are designed to provide reasonable protection against harmful interference when the devices are operated in a commercial environment. They shall be installed and used in accordance with the instruction manual.

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8. Self-Tests

FIPS 140-2 requires that the module perform power-up tests to ensure the integrity of the module and the correctness of the cryptographic functionality at start up. In addition, some functions require continuous testing of the cryptographic functionality, such as the asymmetric key generation. If any self-test fails, the module returns an error code and enters the error state. No data output or cryptographic operations are allowed in error state.

See section 9.2.7 for descriptions of possible self-test errors and recovery procedures.

8.1. Power-Up Tests

The module performs power-up tests when the module is loaded into memory, without operator intervention. Power-up tests ensure that the module is not corrupted and that the cryptographic algorithms work as expected.

While the module is executing the power-up tests, services are not available, and input and output are inhibited. The module is not available for use by the calling application until the power-up tests are completed successfully.

If any power-up test fails, the module returns the error code listed in Table 17 – Error Events, Error Codes and Error Messages and displays the specific error message associated with the returned error code, and then enters error state. The subsequent calls to the module will also fail - thus no further cryptographic operations are possible. If the power-up tests complete successfully, the module will return 1 in the return code and will accept cryptographic operation service requests.

8.1.1. Integrity Tests

The integrity of the module is verified by comparing an HMAC-SHA-256 value calculated at run time with the HMAC value stored in the .hmac file that was computed at build time for each software component of the module. If the HMAC values do not match, the test fails and the module enters the error state.

8.1.2. Cryptographic Algorithm Tests

The module performs self-tests on all FIPS-Approved cryptographic algorithms supported in the Approved mode of operation, using the Known Answer Tests (KAT) and Pair-wise Consistency Tests (PCT) shown in the following table:

Algorithm	Power-Up Tests
AES	• KAT AES ECB mode with 128-bit key, encryption • KAT AES ECB mode with 128-bit key, decryption
Triple DES	• KAT 3-key Triple-DES ECB mode, encryption • KAT 3-key Triple-DES ECB mode, decryption
SHS	• KAT SHA-1 and SHA-512 • KAT SHA-224 and SHA-384 are not required per IG 9.4 • KAT SHA-256 is covered in the Integrity Test which is allowed with IG 9.3

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Algorithm	Power-Up Tests
HMAC	• KAT HMAC is covered in the Integrity Test which is allowed with IG 9.3 and 9.4
DSA	• PCT DSA with L=2048, N=256 and SHA-256
ECDSA	• PCT ECDSA with P-256 and SHA-256 • PCT ECDSA with K-233 and SHA-256
RSA	• KAT RSA with 2048-bit key, PKCS#1 v1.5 scheme and SHA-256, signature generation • KAT RSA with 2048-bit key, PKCS#1 v1.5 scheme and SHA-256, signature verification
DRBG	• KAT Hash_DRBG without PR • KAT HMAC_DRBG without PR • KAT CTR_DRBG without PR, with DF • KAT CTR_DRBG without PR, without DF
EC Diffie-Hellman	• Primitive “Z” Computation KAT with P-256 curve
Diffie-Hellman	• Primitive “Z” Computation KAT with 2048-bit key
TLS KDF	• KAT KDF for TLSv1.0 and v1.1 • KAT KDF for TLSv1.2

Table 14- Self-Tests

For the KAT, the module calculates the result and compares it with the known value. If the answer does not match the known answer, the KAT is failed and the module enters the Error state.

For the PCT, if the signature generation or verification fails, the module enters the Error state. As described in section 3.3, only one AES or SHA implementation is available at run-time.

The KATs cover the different cryptographic implementations available in the operating environment.

8.2. On-Demand Self-Tests

On-Demand self-tests can be invoked by powering-off and reloading the module which cause the module to run the power-up tests again. During the execution of the on-demand self-tests, services are not available and no data output or input is possible.

8.3. Conditional Tests

The module performs conditional tests on the cryptographic algorithms, using the Pair-wise Consistency Tests (PCT) and Continuous Random Number Generator Test (CRNGT), shown in the following table:

Algorithm	Conditional Test
DSA key generation	• PCT using SHA-256, signature generation and verification.

