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May 5, 2014

***SP 800-57 Part 3-Rev.1***

***DRAFT Recommendation for Key Management: Part 3 - Application-Specific Key Management Guidance***

NIST would like to request comments on a Draft Revision of SP 800-57 Part 3, Recommendation for Key Management: Application-Specific Key Management Guidance.

This revision updates cryptographic requirements for the protocols and applications in the document so that the current required security strengths, as specified in SP 800-131A, can be achieved. This revision also adds security-related updates from the protocols addressed in the original version of the document, and a new section for Secure Shell (SSH).

Comments should be sent to [SP80057Part3\\_@nist.gov](mailto:SP80057Part3_@nist.gov), with "Comments on SP 800-57, Part 3" in the subject line. Comments should be submitted by **July 5th, 2014**.

**Draft NIST Special Publication 800-57 Part 3**  
**Revision 1**

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# **Recommendation for Key Management**

## ***Part 3: Application-Specific Key Management Guidance***

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**Elaine Barker**  
**Quynh Dang**

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**C O M P U T E R   S E C U R I T Y**

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**NIST**  
**National Institute of  
Standards and Technology**  
U.S. Department of Commerce

**Draft NIST Special Publication 800-57 Part 3**  
**Revision 1**

# **Recommendation for Key Management**

## ***Part 3: Application-Specific Key Management Guidance***

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May 2014



U.S. Department of Commerce  
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National Institute of Standards and Technology  
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### **Abstract**

Special Publication 800-57 provides cryptographic key management guidance. It consists of three parts. Part 1 provides general guidance and best practices for the management of cryptographic keying material. Part 2 provides guidance on policy and security planning requirements for U.S. government agencies. Finally, Part 3 provides guidance when using the cryptographic features of current systems.

### **Keywords**

accreditation; assurances; authentication; authorization; availability; backup; certification; compromise; confidentiality; cryptanalysis; cryptographic key; cryptographic module; digital signature; key management; key management policy; key recovery; private key; public key; public key infrastructure; security plan; trust anchor; validation.

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1  
2 **RECOMMENDATION FOR KEY MANAGEMENT**  
3 **Part 3: Application-Specific Key Management Guidance**  
4

5 **1 Introduction**

6 “Application-Specific Key Management Guidance”, Part 3 of the Recommendation for  
7 Key Management is intended primarily to help system administrators and system  
8 installers adequately secure applications based on product availability and organizational  
9 needs and to support organizational decisions about future procurements. This document  
10 also provides information for end users regarding application options left under their  
11 control in normal use of the application. Recommendations are given for a select set of  
12 applications, namely:

- 13  
14 Section 2 – Public Key Infrastructures (PKI)  
15 Section 3 – Internet Protocol Security (IPsec)  
16 Section 4 – Transport Layer Security (TLS)  
17 Section 5 – Secure/Multipurpose Internet Mail Extensions (S/MIME)  
18 Section 6 – Kerberos  
19 Section 7 – Over-the-Air Rekeying of Digital Radios (OTAR)  
20 Section 8 – Domain Name System Security Extensions (DNSSEC)  
21 Section 9 – Encrypted File Systems (EFS)  
22 Section 10 – Secure Shell (SSH)  
23  
24

25 The following is provided for each topic:

- 26  
27 • A brief description of the system under discussion that is intended to provide  
28 context for the security guidance,  
29 • Recommended algorithm suites and key sizes and associated security and  
30 compliance issues,  
31 • Recommendations concerning the use of the mechanism in its current form for the  
32 protection of Federal government information,  
33 • Security considerations that may affect the security effectiveness of key  
34 management processes,  
35 • General recommendations for purchase decision makers, system installers, system  
36 administrators and end users.  
37

38 Following Section 10 are five appendices with a glossary, an explanation of acronyms,  
39 basic information for novice and end users on obtaining and using keys, references for  
40 documents cited herein, and changes incorporated into this revision.  
41

42 This document does not reflect a comprehensive view of current products and technical  
43 specifications. Future versions of this document will include updates to the topics  
44 covered, and may include additional subjects as new techniques are widely implemented.

## 1.1 Purpose

Part 3 of the *Recommendation for Key Management, Application-Specific Key Management Guidance*, is intended to address the key management issues associated with currently available cryptographic mechanisms. *General Guidance*, Part 1 of the *Recommendation for Key Management*, contains basic key management guidance for users, developers and system managers regarding the "best practices" associated with the generation and use of the various classes of cryptographic keying material. *General Organization and Management Requirements*, Part 2 of the Recommendation, provides a framework and general guidance to support establishing cryptographic key management within an organization, and a basis for satisfying the key management aspects of statutory and policy-based security planning requirements for Federal government organizations.

This document, Part 3 of the Recommendation, is designed for system installers, system administrators and end users of existing key management infrastructures, protocols, and other applications, as well as the people making purchasing decisions<sup>1</sup> for new systems using currently available technology. Note that end users who act as their own system installers, administrators and purchasing agents may find the guidance intended for administrators, installers and purchasers to be beneficial. In centrally managed organizations, the organization's management must establish a security policy that acts as a foundation for all end-user guidance.

Recommendations are made for mechanisms designed to protect stored data and data in transit. This document will not provide a complete restatement of existing standards or implementation directives. Standards and guidelines with this level of detail are referenced where appropriate.

For each of the key management infrastructures, protocols, and applications addressed in Part 3, the following is provided:

- A brief description of the system under discussion that is intended to provide context for the security guidance provided,
- Recommended algorithm suites and key sizes, and associated security and compliance issues,
- Recommendations concerning the use of the mechanism in its current form for the protection of Federal government information,
- Security considerations that may affect the security effectiveness of key management processes, and
- General recommendations for people making purchasing decisions, system installers, system administrators and end users.

The logistics of how one should obtain, store or transfer keys or key pairs within a given application or system are application and implementation-specific and beyond the scope of this document. In large Federal systems, these functions are frequently handled by

---

<sup>1</sup> This is not necessarily a procurement officer, but likely a person making the decision on the IT product to be used.

