

JUNIPER OPENSOURCE CRYPTOGRAPHIC MODULE VERSION 1.0

FIPS 140-2 NON-PROPRIETARY SECURITY POLICY VERSION 1.5

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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 Juniper 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 Juniper 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 v1.0 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 Linux 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.

Table 1 - Security Levels

| 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 |

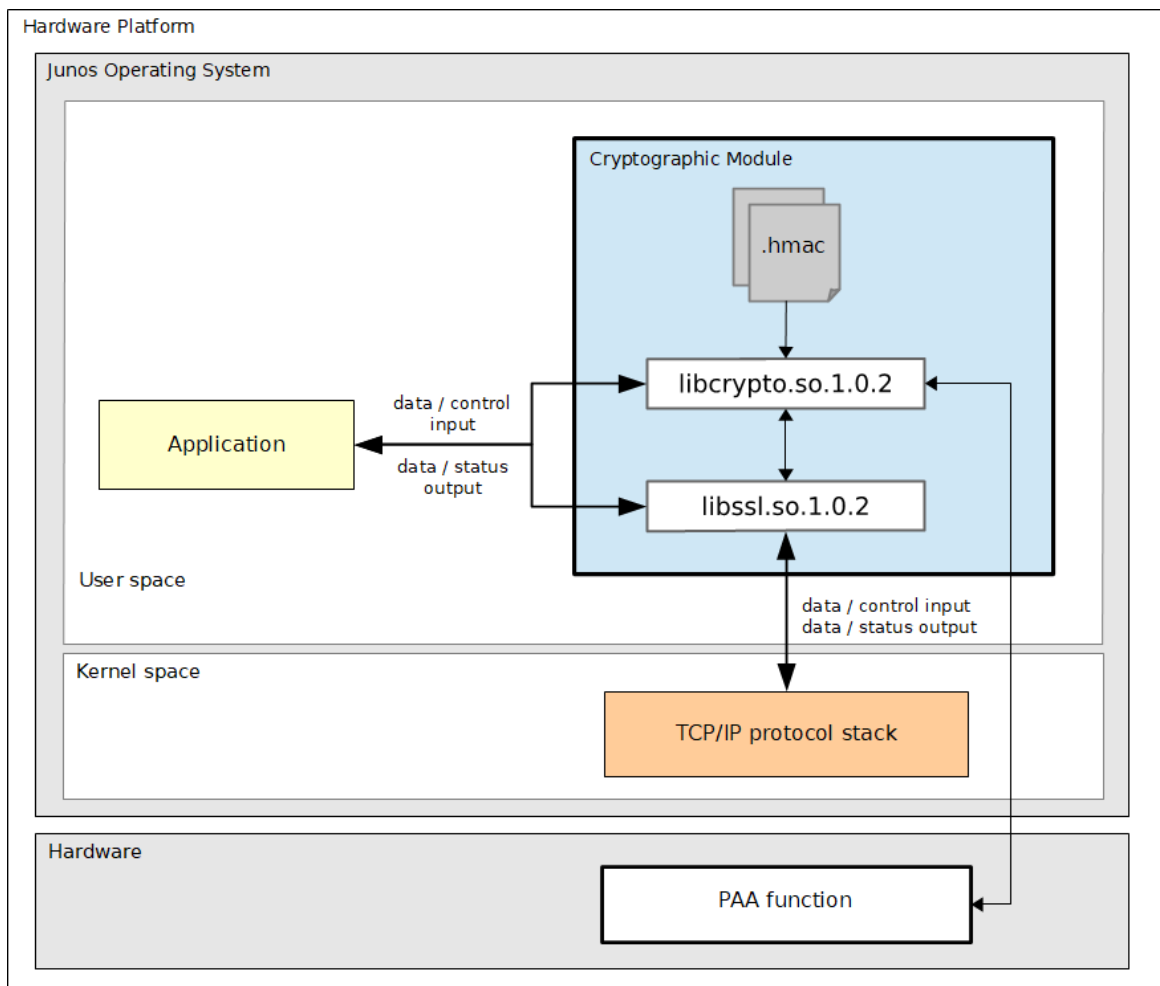
The cryptographic logical boundary consists of all shared libraries and the integrity check files used for Integrity Tests. The following table enumerates the files that comprise the module.