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Algorithm	Conditional Test
ECDSA key generation	• PCT using SHA-256, signature generation and verification.
RSA key generation	• PCT using SHA-256, signature generation and verification. • PCT for encryption and decryption.
DRBG	• CRNGT is not required per IG 9.8
NDRNG	• CRNGT

Table 15 - Conditional Tests

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9. Guidance

9.1. Crypto Officer Guidance

The binaries of the module are contained in the Debian packages for delivery. The Crypto Officer shall follow this Security Policy to configure the operational environment and install the module to be operated as a FIPS 140-2 validated module.

The following Debian packages contain the FIPS validated module:

Processor Architecture	Debian packages
x86_64	libssl1.0.0_1.0.2g-1ubuntu4.fips.4.6.3_amd64.deb libssl1.0.0-hmac_1.0.2g-1ubuntu4.fips.4.6.3_amd64.deb
Power system	libssl1.0.0_1.0.2g-1ubuntu4.fips.4.6.3_ppc64el.deb libssl1.0.0-hmac_1.0.2g-1ubuntu4.fips.4.6.3_ppc64el.deb
z System	libssl1.0.0_1.0.2g-1ubuntu4.fips.4.6.3_s390x.deb libssl1.0.0-hmac_1.0.2g-1ubuntu4.fips.4.6.3_s390x.deb

Table 16 – Debian packages

The `libssl-doc_1.0.2g-1ubuntu4.fips.4.6.3_all.deb` Debian package contains the man pages for the module.

Note: The prelink is not installed on Ubuntu, by default. For proper operation of the in-module integrity verification, the prelink should be disabled.

9.1.1. Operating Environment Configurations

To configure the operating environment to support FIPS, the following shall be performed with the root privilege:

(1) Install the `linux-fips` Debian package.

(2) Install the `fips-initramfs` Debian package. (Optional)

(3) For x86_64 and Power systems, create the file `/etc/default/grub.d/99-fips.cfg` with the content: `GRUB_CMDLINE_LINUX_DEFAULT="$GRUB_CMDLINE_LINUX_DEFAULT fips=1"`. For z system, edit `/etc/zipl.conf` file and append the "`fips=1`" in the parameters line for the specified boot image.

(4) If /boot resides on a separate partition, the kernel parameter `bootdev=UUID=<UUID of partition>` must also be appended in the aforementioned grub or zipl.conf file. Please see the following **Note** for more details.

(5) Execute `update-grub` or `zipl` for z system to update the boot loader.

(6) Execute `reboot` to reboot the system with the new settings.

Now, the operating environment is configured to support FIPS operation. The Crypto Officer should check the existence of the file, `/proc/sys/crypto/fips_enabled`, and that it contains "1". If the file

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does not exist or does not contain “1”, the operating environment is not configured to support FIPS and the module will not operate as a FIPS validated module properly.

Note: If /boot resides on a separate partition, the kernel parameter `bootdev=UUID=<UUID of partition>` must be supplied. The partition can be identified with the command `df /boot`. For example:

```
$ df /boot
Filesystem     1K-blocks   Used Available Use% Mounted on
/dev/sdb2         241965 127948    101525  56% /boot
```

The UUID of the /boot partition can be found by using the command `grep /boot /etc/fstab.` For example:

```
$ grep /boot /etc/fstab
# /boot was on /dev/sdb2 during installation
UUID=cec0abe7-14a6-4e72-83ba-b912468bbb38 /boot    ext2    defaults     0     2
```

Then, the UUID shall be added in the `/etc/default/grub`. For example:

```
GRUB_CMDLINE_LINUX_DEFAULT="quiet bootdev=UUID=cec0abe7-14a6-4e72-83ba-b912468bbb38
fips=1"
```

9.1.2. Module Installation

Once the operating environment configuration is finished, the Crypto Officer can install the Debian packages containing the module listed in Table 16 using normal packaging tool such as Advanced Package Tool (APT). All the Debian packages are associated with hashes for integrity check. The integrity of the Debian package is automatically verified by the packing tool during the installation of the module. The Crypto Officer shall not install the Debian package if the integrity of the Debian package fails.