1 system administrators or completed with direct guidance from system administrators. For  
2 end users faced with these tasks on their own, an informative appendix has been included  
3 with general information intended to point the end user in the right direction.  
4

5 Since some of the infrastructures, protocols and applications addressed in this  
6 Recommendation will be refined or replaced over time, the guidance provided herein will  
7 become obsolete. Similarly, it is anticipated that new infrastructures, protocols, and  
8 applications will be developed. Although this document will be updated as mechanisms  
9 and techniques evolve, it may not always reflect a comprehensive view of current  
10 products and technical specifications. Hence, references to version numbers or other  
11 implementation status information are provided to enable an evaluation of the  
12 applicability of particular elements of guidance to the specific version of an  
13 infrastructure, protocol, or application into which a mechanism is integrated.  
14

15 Note that many of the applications described in Part 3 are currently in use by U.S.  
16 government agencies. Some of these applications were developed and implemented prior  
17 to the release of Part 1 of this Recommendation, and therefore, may not follow all of the  
18 principles identified in Part 1. The use of current implementations of these applications  
19 may be necessary until more carefully designed applications are available. It is very  
20 important that each implementation that does not comply with NIST standards and  
21 guidelines be evaluated for associated risks and that steps be taken to mitigate those risks  
22 as discussed in this Recommendation.  
23

## 24 **1.2 Requirement Terms**

25 This Recommendation often uses “requirement” terms; these terms have the following  
26 meaning in this document:

- 27 1. **shall**: This term is used to indicate a requirement of a Federal Information  
28 Processing Standard (FIPS) or a requirement that must be fulfilled to claim  
29 conformance to this Recommendation. Note that **shall** may be coupled with **not** to  
30 become **shall not**.
- 31 2. **should**: This term is used to indicate an important recommendation. Ignoring the  
32 recommendation could result in undesirable results. Ignoring recommendations to  
33 accommodate the acceptance of messages protected with commonly used,  
34 unapproved cryptography may create interoperability issues. Ignoring  
35 recommendations to select new products with approved, seldom-used  
36 cryptographic mechanisms may leave an organization ill-prepared to migrate  
37 away from mechanisms that will soon be inappropriate for the protection of  
38 Federal systems. Note that **should** may be coupled with **not** to become **should**  
39 **not**.  
40

## 41 **1.3 General Protocol Considerations**

42 There are a number of general issues associated with the protocols discussed in Part 3.  
43 Four of these issues are briefly discussed in order to familiarize the reader with concepts

1 that will be repeated throughout the document and to help frame the upcoming  
2 discussions:

- 3 • Mandatory-to-implement vs. optional-to-implement,
  - 4 • Cryptographic negotiation,
  - 5 • Single or multi-use keys, and
  - 6 • Algorithm and key size transitions.
- 7

### 8 **1.3.1 Mandatory-to-Implement versus Optional-to-Implement**

9 Many of the cryptographic security services described in this document are based on  
10 public standards (e.g., IETF RFCs, American National Standards, etc.). In these  
11 standards, algorithms are frequently described as mandatory-to-implement or optional-to-  
12 implement. Neither of these terms provides information about the security of the  
13 algorithm.

14  
15 Mandatory-to-implement algorithms will be in any product that meets the public  
16 standards, allowing interoperability between products.

17  
18 Optional-to-implement algorithms tend to be next-generation algorithms that may  
19 become mandatory-to-implement algorithms in a future version of the standard. There  
20 could be considerable delay in the widespread use of these new algorithms for a variety  
21 of reasons, ranging from a need for supporting hardware or software upgrades, to issues  
22 of interoperability. For example, an algorithm that is optional-to-implement within an  
23 S/MIME protocol may not currently be supported by the system's cryptographic module.  
24 However, these algorithms often offer improved security that could significantly increase  
25 the longevity of the system. Therefore, one may want to consider buying products that  
26 support the optional-to-implement algorithms, even if those algorithms will not be  
27 available to all end users immediately.

28  
29 As previously defined, the terms **shall** and **should** are used to provide information about  
30 whether algorithms have adequate security for use on Federal computer networks. As  
31 such, there may be mandatory-to-implement algorithms that do not provide adequate  
32 security (e.g., Data Encryption Standard (DES) or RC2), and this document will say they  
33 **shall not** be used. Similarly, there may be optional-to-implement algorithms that have  
34 greater security (e.g., AES), and this document may say that these algorithms **should** or  
35 **shall** be used in a given situation.

36  
37 The distinction between mandatory-to-implement and optional-to-implement is important  
38 when two users on different systems desire to communicate or when different levels of  
39 security may be required for different applications running on the same system. This is  
40 further discussed in the next section on cryptographic negotiation.

### 43 **1.3.2 Cryptographic Negotiation**

44 Parts 1 and 2 of this Recommendation establish a sound basis for selecting appropriate  
45 cryptographic algorithms and managing the corresponding cryptographic keys. However,

1 enforcing these guidelines can be problematic for a number of reasons, including the  
2 unavailability of certain algorithms or key sizes, the preferences of the communicating  
3 parties or other system limitations. When servers dictate the algorithms used, the server  
4 may select the algorithms that optimize overall system performance, rather than the ones  
5 that provide the highest level of security.

6  
7 In some multi-party protocols where multiple algorithms are supported for the same  
8 purpose, a client can enforce the rules in Parts 1 and 2 through negotiation within the  
9 protocol. Some protocols (e.g., S/MIME) allow the initiating client to select the  
10 cryptographic algorithms without negotiating with the receiving client. In this case, as in  
11 the case where applications do not permit negotiation, a receiving client may be presented  
12 with information that has been inadequately protected. For example, a receiving client  
13 may receive a signed and encrypted S/MIME e-mail message that was encrypted using  
14 DES and signed with a 512-bit RSA key<sup>2</sup>. Rejecting such messages does not necessarily  
15 enhance security (in this case, the message has already been sent over the Internet), but  
16 the receiving user should be aware that the security services purportedly provided by the  
17 digital signature and content encryption are suspect and cannot be depended upon. It may  
18 be appropriate to reject the message or terminate the protocol. A risk assessment and  
19 subsequent organizational policy may be required to determine the appropriate course of  
20 action.