Table 2 - Module Components

| Component | Description |
|--|---|
| <code>/usr/lib64/libssl.so.1.0.2</code> | Shared library for TLS/DTLS network protocols. |
| <code>/usr/lib64/libcrypto.so.1.0.2</code> | Shared library for cryptographic implementations. |
| <code>/usr/lib64/.libssl.so.1.0.2.hmac</code> | Integrity check signature for libssl shared library. |
| <code>/usr/lib64/.libcrypto.so.1.0.2.hmac</code> | Integrity check signature for libcrypto shared library. |

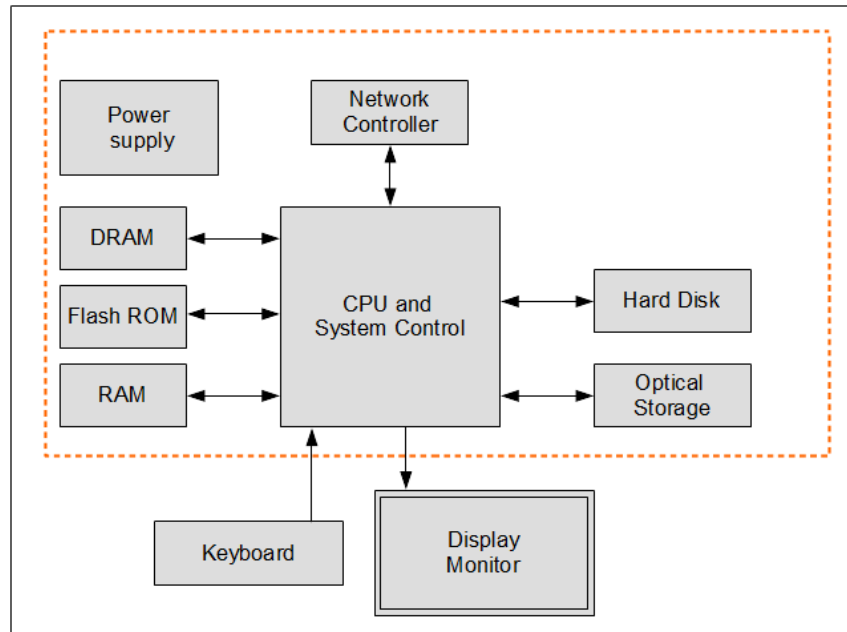
The software block diagram below shows the module, its interfaces with the operational environment and the delimitation of its logical boundary, comprised of all the components within the **BLUE** box.

Figure 1 - Software Block Diagram



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

Figure 2 - Hardware Block Diagram



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

Table 3 - Tested Platforms

| Test Platform | Processor | Test Configuration |
|--|--------------------------|---|
| Juniper Networks® Packet Transport Router Model PTX10003-80C | Intel® Xeon® E5-2628L v4 | Junos OS Evolved version 19.4R2 with and without AES-NI (PAA) |

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.

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.

Table 4 - Ports and Interfaces

| FIPS Interface | Logical Interface |
|----------------------|--|
| Data Input | API input parameters, kernel I/O – network or files on file system, TLS protocol input messages. |
| Data Output | API output parameters, kernel I/O – network or files on file system, TLS protocol output messages. |
| Control Input | API function calls, API input parameters for control. |
| Status Output | API return codes, error messages. |
| Power Input | N/A |

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.

3 Roles, Services and Authentication

3.1 Roles

The module supports the following roles:

- **User role:** performs all services (in both FIPS mode and non-FIPS mode) with the exception of module installation and configuration, and certificate management.
- **Crypto Officer role:** performs module installation and configuration, and certificate 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).

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 (CSPs) and their access rights are listed. The following convention is used to specify access rights to a CSP:

- **Create:** the calling application can create a new CSP.
- **Read:** the calling application can read the CSP.
- **Update:** the calling application can write a new value to the CSP.
- **Zeroize:** the calling application can zeroize the CSP.
- **n/a:** the calling application does not access any CSP or key during its operation.