To download the FIPS validated version of the module, please contact the Canonical representative for the repository path.

Once the module is installed successfully, a subsequent manual install/upgrade of the Debian packages (i.e., `sudo apt install libssl1.0.0 libssl1.0.0-hmac`) is prohibited. It could upgrade the FIPS validated module to latest non-FIPS validated OpenSSL libraries, and this cannot be prevented by "holding" the Debian packages.

Note: During a system update, the installed FIPS validated module could get updated to a later non-FIPS validated OpenSSL libraries. It is recommended to put a "hold" on the module's Debian packages (i.e., `libssl1.0.0` and `libssl1.0.0-hmac`) to exclude the FIPS validated module from automatic system updating/upgrading. The FIPS validated module will remain installed on the system after system update.

To hold the Debian package of the module,

```
$ sudo apt-mark hold libssl1.0.0 libssl1.0.0-hmac
```

To unhold the Debian packages of the module,

```
$ sudo apt-mark unhold libssl1.0.0 libssl1.0.0-hmac
```

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9.2. User Guidance

In order to run in FIPS mode, the module must be operated using the FIPS Approved services, with their corresponding FIPS Approved and FIPS allowed cryptographic algorithms provided in this Security Policy (see section 3.2 Services). In addition, key sizes must comply with [SP800-131A].

9.2.1. TLS

The TLS protocol implementation provides both server and client sides. In order to operate in FIPS mode, digital certificates used for server and client authentication shall comply with the restrictions of key size and message digest algorithms imposed by [SP800-131A]. In addition, as required also by [SP800-131A], Diffie-Hellman with keys smaller than 2048 bits must not be used.

The TLS protocol lacks the support to negotiate the used Diffie-Hellman key sizes. To ensure full support for all TLS protocol versions, the TLS client implementation of the module accepts Diffie-Hellman key sizes smaller than 2048 bits offered by the TLS server.

The TLS server implementation 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)`.

For complying with the requirement to not allow Diffie-Hellman key sizes smaller than 2048 bits, the Crypto Officer must ensure that:

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

9.2.2. AES GCM IV

In case the module's power is lost and then restored, the key used for the AES GCM encryption or decryption shall be redistributed.

The AES GCM IV generation is in compliance with the [RFC5288] and shall only be used for the TLS protocol version 1.2 to be compliant with [FIPS140-2_IG] IG A.5, provision 1 ("TLS protocol IV generation"); thus, the module is compliant with [SP800-52].

9.2.3. AES XTS

The AES algorithm in XTS mode can be only used for the cryptographic protection of data on storage devices, as specified in [SP800-38E]. The length of a single data unit encrypted with the XTS-AES shall not exceed 2^{20} AES blocks that is 16MB of data. To meet the requirement in [FIPS140-2_IG] A.9, the module implements a check to ensure that the two AES keys used in XTS-AES algorithm are not identical.

9.2.4. Random Number Generator

The `RAND_cleanup()` API function must not be used. This call will clean up the internal DRBG state. This call also replaces the DRBG instance with the non-FIPS Approved SSLeay Deterministic Random Number Generator when using the `RAND_*` API calls.

9.2.5. API Functions

Passing "0" to the `FIPS_mode_set()` API function is prohibited.

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Executing the `CRYPTO_set_mem_functions()` API function is prohibited as it performs like a null operation in the module.

9.2.6. Environment Variables

OPENSSL_ENFORCE_MODULUS_BITS

As described in [SP800-131A], less than 2048 bits of DSA and RSA key sizes are disallowed by NIST. Setting the environment variable `OPENSSL_ENFORCE_MODULUS_BITS` can restrict the module to only generate the acceptable key sizes of RSA and DSA. If the environment variable is set, the module can generate 2048 or 3072 bits of RSA key, and at least 2048 bits of DSA key.