21  
22 In other protocols (e.g., TLS), the client proposes a set of options, and the server chooses  
23 from the proposed list during a negotiation phase of the protocol. Where negotiation is  
24 supported, protocols may be designed to negotiate cipher suites or to negotiate each  
25 algorithm independently. In either case, a client or server may be faced with a situation  
26 where the preferred algorithms of the client or server and the proposed algorithms of the  
27 other party are not of the same security strength, or where approved algorithms are not  
28 available.

29  
30 Another issue may arise when a protocol is designed to negotiate algorithms, but not key  
31 sizes. In such a case, the clients may find themselves communicating with approved  
32 algorithms, but inadequate key sizes. For example, after negotiating for RSA signatures,  
33 the client might get a message signed with a 512-bit RSA key<sup>3</sup>.

34  
35 Enforcing the recommendations from Parts 1 and 2 may also be complicated by system or  
36 application design decisions. Systems may have application-specific controls for  
37 cryptographic algorithms, or they may have system-wide controls. For example, a user  
38 may wish to restrict one application to using AES, and another to using TDEA, while the  
39 system design may only allow the use of TDEA. Often the only limitation on public key  
40 sizes is an indirect limitation through the choice of root CA keys. (See Section 2.1).

41  
42 When there are a variety of algorithms or key sizes available for a given communication  
43 protocol, the following questions need to be addressed:

- 44
- Is negotiation mandatory, optional or unsupported?

---

<sup>2</sup> The DES algorithm and the 512-bit RSA key size do not provide adequate security (see Part 1).

<sup>3</sup> A 512-bit RSA key does not provide an acceptable security strength (see Part 1).

- 1 • When negotiation is supported, who proposes the cryptographic mechanisms to be  
2 used, who selects the mechanisms, and what are the selection criteria?
- 3 • Is negotiation based on predefined cipher suites, or is each algorithm proposed  
4 independently?
- 5 • What is the granularity for the negotiation: just algorithms, both algorithms and  
6 key sizes, combinations of algorithms and/or key sizes, or protocol versions?
- 7 • What cannot be specified?

8 A good start at ensuring communication security in a multi-algorithm setting would be to:

- 9 • Limit the list of algorithms available to the application to those best suited for  
10 users of the system and those needed for interoperability,
- 11 • Adopt a policy that disallows sending messages using an inadequate level of  
12 protection,
- 13 • Adopt a policy explaining how to respond to messages received without adequate  
14 protection, and
- 15 • Adopt a policy explaining what to do when faced with a need for secure  
16 communications with a party using un-approved algorithms or inadequate key  
17 sizes.

### 19 **1.3.3 Single or Multi-Use Keys**

20 A major thrust from Part 1 of this Recommendation is that, in general, keys **shall not** be  
21 used for multiple cryptographic purposes. For example, the same key **shall not** be used to  
22 generate a digital signature and to establish other keying material (see Part 1, Section  
23 8.1.5.1.1.2 for the rare exceptions to this guidance). It is less clear as to whether a digital  
24 signature key, for example, can be used only for a specific application (e.g., signing e-  
25 mail) or for multiple applications (e.g., for both signing e-mail and signing documents).  
26 In some cases, it may be acceptable for an application to share keys with other  
27 applications. In other cases, sharing keys may not be desirable. For example, best  
28 practices indicate that a server's TLS keys **should not** be used to support other  
29 applications. Even where keys are used to perform the same cryptographic operation  
30 (e.g., digital signatures), sharing keys may be inappropriate because one application  
31 could be providing one service (e.g., authentication), while a second application could be  
32 providing a different service (e.g., non-repudiation). It is important to remember that it  
33 may be a bad idea to use keys for multiple applications.

34  
35 An agency **should** perform a risk assessment when considering the use of the same key  
36 for multiple applications.

### 38 **1.3.4 Algorithm and Key Size Transition**

39 Part 1 of this Recommendation provides timeframes for transitioning from algorithms  
40 and key sizes currently in use by many applications and protocols in order to increase the  
41 strength of the security mechanisms in the future. In many cases, the algorithms and key  
42 sizes required to provide adequate security are not available within the current  
43 implementations or are unavailable uniformly across the community of users that need to



1 interoperate. Transitions to new algorithms or key sizes will not necessarily occur  
2 instantaneously, but will require gradual upgrades across a system. For example, a system  
3 owner may have the need to upgrade his system's e-mail package before upgrading the  
4 cryptographic module. Hence, for a period of time, the system may be running with an e-  
5 mail package capable of TDEA and AES 128 encryption, but a cryptographic module that  
6 can only handle TDEA. There will be a need to upgrade components of a system with  
7 new capabilities, while continuing to support the old capabilities, until all components  
8 have been upgraded.

9 During this transition period, interaction between components can proceed in one of the  
10 following ways:

- 11 1. Some means is provided to determine when the new security mechanism is  
12 available to all parties in a given transaction so that it can be used instead of the  
13 old security mechanism (e.g., using a protocol that negotiates the security  
14 mechanisms to be used). When the new security mechanism is not available to all  
15 parties involved in a transaction, the old security mechanism can be used. This  
16 approach has the advantage that when a set of parties have the newer mechanism,  
17 their transactions are protected at a higher security level. The disadvantage is that  
18 those transactions using the old security mechanism are not as well protected; this  
19 also raises the possibility that the same information could be sent in different  
20 transactions between two or more sets of parties using security mechanisms of  
21 different strengths – in effect, nullifying the higher security strength provided by  
22 the new security mechanism<sup>4</sup>.
- 23 2. All components use the old security mechanism until all components have been  
24 updated; at that time, the system immediately transitions to the new capability.  
25 This approach has the potential problem that all components would not be  
26 updated by the deadline, thus providing inadequate protections for all information  
27 during the period following the deadline until such time as all components have  
28 been upgraded. However, this approach has the advantage that the same data will  
29 not be sent at two different security levels.<sup>5</sup>

30 Most of the applications and protocols discussed in Part 3 require an upgrade of the  
31 available security mechanisms to be compliant with Part 1. The following sections  
32 provide guidance on how the existing mechanisms may best be used until appropriate  
33 upgrades can be made. Organizations and system administrators must determine the  
34 approach for transitioning to stronger security mechanisms within a system.