If the services involve the use of the cryptographic algorithms, the corresponding Cryptographic Algorithm Validation Program (CAVP) certificate numbers of the cryptographic algorithms can be found in Table 7 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.

Table 5 - Services in FIPS mode of operation

| Service | Algorithms | Role | Access | Keys/CSP |
|---|-------------|------|--------|-------------------------------|
| Cryptographic Library Services | | | | |
| Symmetric Encryption and Decryption | AES | User | Read | AES key |
| RSA key generation | RSA, DRBG | User | Create | RSA public and private keys |
| RSA digital signature generation and verification | RSA | User | Read | RSA public and private keys |
| ECDSA key generation | ECDSA, DRBG | User | Create | ECDSA public and private keys |
| ECDSA public key validation | ECDSA | User | Read | ECDSA public key |

| Service | Algorithms | Role | Access | Keys/CSP |
|---|---|----------------|--------------|--------------------------------------|
| ECDSA signature generation and verification | ECDSA | User | Read | ECDSA public and private keys |
| 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 |
| Key wrapping | AES-KW | User | Read | AES key |
| Key Derivation | SSH KDF | User | Read | Shared secret |
| | | | Create | Derived keys |
| Other Services | | | | |
| Show status | n/a | User | n/a | None |
| Zeroization | n/a | User | Zeroize | All CSPs |
| Self-Tests | AES, SHS, HMAC, RSA, ECDSA, DRBG | User | n/a | None |
| Module installation | n/a | Crypto Officer | n/a | None |
| Module configuration | n/a | Crypto Officer | n/a | None |

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

Table 6 - Services in non-FIPS mode of operation

| Service | Algorithms / Key sizes | Role | Access | Keys |
|---|--|------|--------|--------------------------------|
| Symmetric encryption and decryption | Algorithms listed in Table 9 | User | Read | Symmetric key |
| Symmetric decryption | 2-key Triple-DES listed in Table 9 | 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 9 | User | Read | AES key, HMAC key |
| Message digest | Algorithms listed in Table 9 | User | n/a | None |
| Message authentication | HMAC and CMAC | User | Read | HMAC key, 2-key Triple-DES key |

| code (MAC) | restrictions listed in Table 9 | | | |
|---|--|----------------|--------------|---|
| Domain Parameter Generation | DSA | User | Read | N/A |
| Key Pair generation | RSA, ECDSA restrictions listed in Table 9 DSA with any key sizes | User | Create | Asymmetric public and private keys |
| Public Key Validation | ECDSA restrictions listed in Table 9 | User | Read | Asymmetric public and private keys |
| Digital signature generation | RSA, ECDSA restrictions listed in Table 9 DSA with any key sizes | User | Read | Asymmetric public and private keys |
| Digital signature Verification | RSA, ECDSA and message digest restrictions listed in Table 9 DSA with any key sizes | User | Read | Asymmetric public and private keys |
| Key agreement | SRP, J-PAKE | User | Create, Read | Asymmetric public and private keys |
| Key agreement | Diffie-Hellman, EC Diffie-Hellman | User | Create, Read | Diffie-Hellman, EC Diffie-Hellman public and private keys Create Shared secret |
| Shared secret computation | Diffie-Hellman, EC Diffie-Hellman | User | Create, Read | Diffie-Hellman, EC Diffie-Hellman public and private keys Create Shared secret |
| Key encapsulation | RSA | User | Read | RSA public and private keys |
| Key Derivation | TLS KDF | User | Read | Shared secret Create Derived keys |
| Transport Layer Security (TLS) network protocol v1.0, v1.1 and v1.2 | RSA, DSA, ECDSA Diffie-Hellman, EC Diffie-Hellman, AES, Triple-DES, HMAC, TLS KDF | User | Read | RSA, DSA or ECDSA public and/or private keys Create, Read TLS pre_master_secret, TLS master_secret, Diffie Hellman or EC Diffie Hellman public and private keys, AES or Triple-DES key, HMAC key |
| TLS extensions | n/a | User | Read | RSA, DSA or ECDSA public and/or private keys |
| Certificate management | n/a | Crypto Officer | Read | RSA, DSA or ECDSA public and/or private keys |

3.3 Algorithms

The Juniper 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 using a processor capability mask in the operational environment. Please note that only one AES, SHA and/or GHASH implementation can be executed in runtime.