OPENSSL_FIPS_NON_APPROVED_MD5_ALLOW

As described in [SP800-52], MD5 is allowed to be used in TLS versions 1.0 and 1.1 as the hash function used in the PRF, as defined in [RFC2246] and [RFC4346]. By default, the module disables the MD5 algorithm. Setting the environment variable `OPENSSL_FIPS_NON_APPROVED_MD5_ALLOW` can enable the MD5 algorithm in the module. The MD5 algorithm shall not be used for other purposes other than the PRF in TLS version 1.0 and 1.1.

9.2.7. Handling FIPS Related Errors

When the module fails any self-test, the module will return an error code to indicate the error and enters error state that any further cryptographic operation is inhibited. Errors occurred during the self-tests and conditional tests transition the module into an error state. Here is the list of error codes when the module fails any self-test, in error state or not supported in FIPS mode:

Error Events	Error Codes/Messages
When the Integrity Test fails at the power-up	FIPS_R_FINGERPRINT_DOES_NOT_MATCH (111) “fingerprint does not match”
When the AES, TDES, SHA-1, SHA-512 KAT fails at the power-up	FIPS_R_SELFTEST_FAILED (134) “selftest failed”
When the KAT for RSA fails, or the PCT for ECDSA or DSA fails at the power-up	FIPS_R_TEST_FAILURE (137) “test failure”
When the KAT of DRBG fails at the power-up	FIPS_R_NOPR_TEST1_FAILURE (145) “nopr test1 failure”
When the KAT of Diffie-Hellman or EC Diffie-Hellman fails at the power-up	0
When the new generated RSA, DSA or ECDSA key pair fails the PCT	FIPS_R_PAIRWISE_TEST_FAILED (127) “pairwise test failed”
When the CRNGT fails the output of the NDRNG	FIPS_R_ENTROPY_SOURCE_STUCK (142) “entropy source stuck”
When the SSLv2.0 or SSL v3.0 are called	SSL_R_ONLY_TLS_ALLOWED_IN_FIPS_MODE (297) “only tls allowed in fips mode”

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When the module is in error state and any cryptographic operation is called	FIPS_R_FIPS_SELFTEST_FAILED (115) "fips selftest failed"
	FIPS_R_SELFTEST_FAILED (134) "selftest failed"
When the AES key and tweak keys for XTS-AES are the same	FIPS_R_AES_XTS_WEAK_KEY (201) "identical keys are weak"

Table 17 – Error Events, Error Codes and Error Messages

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

When the module is in the error state and the application calls a crypto function of the module that cannot return an error in normal circumstances (void return functions), the error message: "`OpenSSL internal error, assertion failed: FATAL FIPS SELFTEST FAILURE`" is printed to `stderr` and the application is terminated with the `abort()` call. The only way to recover from this error is to restart the application. If the failure persists, the module must be reinstalled.

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10. Mitigation of Other Attacks

10.1. Blinding Against RSA Timing Attacks

RSA is vulnerable to timing attacks. In a configuration 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 module provides the API functions `RSA_blinding_on()` and `RSA_blinding_off()` to turn the blinding on and off for RSA. When the blinding is on, the module generates a random value to form a blinding factor in the RSA key before the RSA key is used in the RSA cryptographic operations.

Please note that the DRBG must be seeded prior to calling `RSA_blinding_on()` to prevent the RSA Timing Attack.

10.2. Weak Triple-DES Keys Detection

The module implements the `DES_set_key_checked()` for checking the weak Triple-DES key and the correctness of the parity bits when the Triple-DES key is going to be used in Triple-DES operations. The checking of the weak Triple-DES key is implemented in the API function `DES_is_weak_key()` and the checking of the parity bits is implemented in the API function `DES_check_key_parity()`. If the Triple-DES key does not pass the check, the module will return -1 to indicate the parity check error and -2 if the Triple-DES key matches to any value listed below:

```
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}
};
```

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Appendix A. TLS Cipher Suites

The module supports the following cipher suites for the TLS protocol. Each cipher suite defines the key exchange algorithm, the bulk encryption algorithm (including the symmetric key size) and the MAC algorithm.