35

---

<sup>4</sup> This becomes an issue when higher security-level users are unaware that others may be using a lower security-level mechanism to protect the same information.

<sup>5</sup> Assuming that data sent before the transition is not also sent after the transition.

## 2 Public Key Infrastructure (PKI)

### 2.1 Description

A PKI is the most common key management approach for the distribution of public keys. As described in SP 800-57, Part 1, [SP 800-57, Part 1] public keys are used to establish security services after obtaining a variety of assurances: assurance of integrity, assurance of domain parameter validity (where appropriate), assurance of public key validity, and assurance of private key possession. In most cases, applications must also establish the identity of the user associated with this key pair. In a PKI, the infrastructure establishes the user's identity and the required assurances to provide a strong foundation for security services in PKI-enabled applications and protocols, including IPsec (Section 3), Transport Layer Security (Section 4), S/MIME secure e-mail (Section 5) and some versions of Kerberos (Section 6). This section presents basic guidance for PKI-based key management. For broader and more detailed information on PKI, see SP 800-32 [SP 800-32].

Public key certificates bind two names to a public key, the user's name and the issuer's name, using a digital signature generated by the issuer. The user is the party authorized to use the private key associated with the public key in the certificate. The issuer is a trusted third party that generates and signs the certificate after verifying: the identity of the user; the validity of the public key, associated algorithms and any relevant parameters; and the user's possession of the corresponding private key. The issuer is known as a Certificate Authority (CA). In many cases, the CA will delegate responsibility for the verification of the subject's identity to a Registration Authority (RA). The certificate is used to distribute the user's public key to other interested parties, known as relying parties, since they rely on the assurances provided by the PKI and the certificate creation process.

CAs generally issue a self-signed certificate called a *root certificate* (sometimes also called a *trust anchor*); this is used by applications and protocols to validate the certificates issued by a CA. CA certificates play a key role in many protocols and applications, and are generally kept in what is often called a *root certificate store*. Much of the business of properly configuring applications and protocols consists of ensuring that only appropriate root certificates are loaded into the root certificate store. In Microsoft Windows operating systems, there are root certificate stores that are maintained by the operating system for various purposes that are shared by various Microsoft protocols and applications, and by other applications that may choose to use them. There is a similar "Keychain" facility in the Apple operating systems. Some applications, intended to be portable between operating systems, can maintain their own root certificate stores and also have a feature that allows them to share a root certificate store with other applications.<sup>6</sup>

---

<sup>6</sup> The various Mozilla browsers and e-mail clients, and the Apache web servers are examples. Microsoft Internet Explorer, Outlook and Internet Information Server all use the Windows root certificate store; Apple Safari and Mail use the Keychain; and Mozilla Firefox, Thunderbird and SeaMonkey all have their own root certificate stores, and they also can share a root certificate store from Mozilla's Network Security Services (NSS) utility.

1 Certificates are generally issued in accordance with a *certificate policy*. Generally that  
2 policy can be found on the issuing CA's website. If an organization's policy, for  
3 example, is to accept only certificates that use at least 2048-bit RSA, 2048-bit DSA or  
4 224-bit elliptic curve cryptography, and either, SHA-224 or SHA-256, then the only  
5 practical way to ensure that public key sizes meet the requirements is usually to ensure  
6 that the root certificate store contains only root certificates with a certificate policy that  
7 requires these algorithms and key sizes in its subordinate certificates. Current  
8 applications that use PKI will check to ensure that a certificate has been issued under the  
9 root certificate in the application's root store, and that it has not been subsequently  
10 revoked, but will not otherwise check the suitability of the public key or hash algorithms  
11 used in the certificate – the application will simply use the specified keys to compute the  
12 mathematically correct results. So, correctly configuring root certificate stores is a critical  
13 step in key management.

14  
15 The specifics of where the root certificate store is located and how it is managed for each  
16 application and protocol are beyond the scope of this Recommendation. Typically,  
17 however, there are menus for viewing and managing certificate stores in the browser  
18 applications, but this is subject to change with each product update. There may also be  
19 utilities and features in the operating system or application for centralized management  
20 by the system administrator. When a browser or other application encounters an  
21 unrecognized CA certificate, end users may be prompted to add that certificate to their  
22 permanent trusted certificate store, temporarily trust the certificate, or reject the  
23 certificate and close the application.

24  
25 The most common certificate format is the X.509 version 3 (X.509v3) certificate; see  
26 RFC 5280 [RFC 5280]. In addition to the user and issuer names and the public key, all  
27 X.509 certificates also include a digital signature, validity (starting and expiring times),  
28 and identifiers that specify the cryptographic algorithm(s) to be used with the public key  
29 and signature. X.509v3 certificates include an extensibility feature; CAs usually include  
30 standard extensions in their certificates to indicate which cryptographic operations the  
31 public key was intended to support, the policy that governed certificate issuance, and  
32 where to find out if the certificate has been revoked (i.e., an authoritative source for  
33 certificate status information). CAs may also include "private" extensions in their  
34 certificates that contain information particular to an application or domain of users.

35  
36 A relying party is an individual or organization that relies on the certificate and the CA  
37 that issued the certificate to provide valid information (see Appendix A). Before a relying  
38 party uses the public key in a certificate, he must determine whether the key used by the  
39 issuer to sign this certificate can be trusted. In the simplest case, the relying party knows  
40 about the issuer, and has already decided to trust certificates issued by that CA. CAs that  
41 a relying party trusts directly are called *trust anchors*. When multiple trust anchors are  
42 recognized, the set of trust anchors is referred to as the trust list.

43  
44 In some cases, a relying party will wish to process user certificates that were signed by  
45 issuers other than a CA in its trust list. To support this goal, CAs issue cross certificates  
46 that bind another issuer's name to that issuer's public key. Cross certificates are an  
47 assertion that a public key may be used to verify signatures on other certificates. A  
48 relying party may be able to develop a certification path – a sequence of certificates –

1 demonstrating that a user’s public key certificate can be trusted, even though it was  
2 issued by a CA that is not in the relying party’s trust list. All certification paths begin  
3 with a trust anchor, include zero or more intermediate certificates, and end with the  
4 certificate that contains the user’s public key. This can be an iterative process, and  
5 finding the appropriate intermediate certificates (a.k.a., path discovery) is one of PKI’s  
6 challenges.