The module supports the use of AES-NI, SSSE3 and strict assembler for AES implementations, the use of AVX2, SSSE3 and strict assembler for SHA implementations, and the use of CLMUL instruction set and strict assembler for GHASH that is used for GCM mode. The module uses the most efficient implementation based on the processor's capability. In the case of the tested environment, only the implementations for AES, SHA-1 and SHA-2 using either AES-NI (PAA) and strict assembler (non PAA) have been CAVP tested. Therefore, these are the only approved functions.

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

Table 7 - Cryptographic Algorithms

| Algorithm | Mode / Method | Key Lengths, Curves or Moduli (in bits) | Use | Standard | CAVP Certs |
|-----------|--|---|---|------------------------|---------------|
| AES | ECB, CBC, OFB, CFB1, CFB8, CFB128, CTR | 128, 192, 256 | Data Encryption and Decryption | [FIPS197], [SP800-38A] | A650 A2017 |
| | CMAC | 128, 192, 256 | MAC Generation and Verification | [SP800-38B] | A650 A2017 |
| | CCM | 128, 192, 256 | Data Encryption and Decryption | [SP800-38C] | A650 A2017 |
| | XTS | 128, 256 | Data Encryption and Decryption for Data Storage | [SP800-38E] | A650 A2017 |
| | KW | 128, 192, 256 | Key Wrapping and Unwrapping | [SP800-38F] | A650 A2017 |
| DRBG | Hash_DRBG: SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 without PR | n/a | Deterministic Random Bit Generation | [SP800-90A] | A650 |
| | HMAC_DRBG: SHA-1, SHA-224, SHA-256, | | | | A650 |

| Algorithm | Mode / Method | Key Lengths, Curves or Moduli (in bits) | Use | Standard | CAVP Certs |
|------------|--|---|---|-------------|--------------|
| | SHA-384, SHA-512 without PR | | | | |
| | CTR_DRBG: AES-128, AES-192, AES-256 with/without DF, without PR | | | | A650 |
| ECDSA | | P-256, P-384, P-521 | Key Pair Generation | [FIPS186-4] | A650 |
| | | P-192, P-224, P-256, P-384, P-521 | Public Key Verification | [FIPS186-4] | A650 |
| | SHA-224, SHA-256, SHA-384, SHA-512 | P-224, P-256, P-384, P-521 | Digital Signature Generation | [FIPS186-4] | A650 |
| | SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 | P-192, P-224, P-256, P-384, P-521 | Digital Signature Verification | [FIPS186-4] | A650 |
| HMAC | SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 | 112 or greater | Message Authentication Code | [FIPS198-1] | A650 |
| SSH v2 KDF | SHA-1, SHA-256, SHA-384, SHA-512 | n/a | Key Derivation in the SSHv2 protocol | [SP800-135] | CVL. A650 |
| RSA | B.3.3 | 2048, 3072, 4096 | Key Pair Generation | [FIPS186-4] | A650 |
| | X9.31 with SHA-256, SHA-384, SHA-512 | 2048, 3072, 4096 | Digital Signature Generation | [FIPS186-4] | A650 |
| | X9.31 with SHA-1, SHA-256, SHA-384, SHA-512 | 1024, 2048, 3072, 4096 | Digital Signature Verification | [FIPS186-4] | A650 |
| | PKCS#1v1.5, PSS with SHA-224, | 2048, 3072, 4096 | Digital Signature Generation | [FIPS186-4] | A650 |

| Algorithm | Mode / Method | Key Lengths, Curves or Moduli (in bits) | Use | Standard | CAVP Certs |
|-----------|--|---|--------------------------------|-------------|---------------|
| | SHA-256, SHA-384, SHA-512 | | | | |
| | PKCS#1v1.5, PSS with SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 | 1024, 2048, 3072, 4096 | Digital Signature Verification | [FIPS186-4] | A650 |
| SHS | SHA-1, SHA-224, SHA-256, SHA-384, SHA-512 | n/a | Message Digest | [FIPS180-4] | A650 A2017 |
| KTS | AES KW | 128, 192, 256 | Key Wrapping and unwrapping | SP800-38F | A650 A2017 |