Cipher Suite	Reference
TLS_RSA_WITH_3DES_EDE_CBC_SHA	RFC2246
TLS_DH_DSS_WITH_3DES_EDE_CBC_SHA	RFC2246
TLS_DH_RSA_WITH_3DES_EDE_CBC_SHA	RFC2246
TLS_DHE_DSS_WITH_3DES_EDE_CBC_SHA	RFC2246
TLS_DHE_RSA_WITH_3DES_EDE_CBC_SHA	RFC2246
TLS_DH_anon_WITH_3DES_EDE_CBC_SHA	RFC2246
TLS_RSA_WITH_AES_128_CBC_SHA	RFC3268
TLS_DH_DSS_WITH_AES_128_CBC_SHA	RFC3268
TLS_DH_RSA_WITH_AES_128_CBC_SHA	RFC3268
TLS_DHE_DSS_WITH_AES_128_CBC_SHA	RFC3268
TLS_DHE_RSA_WITH_AES_128_CBC_SHA	RFC3268
TLS_DH_anon_WITH_AES_128_CBC_SHA	RFC3268
TLS_RSA_WITH_AES_256_CBC_SHA	RFC3268
TLS_DH_DSS_WITH_AES_256_CBC_SHA	RFC3268
TLS_DH_RSA_WITH_AES_256_CBC_SHA	RFC3268
TLS_DHE_DSS_WITH_AES_256_CBC_SHA	RFC3268
TLS_DHE_RSA_WITH_AES_256_CBC_SHA	RFC3268
TLS_DH_anon_WITH_AES_256_CBC_SHA	RFC3268
TLS_RSA_WITH_AES_128_CBC_SHA256	RFC5246
TLS_RSA_WITH_AES_256_CBC_SHA256	RFC5246
TLS_DH_DSS_WITH_AES_128_CBC_SHA256	RFC5246
TLS_DH_RSA_WITH_AES_128_CBC_SHA256	RFC5246
TLS_DHE_DSS_WITH_AES_128_CBC_SHA256	RFC5246
TLS_DHE_RSA_WITH_AES_128_CBC_SHA256	RFC5246
TLS_DH_DSS_WITH_AES_256_CBC_SHA256	RFC5246
TLS_DH_RSA_WITH_AES_256_CBC_SHA256	RFC5246
TLS_DHE_DSS_WITH_AES_256_CBC_SHA256	RFC5246

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Cipher Suite	Reference
TLS_DHE_RSA_WITH_AES_256_CBC_SHA256	RFC5246
TLS_DH_anon_WITH_AES_128_CBC_SHA256	RFC5246
TLS_DH_anon_WITH_AES_256_CBC_SHA256	RFC5246
TLS_PSK_WITH_3DES_EDE_CBC_SHA	RFC4279
TLS_PSK_WITH_AES_128_CBC_SHA	RFC4279
TLS_PSK_WITH_AES_256_CBC_SHA	RFC4279
TLS_RSA_WITH_AES_128_GCM_SHA256	RFC5288
TLS_RSA_WITH_AES_256_GCM_SHA384	RFC5288
TLS_DHE_RSA_WITH_AES_128_GCM_SHA256	RFC5288
TLS_DHE_RSA_WITH_AES_256_GCM_SHA384	RFC5288
TLS_DH_RSA_WITH_AES_128_GCM_SHA256	RFC5288
TLS_DH_RSA_WITH_AES_256_GCM_SHA384	RFC5288
TLS_DHE_DSS_WITH_AES_128_GCM_SHA256	RFC5288
TLS_DHE_DSS_WITH_AES_256_GCM_SHA384	RFC5288
TLS_DH_DSS_WITH_AES_128_GCM_SHA256	RFC5288
TLS_DH_DSS_WITH_AES_256_GCM_SHA384	RFC5288
TLS_DH_anon_WITH_AES_128_GCM_SHA256	RFC5288
TLS_DH_anon_WITH_AES_256_GCM_SHA384	RFC5288
TLS_ECDH_ECDSA_WITH_3DES_EDE_CBC_SHA	RFC4492
TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA	RFC4492
TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA	RFC4492
TLS_ECDHE_ECDSA_WITH_3DES_EDE_CBC_SHA	RFC4492
TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA	RFC4492
TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA	RFC4492
TLS_ECDH_RSA_WITH_3DES_EDE_CBC_SHA	RFC4492
TLS_ECDH_RSA_WITH_AES_128_CBC_SHA	RFC4492
TLS_ECDH_RSA_WITH_AES_256_CBC_SHA	RFC4492
TLS_ECDHE_RSA_WITH_3DES_EDE_CBC_SHA	RFC4492
TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA	RFC4492
TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA	RFC4492
TLS_ECDH_anon_WITH_3DES_EDE_CBC_SHA	RFC4492
TLS_ECDH_anon_WITH_AES_128_CBC_SHA	RFC4492