7  
8 The entire path must be examined to ensure that the certificates have not been revoked,  
9 were issued under appropriate policies, and that each public key is suitable for the use to  
10 which it has been put. This process is known as path validation.

11  
12 As noted above, the certificate itself will usually include a pointer to an authoritative  
13 source for certificate status information. Certificate status information may be provided  
14 using one of two standard mechanisms:

- 15  
16 • The most common source is a certificate revocation list, or CRL. An X.509 CRL  
17 contains a list of certificates issued by that CA that have been revoked, indicates  
18 when they were revoked, and may include the reason for revocation (see RFC  
19 5280). If the serial number of an unexpired certificate does not appear on the  
20 CRL, then it is still valid. CRLs are digitally signed, like a certificate, so they can  
21 be distributed through untrusted systems. Most commonly, CRLs are distributed  
22 via LDAP<sup>7</sup> directories or web servers.
- 23 • An alternative source for this information is an Online Certificate Status Protocol  
24 (OCSP) responder (see RFC 6960 [RFC 6960]). An OCSP responder is a trusted  
25 system, and provides signed status information, on a per certificate basis, in  
26 response to a request from a relying party. Relying parties can authenticate the  
27 response by verifying the OCSP responder’s digital signature. As the OCSP  
28 responder is providing authoritative status information, there is generally a formal  
29 (e.g., contractual) relationship between the CA and OCSP responder.

30  
31 In many cases, PKIs will also provide key recovery services (using Recovery Servers) to  
32 support business continuity. Key recovery services store private keys that support key  
33 establishment to ensure that the plaintext of encrypted data may be recovered in the  
34 future. These services can provide the private key to the user in the event of loss or  
35 failure of their cryptographic module, or to the user’s management when policy or legal  
36 requirements exist. When supported, this service removes a key management burden  
37 from PKI-enabled applications.

38  
39 This section provides guidance for general-purpose PKIs when users from different  
40 organizations need to support a variety of applications. For large, general-purpose PKIs,  
41 interoperability is an important consideration. Less commonly, PKIs may be deployed to  
42 support a small, closed community of users or for a single application, where wider  
43 interoperability is less important. The requirements within this section are focused on

---

<sup>7</sup> **Lightweight Directory Access Protocol** (LDAP) is a software protocol for enabling anyone to locate organizations, individuals, and other resources, such as files and devices in a network, whether on the Internet or on a corporate intranet. See [RFC 4511] Lightweight Directory Access Protocol (LDAP): The Protocol and [RFC 4512] Lightweight Directory Access Protocol (LDAP): Directory Information Models.

1 large, general-purpose PKIs, such as the Federal PKI. For PKIs requiring less  
2 interoperability, these requirements **should** be evaluated for appropriateness within their  
3 systems. In general, cryptographic algorithm and key size standards **should** be met by all  
4 PKIs.  
5

## 6 **2.2 Security and Compliance Issues**

### 7 **2.2.1 Recommended Key Sizes and Algorithms**

8 Table 2-1 below summarizes the recommended key sizes for key pairs used by PKI users  
9 and infrastructure components. The PKI uses the term *digital signature key* to refer to a  
10 private signature key or public signature verification key (as defined in Part 1) that  
11 provides a non-repudiation service. The term *authentication key* is used by the PKI to  
12 refer to a private authentication key or public authentication key as defined in Part 1.  
13 Note that both a digital signature key and an authentication key are used with a digital  
14 signature algorithm.  
15

16 The dates in this table are consistent with those that appear in Part 1, where:

- 17 • A digital signature key is as defined above.
- 18 • A key establishment key is an asymmetric key pair used to provide key agreement  
19 or key transport, and
- 20 • A CA and OCSP responder signing key is an asymmetric key pair used to sign  
21 and verify certificates.  
22

23 Approved algorithms and key sizes specified in Table 2-1 and certificate expiration dates  
24 are two different things. These algorithms and key sizes are approved for use beyond the  
25 year 2013. However, a digital signature or key establishment certificate may expire at any  
26 time, depending on the organization's security policy.

1 **Table 2-1 Recommended Algorithms and Key Sizes**

Key Type	Algorithms and Key Sizes
Digital Signature keys used for authentication (for Users or Devices)	RSA (2048 bits) ECDSA (Curve P-256)
Digital Signature keys used for non-repudiation (for Users or Devices)	RSA (2048 bits) ECDSA (Curves P-256 or P-384)
CA and OCSP Responder Signing Keys	RSA: (2048 or 3072bits) ECDSA: (Curves P-256 or P-384)
Key Establishment keys (for Users or Devices)	RSA (2048 bits) Diffie-Hellman (2048 bits) ECDH (Curves P-256 or P-384)

2  
3 Note that some approved algorithms and key sizes, such as DSA 2048, are omitted to  
4 enhance interoperability. RSA and ECDSA, which are included in Table 2-1 above, have  
5 been widely deployed in PKIs. Therefore, they are recommended for use to enhance  
6 interoperability. However, DSA (2048 and 3072) as specified in FIPS 186-4 are allowed  
7 as long as the required security strength is satisfied. For ECDSA, only the two elliptic  
8 curves listed in Table 2-1 above of the elliptic curves are recommended for use in PKIs  
9 for digital signatures [FIPS 186-4]. Similarly, Elliptic Curve Diffie-Hellman (ECDH) is  
10 recommended to support key establishment, rather than Elliptic Curve MQV.

11  
12 While Table 2-1 is focused on the strength of the public key contained in a certificate, the  
13 strength of the digital signature on a certificate itself is equally important. The signature  
14 security strength also reflects the security strength of the hash algorithm, and possibly the  
15 padding scheme<sup>8</sup>, in addition to the strength of the private key used to generate the  
16 signature. Table 2-2 below summarizes the recommended algorithms, key sizes, hash  
17 functions, and padding schemes for signing certificates and CRLs by CAs, and OCSP  
18 status messages by OCSP responders.

19

---

<sup>8</sup> RSA has two padding schemes used in the PKI: PKCS #1 v1.5, and PSS. The security strength of a digital signature generated using ECDSA is not affected by a padding scheme.