3.3.1 Allowed Algorithms

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

Table 8 - FIPS-Allowed Cryptographic Algorithms

| Algorithm | Caveat | Use |
|-----------|--------|--|
| NDRNG | n/a | The module obtains the entropy data from NDRNG to seed the DRBG. |

3.3.2 Non-Approved Algorithms

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

Table 9 - Non-Approved Cryptographic Algorithms

| Algorithm | Use |
|---|--------------------------------|
| Blowfish, Camellia, CAST, DES, IDEA, RC2, RC4, RC5 and SEED | Data Encryption and Decryption |
| AES in XTS mode with 192-bit key | Data Encryption and Decryption |
| Triple-DES | Data Encryption and Decryption |
| MD2, MD4, MD5, MDC-2, RMD160, Whirpool | Message Digest |

| Algorithm | Use |
|---|--|
| J-PAKE | Password Authenticated Key Exchange |
| RSA with key size smaller than 2048 bits or greater than 4096 bits | Key Pair Generation, Digital Signature Generation |
| RSA with key size smaller than 1024 bits or greater than 4096 bits | Digital Signature Verification |
| RSA Key Encapsulation with Encryption and Decryption Primitives | Key Establishment; |
| DSA with any key sizes | Key Pair Generation, Domain Parameter Generation, Digital Signature Generation, Digital Signature Verification |
| ECDSA with curve P-192 | Key Pair Generation, Public Key Validation, Digital Signature Generation |
| ECDSA with curve P-224 | Key Pair Generation |
| ECDSA with K and B curves, and non-NIST curves | Key Pair Generation, Public Key Validation, Digital Signature Generation and Verification |
| Diffie-Hellman with any key sizes | Key Agreement, Shared Secret Computation |
| EC Diffie-Hellman with any curve. | Key Agreement, Shared Secret Computation |
| SHA-1 | Digital Signature Generation |
| AES-GMAC | Message Authentication Code |
| HMAC with less than 112 bits key | Message Authentication Code |
| CMAC with 2-key Triple-DES | Message Authentication Code |
| SRP | Key Agreement |
| Multiblock ciphers using AES in CBC mode with 128 and 256 bit keys and HMAC SHA-1 and SHA-256 | Authenticated Data Encryption and Decryption |
| SSLLeay Deterministic Random Number Generator (PRNG) | Random Number Generation |
| AES, SHA-1 and SHA-2 algorithm implementations not using AES-NI or strict assembler. | All services where these algorithms are involved. |
| TLS v1.0, v1.1 and v1.2 KDF | Key Derivation in the TLS protocol |
| MD5 | Pseudo-random function (PRF) in TLS v1.0 and v1.1 |
| AES CCM | Key Wrapping and Unwrapping for the TLS protocol. |
| AES GCM | |
| AES CBC and HMAC | |
| Triple-DES CBC and HMAC | |

| Algorithm | Use |
|---------------|--|
| AES GCM | Data Encryption and Decryption |
| RSA and ECDSA | Signature operation in the context of TLS protocol |

3.4 Operator Authentication

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

4 Physical Security

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

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.

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.

6 Cryptographic Key Management

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

Table 10 - Lifecycle of Critical Security Parameters (CSPs)

| Name | Generation | Entry and Output | Zeroization |
|---------------------------------|--|---|--------------------------|
| AES keys | Key material is entered via API parameter | The key is passed into the module via API input parameters in plaintext. | EVP_CIPHER_CTX_cleanup() |
| HMAC keys | | | HMAC_CTX_cleanup() |
| RSA public and private keys | Public and private keys are generated using the FIPS 186-4 key Generation method; random values are obtained using the SP800 90A DRBG. | The key is passed into the module via API input parameters in plaintext. | RSA_free() |
| ECDSA public and private keys | | The key is passed out of the module via API output parameters in plaintext. | EC_KEY_free() |
| Derived key | Generated during SSH KDF. | Keys are passed out of the module via API output parameters in plaintext. | EVP_PKEY_free() |
| Entropy input string | Obtained from the NDRNG. | None | FIPS_drbg_free() |
| DRBG internal state (V, C, Key) | During DRBG initialization. | None | FIPS_drbg_free() |