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Cipher Suite	Reference
TLS_ECDH_anon_WITH_AES_256_CBC_SHA	RFC4492
TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA256	RFC5289
TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA384	RFC5289
TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA256	RFC5289
TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA384	RFC5289
TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA256	RFC5289
TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA384	RFC5289
TLS_ECDH_RSA_WITH_AES_128_CBC_SHA256	RFC5289
TLS_ECDH_RSA_WITH_AES_256_CBC_SHA384	RFC5289
TLS_ECDHE_ECDSA_WITH_AES_128_GCM_SHA256	RFC5289
TLS_ECDHE_ECDSA_WITH_AES_256_GCM_SHA384	RFC5289
TLS_ECDH_ECDSA_WITH_AES_128_GCM_SHA256	RFC5289
TLS_ECDH_ECDSA_WITH_AES_256_GCM_SHA384	RFC5289
TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256	RFC5289
TLS_ECDHE_RSA_WITH_AES_256_GCM_SHA384	RFC5289
TLS_ECDH_RSA_WITH_AES_128_GCM_SHA256	RFC5289
TLS_ECDH_RSA_WITH_AES_256_GCM_SHA384	RFC5289

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Appendix B. Glossary and Abbreviations

AES	Advanced Encryption Standard
AES-NI	Advanced Encryption Standard New Instructions
API	Application Program Interface
APT	Advanced Package Tool
CAVP	Cryptographic Algorithm Validation Program
CAVS	Cryptographic Algorithm Validation System
CBC	Cipher Block Chaining
CCM	Counter with Cipher Block Chaining-Message Authentication Code
CFB	Cipher Feedback
CLMUL	Carry-less Multiplication
CMAC	Cipher-based Message Authentication Code
CMVP	Cryptographic Module Validation Program
CPACF	CP Assist for Cryptographic Function
CRNGT	Continuous Random Number Generator Test
CSP	Critical Security Parameter
CTR	Counter Mode
DES	Data Encryption Standard
DF	Derivation Function
DSA	Digital Signature Algorithm
DTLS	Datagram Transport Layer Security
DRBG	Deterministic Random Bit Generator
ECB	Electronic Code Book
ECC	Elliptic Curve Cryptography
EMI/EMC	Electromagnetic Interference/Electromagnetic Compatibility
FCC	Federal Communications Commission
FFC	Finite Field Cryptography
FIPS	Federal Information Processing Standards Publication
GCM	Galois Counter Mode
GPC	General Purpose Computer
HMAC	Hash Message Authentication Code
IG	Implementation Guidance
KAS	Key Agreement Schema

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KAT	Known Answer Test
KDF	Key Derivation Function
KW	Key Wrap
LPAR	Logical Partitions
MAC	Message Authentication Code
NIST	National Institute of Science and Technology
NDRNG	Non-Deterministic Random Number Generator
OFB	Output Feedback
PAA	Processor Algorithm Acceleration
PAI	Processor Algorithm Implementation
PCT	Pair-wise Consistency Test
PR	Prediction Resistance
PRNG	Pseudo-Random Number Generator
PSS	Probabilistic Signature Scheme
RSA	Rivest, Shamir, Addleman
SHA	Secure Hash Algorithm
SHS	Secure Hash Standard
SSSE3	Supplemental Streaming SIMD Extensions 3
TLS	Transport Layer Security
XTS	XEX-based Tweaked-codebook mode with ciphertext Stealing

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