1 **Table 2-2 Digital Signature Recommendations for CAs and OCSP Responders**

Public Key Algorithms and Key Sizes	Hash Algorithms	Padding Scheme
RSA (2048 or 3072 bits)	SHA-256	PKCS #1 v1.5, PSS
ECDSA (Curve P-256)	SHA-256	N/A
ECDSA (Curve P-384)	SHA-384	N/A

2

3 User certificates containing RSA or Diffie-Hellman public keys **should** be signed using  
 4 the RSA signature algorithm. User certificates containing elliptic curve public keys  
 5 **should** be signed using ECDSA.

6

7 Not all combinations of algorithms and key sizes are appropriate for the protection of  
 8 Federal government information. To enhance interoperability, users **should** obtain  
 9 authentication, signature, and key establishment certificates with complementary  
 10 algorithms for all public keys.<sup>9</sup> For most users, signature and key establishment keys  
 11 **should** provide the same cryptographic strength. Table 2-3 below shows preferred  
 12 combinations for user keys.

13

14 While symmetric key cryptography is not strictly required, block ciphers are used in  
 15 practically all PKI implementations and PKI-enabled applications. All components using  
 16 block ciphers **shall** support the AES-128 algorithm. To support legacy implementations,  
 17 components that process RSA keys **should** support three-key Triple-DEA (see [SP 800-  
 18 67]). Components that support P-384 elliptic curve keys and the SHA-384 algorithm  
 19 **shall** support AES-256.

20 **Table 2-3 Recommended Combinations for the Recommended Algorithms and Key**  
 21 **Sizes**

Authentication Key Type	Signature Key	Key Establishment Key
RSA 2048	RSA 2048	RSA 2048
RSA 2048	RSA 2048	Diffie-Hellman 2048
ECDSA P-256	ECDSA P-256	ECDH P-256
ECDSA P-256	ECDSA P-384	ECDH P-384
ECDSA P-384	ECDSA P-384	ECDH P-384

22

<sup>9</sup> In general, protocols and applications are designed to use cryptographic algorithms from one mathematical family. For example, applications that encounter certificates with ECDSA digital signatures would expect to use elliptic curve Diffie-Hellman for key establishment services. Users that obtain an ECDSA certificate (i.e., a certificate containing an ECDSA public key to be used for verifying digital signatures), and an RSA key establishment certificate (i.e., a certificate containing an RSA public key to be used for key establishment), for example, may find they cannot use the keys together in a single application. Other combinations of certificates are commonly used (see Table 2-3). It is advisable that users obtain authentication, signature, and key establishment certificates that are complementary to ensure that the keys can be used together in applications and protocols.

## 1 **2.3 Procurement Guidance**

2 The following provides guidance for those responsible for making decisions about which  
3 products to purchase in support of a PKI.

### 4 **2.3.1 CA/RA Software and Hardware:**

- 5 1. CA and RA software **shall** support at least one of these protocols: the Certificate  
6 Management Protocol (CMP) [RFC 4210], Enrollment over Secure Transport (EST)  
7 [RFC 7030] and Certificate Management Using Cryptographic Message Syntax  
8 (CMC); see RFC 5272 [RFC 5272].  
9
- 10 2. CAs **shall** follow the practices outlined in their respective Certificate Policy and  
11 Certification Practices Statement. Recommended practices are described in NIST IR  
12 7924 [NISTIR 7924].  
13
- 14 3. All CAs **shall** support the generation of certificates and CRLs that conform to RFC  
15 5280. (Specific requirements with respect to certificate and CRL extensions are  
16 detailed below.)  
17
- 18 4. CAs **shall** be capable of issuing multiple certificates to users, and for all said  
19 certificates, asserting the key usage extension. Each key **shall** be used for only one  
20 purpose.  
21
- 22 5. CAs **shall** be capable of including the CRL distribution points extension. At a  
23 minimum, CAs **shall** support the inclusion of LDAP and HTTP URLs to specify the  
24 location of CRLs. CAs **shall** be capable of specifying an authoritative OCSP  
25 responder in the Authority Information Access extension.  
26
- 27 6. Each PKI has its own certificate profile, identifying certificate extensions that appear  
28 in the certificates and CRLs it issues.<sup>10</sup> CAs **shall** be able to generate all mandatory  
29 extensions in the appropriate profiles. For CAs owned or operated on behalf of  
30 Federal agencies, the following specific guidance applies:  
31
  - 32 a) CAs that implement Federal agency-specific policies **shall** be able to generate  
33 certificates and CRLs that meet the agency profile and the Federal PKI Certificate  
34 Profile [FPKI PROF].
  - 35 b) CAs that implement the Common Policy Framework [COMMON] **shall** be able  
36 to generate certificates and CRLs meeting the Shared Services Certificate and  
37 CRL Profile [COMMON PROF].  
38
- 39 7. CAs **should** support the inclusion of “private” extensions in certificates and CRLs.<sup>11</sup>  
40

---

<sup>10</sup> This profile is often documented explicitly, but may be implicitly specified through the certificate policy.

<sup>11</sup> Private extensions are defined by an organization to meet their own unique requirements. Note that noncritical private extensions do not impact the interoperability of certificates or CRLs.



- 1 8. CAs **shall** support at least one of the following algorithms for digitally signing  
2 certificates and CRLs: RSA with PKCS#1 v1.5 padding; RSA with PSS Padding  
3 [RFC 3447], DSA or ECDSA. To maximize flexibility, CAs **should** support RSA and  
4 ECDSA.<sup>12</sup>  
5
- 6 9. CAs **shall** include backup and archive capabilities to support reconstitution of the CA  
7 in the event that the root key is corrupted, destroyed or lost, and it is necessary to  
8 rebuild the CA using a backup root key, rather than simply recovering the lost state of  
9 the CA. CAs **should** include backup and archive capabilities in order to establish  
10 when certificates were issued and revoked, and under whose authority.  
11
- 12 10. CA/RA components **shall** be shipped or delivered via controlled methods that provide  
13 a continuous chain of accountability, from the purchase location to the CA's or RA's  
14 physical location.