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

6.1 Random Number Generation

The module employs a Deterministic Random Bit Generator (DRBG) based on [SP800-90A] for the creation of key components of asymmetric keys. 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, with 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) as the entropy source for seeding the DRBG. The NDRNG is provided by the operational environment (i.e., the Linux RNG via /dev/urandom), 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 Linux kernel performs conditional self-tests on the output of NDRNG to ensure that consecutive random numbers do not repeat. The module performs the DRBG health tests as defined in section 11.3 of [SP800-90A].

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

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

For generating RSA 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.

6.3 Key Agreement / Key Transport / Key Derivation

The module does not provide any key agreement in FIPS approved mode of operation.

The module provides the following key transport mechanisms:

- Key wrapping using AES-KW.

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

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

The module supports the following key derivation methods according to [SP800-135]:

- KDF for the SSHv2 protocol.

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 10. The zeroization functions overwrite the memory occupied by keys with “zeros” and deallocate the memory with the regular memory deallocation operating system call.

7 Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC)

The test platforms listed in Table 3 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.

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 9.3 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 13 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:

Table 11 - Self-tests³

| Algorithm | Power-Up Tests |
|-----------|--|
| AES | <ul style="list-style-type: none"> • KAT AES ECB mode with 128-bit key, encryption and decryption (separately tested) • KAT AES CCM mode with 192-bit key, encryption and decryption (separately tested) • KAT AES XTS mode with 128 and 256 bit key, encryption and decryption (separately tested) |

³ Additionally, the module implements KATs for Diffie-Hellman/EC Diffie-Hellman primitive "Z" computation, Triple-DES encryption, RSA encrypt/decrypt and AES GCM as well as DSA PCT as part of power-on self-tests. However, these self-tests are not listed here as these algorithms are non-Approved.

| Algorithm | Power-Up Tests |
|-----------|--|
| CMAC | <ul style="list-style-type: none"> • KAT AES CMAC with 128, 192 and 256 bit keys, MAC generation |
| SHS | <ul style="list-style-type: none"> • KAT SHA-1, SHA-256 and SHA-512 |
| HMAC | <ul style="list-style-type: none"> • KAT HMAC-SHA-1, HMAC-SHA-224, HMAC-SHA-256, HMAC-SHA-384 and HMAC-SHA-512 |
| ECDSA | <ul style="list-style-type: none"> • PCT ECDSA with P-256 and SHA-256 |
| RSA | <ul style="list-style-type: none"> • KAT RSA PKCS#1 v1.5 scheme with 2048-bit key, using SHA-1, SHA-224, SHA 256, SHA-384 and SHA-512, signature generation and verification (separately tested) • KAT RSA PSS scheme with 2048-bit key, using SHA-1, SHA-224, SHA 256, SHA-384 and SHA-512, signature verification and verification (separately tested) |
| DRBG | <ul style="list-style-type: none"> • KAT CTR_DRBG with AES with 256-bit key, without PR, with DF • KAT CTR_DRBG with AES with 256-bit key, without PR, without DF • KAT Hash_DRBG with SHA-256, without PR • KAT HMAC_DRBG with SHA-256, without PR |

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.

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:

Table 12 - Conditional Tests⁴

| Algorithm | Conditional Test |
|----------------------|---|
| ECDSA key generation | <ul style="list-style-type: none"> • PCT using SHA-256, signature generation and verification. |
| RSA key generation | <ul style="list-style-type: none"> • PCT using SHA-256, signature generation and verification. |
| DRBG | <ul style="list-style-type: none"> • CRNGT is not required per IG 9.8 |

⁴ Additionally, the module implements DSA key generation PCT and RSA PCT with encrypt/decrypt but these are not listed here as these algorithm are non-Approved.

NDRNG

- CRNGT (not performed by the module, but by the underlying Linux Operating System)
-

9 Guidance

9.1 Crypto Officer Guidance

The binaries of the module are contained in the base Junos Evolved installation image. 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.

9.1.1 Operating Environment Configurations

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

- (1) Enter CLI configuration mode.
- (2) Commit changes:
`commit`
- (3) Configure FIPS level to 1:
`set system fips level 1`
- (4) Commit changes:
`commit`
- (5) Exit configuration mode to enter operational mode:
`exit`
- (6) Reboot the system with the new settings (answer *yes* to prompt):
`request system reboot`

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 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.

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). In addition, key sizes must comply with [SP800-131A].

9.2.1 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.

Note: AES-XTS shall be used with 128 and 256-bit keys only. AES-XTS with 192-bit keys is not an Approved service.

9.2.2 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.

9.2.3 API Functions

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

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

9.2.4

9.2.4 Environment Variables

OPENSSL_ENFORCE_MODULUS_BITS

As described in [SP800-131A], less than 2048 bits of 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. If the environment variable is set, the module can generate RSA keys with 2048 bits or more (actually only keys with 2048, 3072 and 4096 bits are allowed in FIPS mode of operation).

OPENSSL_ia32cap

This capability mask environment variable can be used to remove one or more processor capabilities, forcing the module to use different (and less efficient) algorithm implementations for AES and SHA. Altering the processor capabilities is not recommended.

Should the environment variable be used to mask off the PAA implementations, the only value allowed in the approved mode of operation is the following:

```
OPENSSL_ia32cap=~0x1200020200000000:~0x0020000020"
```

9.3 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 self-tests and conditional tests forces the module to transition to 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:

Table 13 - Error Events, Error Codes and Error Messages

| 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, 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 ⁵ fails at the power-up | FIPS_R_TEST_FAILURE (137) |

⁵ The module implements DSA key generation PCT although this algorithm is non-Approved.

| | "test failure" |
|---|---|
| When the KAT of DRBG fails at the power-up | FIPS_R_NOPR_TEST1_FAILURE (145) "nopr test1 failure" |
| When the new generated RSA or ECDSA key pair fails the PCT | FIPS_R_PAIRWISE_TEST_FAILED (127) "pairwise test failed" |
| 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" |

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.