### 15 **2.3.2 OCSP Responders:**

- 16 1. OCSP responders **shall** conform to RFC 6960, Online Certificate Status Protocol.  
17
- 18 2. OCSP responders **shall** be capable of processing both signed and unsigned requests  
19 and **shall** be capable of processing requests that either include or omit the name of the  
20 relying party making the request. However, OCSP responders may ignore signatures  
21 and requester names, if present.  
22
- 23 3. OCSP responders **shall** be capable of processing certificate status requests and  
24 generating responses for non-error conditions as specified in RFC 5019 [RFC 5019].  
25
- 26 4. Where supported, the OCSP responder **should** sign the OCSP response with the  
27 algorithm and key size used to sign the certificate. OCSP responders **shall** support at  
28 least one of the following algorithms for digitally signing response messages: RSA  
29 with PKCS#1 v1.5 padding; RSA with PSS Padding, DSA or ECDSA. The supported  
30 algorithms **should** include the algorithm(s) used by the corresponding CA when  
31 signing the certificate whose status is in question. To support future algorithm  
32 transitions by the CA, OCSP responders **should** support RSA and ECDSA.<sup>13</sup>  
33

### 34 **2.3.3 Cryptographic Modules**

- 35 1. Cryptographic modules for CAs, Key Recovery Servers, and OCSP responders **shall**  
36 be hardware modules validated as meeting FIPS 140-2 Level 3 or higher.  
37

---

<sup>12</sup> The algorithm used to sign certificates and CRLs in an operational CA is dependent upon both the cryptographic module in use and the CA's software. The selected algorithm must appear in both sets of supported algorithms.

<sup>13</sup> As with CAs, the algorithm used to sign responses in an operational OCSP responder is dependent upon both the cryptographic module in use and the OCSP responder's software. The selected algorithm must appear in both sets of supported algorithms.

- 1 2. Cryptographic modules for RAs **shall** be hardware cryptographic modules validated  
2 as meeting FIPS 140-2 Level 2 or higher.  
3
- 4 3. Relying party and user cryptographic modules **shall** be validated as meeting FIPS  
5 140-2 Level 1 or higher.  
6

#### 7 **2.3.4 Key Recovery Servers**

- 8 1. If the PKI supports key establishment (i.e., certificates will include key transport or  
9 key agreement keys), the PKI **should** include a key recovery mechanism.  
10
- 11 2. Implementations **should** support automated, user-initiated key recovery; key recovery  
12 by the organization **should** also be supported.<sup>14</sup>  
13

#### 14 **2.3.5 Relying Party Software**

- 15 1. Relying party path validation  
16 a) Relying party implementations **shall** implement RFC 5280-conformant path  
17 validation; see RFC 5280.  
18 b) Where interoperability outside a single organization is required (e.g., a single  
19 Federal agency), path validation modules **should** conform to requirements for an  
20 Enterprise path validation module (PVM), as specified in NIST Recommendation  
21 for X.509 Path Validation[X.509 Path Validation].  
22 c) Where interoperability across organizations is required, path validation modules  
23 **should** conform to requirements for a Bridge-Enabled PVM, as specified in NIST  
24 Recommendation for X.509 path validation [X.509 Path Validation].  
25 d) Relying party implementations **shall** support CRLs for certificate status, and  
26 **should** support OCSP for certificate status.  
27
- 28 2. Building certificate paths  
29 a) Relying party implementations **shall** be able to build certification paths.  
30 b) At a minimum, relying party implementations **should** be able to obtain CA  
31 certificates and CRLs using LDAP from an organizationally designated local  
32 directory, as well as locations specified within a user certificate.  
33 c) Implementations **should** support http-based certificate retrieval.  
34
- 35 3. Relying parties that work within a single organizational PKI (e.g., a PKI that supports  
36 a company or agency) **should** be able to discover paths for user certificates issued by  
37 CAs that are hierarchically subordinate to the trust anchor CA.  
38
- 39 4. Relying parties that accept certificates from other organizations **should** be able to  
40 discover paths in non-hierarchical PKIs.  
41

---

<sup>14</sup> Organizational key recovery should emphasize security and privacy, rather than performance. Dual control for recovery of a user's keys by the organization is strongly recommended.

### 2.3.6 Client Software

1. Client implementations **shall** support multiple private keys and certificates for each end user to support different cryptographic services. For example, the client implementation **should** support and differentiate between private keys associated with public keys in certificates supporting digital signatures, and private keys associated with public keys in certificates supporting key establishment.
2. Client cryptographic modules **shall** be validated at FIPS 140-2 Level 1 or higher.
3. Client implementations **should** support the certificate management protocol supported by the organization's CA.<sup>15</sup>

## 2.4 Recommendations for System Installers/Administrators

The system installer and administrator is the person (or people) who are responsible for establishing the PKI and who are responsible for the tasks associated with its day-to-day operation. The system administrator **shall** ensure that end users are trained and that the organization's security policy is enforced.

### 2.4.1 Certificate Issuance

1. CAs **shall** be configured to ensure that certificates specify public keys with approved key sizes, valid domain parameters (if appropriate), and approved algorithms.
2. For maximum interoperability, CAs and users **should** use RSA key pairs for digital signatures and key transport.
3. For maximum security and performance, CAs and users **should** use elliptic curve key pairs for digital signatures and key agreement.
4. When signing certificates or CRLs, CAs **shall** generate digital signatures using a signing algorithm, hash function and a padding scheme (if the signing algorithm is RSA) combination specified in Table 2-2.
5. For digital signature certificates, CAs **shall** sign the certificate using a digital signature process (i.e., signature algorithm, hash function and key) whose security strength is equal to or greater than the security strength of the subject public key in the certificate. For key establishment certificates, CAs may sign the certificate using a digital signature process whose security strength is less than the security strength of the subject public key in the certificate<sup>16</sup>.

---

<sup>15</sup> Where keys and certificates are stored on smart cards, and all updates are performed at the RA, user implementations need not support the certificate management protocol.