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}
};
11
11
```

11 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 |
| 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 |
| 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 |
| 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 |

12 Appendix C - References

- FIPS140-2 **FIPS PUB 140-2 - Security Requirements For Cryptographic Modules**
May 2001
<http://csrc.nist.gov/publications/fips/fips140-2/fips1402.pdf>
- FIPS140-2_IG **Implementation Guidance for FIPS PUB 140-2 and the Cryptographic Module Validation Program**
August 12, 2020
<http://csrc.nist.gov/groups/STM/cmvp/documents/fips140-2/FIPS1402IG.pdf>
- FIPS180-4 **Secure Hash Standard (SHS)**
March 2012
<http://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.180-4.pdf>
- FIPS186-4 **Digital Signature Standard (DSS)**
July 2013
<http://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.186-4.pdf>
- FIPS197 **Advanced Encryption Standard**
November 2001
<http://csrc.nist.gov/publications/fips/fips197/fips-197.pdf>
- FIPS198-1 **The Keyed Hash Message Authentication Code (HMAC)**
July 2008
http://csrc.nist.gov/publications/fips/fips198-1/FIPS-198-1_final.pdf
- LMAN **Linux Man Pages**
<http://man7.org/linux/man-pages/>
- PKCS#1 **Public Key Cryptography Standards (PKCS) #1: RSA Cryptography Specifications Version 2.1**
February 2003
<http://www.ietf.org/rfc/rfc3447.txt>
- RFC2246 **The TLS Protocol Version 1.0**
January 1999
<https://www.ietf.org/rfc/rfc2246.txt>
- RFC3268 **Advanced Encryption Standard (AES) Ciphersuites for Transport Layer Security (TLS)**
June 2002
<https://www.ietf.org/rfc/rfc3268.txt>

- RFC4279 **Pre-Shared Key Ciphersuites for Transport Layer Security (TLS)**
December 2005
<https://www.ietf.org/rfc/rfc4279.txt>
- RFC4346 **The Transport Layer Security (TLS) Protocol Version 1.1**
April 2006
<https://www.ietf.org/rfc/rfc4346.txt>
- RFC4492 **Elliptic Curve Cryptography (ECC) Cipher Suites for Transport Layer Security (TLS)**
May 2006
<https://www.ietf.org/rfc/rfc4492.txt>
- RFC5116 **An Interface and Algorithms for Authenticated Encryption**
January 2008
<https://www.ietf.org/rfc/rfc5116.txt>
- RFC5246 **The Transport Layer Security (TLS) Protocol Version 1.2**
August 2008
<https://tools.ietf.org/html/rfc5246.txt>
- RFC5288 **AES Galois Counter Mode (GCM) Cipher Suites for TLS**
August 2008
<https://tools.ietf.org/html/rfc5288.txt>
- RFC5487 **Pre-Shared Key Cipher Suites for TLS with SHA-256/384 and AES Galois Counter Mode**
March 2009
<https://tools.ietf.org/html/rfc5487.txt>
- RFC6655 **AES-CCM Cipher Suites for Transport Layer Security (TLS)**
July 2012
<https://tools.ietf.org/html/rfc6655.txt>
- RFC7251 **AES-CCM Elliptic Curve Cryptography (ECC) Cipher Suites for TLS**
June 2014
<https://tools.ietf.org/html/rfc7251.txt>
- SP800-38A **NIST Special Publication 800-38A - Recommendation for Block Cipher Modes of Operation Methods and Techniques**
December 2001
<http://csrc.nist.gov/publications/nistpubs/800-38a/sp800-38a.pdf>

- SP800-38B **NIST Special Publication 800-38B - Recommendation for Block Cipher Modes of Operation: The CMAC Mode for Authentication**
May 2005
http://csrc.nist.gov/publications/nistpubs/800-38B/SP_800-38B.pdf
- SP800-38C **NIST Special Publication 800-38C - Recommendation for Block Cipher Modes of Operation: the CCM Mode for Authentication and Confidentiality**
May 2004
<http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-38c.pdf>
- SP800-38D **NIST Special Publication 800-38D - Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC**
November 2007
<http://csrc.nist.gov/publications/nistpubs/800-38D/SP-800-38D.pdf>
- SP800-38E **NIST Special Publication 800-38E - Recommendation for Block Cipher Modes of Operation: The XTS AES Mode for Confidentiality on Storage Devices**
January 2010
<http://csrc.nist.gov/publications/nistpubs/800-38E/nist-sp-800-38E.pdf>
- SP800-38F **NIST Special Publication 800-38F - Recommendation for Block Cipher Modes of Operation: Methods for Key Wrapping**
December 2012
<http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-38F.pdf>
- SP800-52 **NIST Special Publication 800-52 Revision 1 - Guidelines for the Selection, Configuration, and Use of Transport Layer Security (TLS) Implementations**
April 2014
<http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-52r1.pdf>
- SP800-56B **NIST Special Publication 800-56B Revision 1 - Recommendation for Pair-Wise Key-Establishment Schemes Using Integer Factorization Cryptography**
September 2014
<https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-56Br1.pdf>
- SP800-57 **NIST Special Publication 800-57 Part 1 Revision 4 - Recommendation for Key Management Part 1: General**
January 2016
<http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-57pt1r4.pdf>

- SP800-67 **NIST Special Publication 800-67 Revision 1 - Recommendation for the Triple Data Encryption Algorithm (TDEA) Block Cipher**
January 2012
<http://csrc.nist.gov/publications/nistpubs/800-67-Rev1/SP-800-67-Rev1.pdf>
- SP800-90A **NIST Special Publication 800-90A - Revision 1 - Recommendation for Random Number Generation Using Deterministic Random Bit Generators**
June 2015
<http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-90Ar1.pdf>
- SP800-131A **NIST Special Publication 800-131A - Revision 2 - Transitioning the Use of Cryptographic Algorithms and Key Lengths**
March 2019
<https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-131Ar2.pdf>
- SP800-135 **NIST Special Publication 800-135 Revision 1 - Recommendation for Existing Application-Specific Key Derivation Functions**
December 2011
<http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-135r1.pdf>