<sup>16</sup> A public key certificate used for key establishment involves two keys: the subject (key establishment) public key, which is used to establish a symmetric key that will protect data, and the signing key of the Certification Authority (CA), which is used to sign the certificate. The CA's signing key needs to be secure only until the key-establishment certificate expires, but the subject (key establishment) public key

- 1
- 2 6. Generating key pairs:
  - 3 a) Users **should** generate their own digital signature key pairs.
  - 4 b) Key establishment key pairs may be generated by the user or by the PKI on the  
5 user's behalf; where required, the PKI that generated a user's key pair may retain  
6 copies of the key-establishment private key to permit key recovery.
  - 7 c) CAs **should** perform proof of possession for all key pairs before issuing  
8 certificates.
  - 9
- 10 7. CAs **shall obtain** assurance of public-key validity before issuing certificates.
- 11
- 12 8. Key usage extension.
  - 13 a) All certificates issued **shall** include the key-usage extension.
  - 14 b) The key-usage extension **shall** restrict acceptance of the private key to a single  
15 cryptographic function: digital signatures, user authentication, or key  
16 establishment.
  - 17
- 18 9. All certificates **shall** include the CRL distribution-points extension to support the  
19 retrieval of status information.
- 20
- 21 10. If an OCSP responder is supported, a certificate **shall** include an appropriate URL in  
22 the Authority Information Access extension.
- 23
- 24 11. Certificates **should** be renewed before they expire and replaced if there is a change in  
25 the certificate's contents, such as the domain name or the embedded e-mail address.  
26

#### 27 **2.4.2 Certificate Revocation Requests**

- 28 1. CAs **should** be configured to automate revocation processing where practical:
  - 29 a) CAs **should** be configured to authenticate and process revocation requests  
30 electronically.
  - 31 b) Where the CA can authenticate a digitally signed request submitted by the user of  
32 the associated key pair or an RA, the request **should** be handled without manual  
33 intervention.
  - 34
- 35 2. RAs **should** be configured to submit digitally signed revocation requests on behalf of  
36 users or the organization.  
37

---

needs to be secure as long as the data must be secure, which may be long after the key establishment certificate expiration date. As long as the CA's signing key is secure during the certificate's lifetime, and the certificate has been securely archived, any break of the CA signing key after the expiration of the certificate does not affect the validity of the subject (key-establishment) public key or the security that it (the subject public key) can provide. For example, if the security strength of the subject (key establishment) public key is greater than that of the CA's signing key, any break of the signing key after the subject public key is signed does not affect the security of that public key. Therefore, it is acceptable for a key transport or key agreement subject public key to be stronger than the CA key used to sign a certificate containing the key agreement or key transport public key.

### 2.4.3 Certificate Revocation List Generation

1. To maximize interoperability, all CAs **should** be configured to generate full CRLs. A full CRL is a single CRL that lists all revoked and unexpired certificates issued by a particular CA.
2. CAs that serve a large community **should** generate CRL distribution points in addition to full CRLs. Each CRL distribution point lists a subset of the revoked certificates for a given CA. The number of certificates covered by a CRL distribution point **should** be limited to a maximum of 250,000 to ensure that the distribution point CRLs do not grow to an unmanageable size.

### 2.4.4 PKI Repositories for the Distribution of Certificates and CRLs

1. PKIs **should** be configured to provide certificates and CRLs to requesters without authentication of the requester.
2. PKI repositories **shall** be configured to require authenticated access to modify the set of certificates and CRLs distributed by the repository.
3. At a minimum, repositories **shall** support either the HTTP version 1.1 or LDAP version 3 interface.
4. For maximum interoperability, both HTTP and LDAP **should** be supported.
5. Replication of repositories (e.g., through directory shadowing or web server replication) to maximize availability **should** be considered.
6. PKI repositories **should** contain all CA certificates issued by or to the corresponding PKI.
7. PKI repositories **shall** contain all current CRLs.

### 2.4.5 OCSP Responders

For Federal agencies, detailed configuration guidance for OCSP responders is specified in *Draft Guidance for OCSP Responders in the U.S. Federal PKI*.<sup>17</sup>

1. If maximum interoperability is required then:
  - a) OCSP responders **shall not** require that requests be signed and **shall not** limit the set of relying parties to which certificate status information is provided.
  - b) The responders **shall** generate OCSP basic responses, and the responses **shall not** include critical extensions.
2. Where interoperability requirements are limited to a closed community:

---

<sup>17</sup> Draft guidance is available at <http://cio.nist.gov/esd/emaildir/lists/pkits/doc00000.doc>.

- 1 a) OCSP responders may require signed requests, and may reject requests from
- 2 entities outside that community.
- 3 b) OCSP response messages may include private extensions known within the target
- 4 community.
- 5

#### 6 **2.4.6 Backup and Archive**

- 7 1. To maintain the availability of status information, CAs **shall** ensure that sufficient
- 8 information is stored in a secure location to reconstitute the CA after a disaster.
- 9
- 10 2. CAs **should** archive sufficient information to establish when certificates were
- 11 issued, and under whose authority.
- 12
- 13 3. As a general rule, audit logs **should** be maintained, along with any certificates and
- 14 CRLs issued by the CA.
- 15
- 16 4. User public signature verification keys **should** be archived, along with their
- 17 corresponding certificates as long as required.
- 18

#### 19 **2.4.7 Relying Party Integration and Configuration**

- 20 1. Path discovery components **shall** be configured to enable path discovery and
- 21 require the retrieval of status information.
- 22
- 23 2. Status information **should** be accepted in both CRL and OCSP formats.
- 24
- 25 3. Relying party implementations **shall** be configured to recognize the smallest set
- 26 of acceptable trust anchors possible.
- 27
- 28 4. For business-to-government and government-to-government applications, Federal
- 29 agencies **should** use either the Common Policy Root CA or an agency CA that is
- 30 cross-certified with the Common Policy Root CA or the Federal Bridge as the
- 31 trust anchor.
- 32
- 33 5. For citizen-to-government applications with limited security requirements (e.g.
- 34 Level 2 e-Authentication requirements as specified in [OMB 04-04]) and high
- 35 interoperability requirements, agency applications may use the pre-installed trust
- 36 anchors provided in COTS products.
- 37
- 38 6. Path validation modules:
- 39 a) For end-user applications and applications with minimal security
- 40 requirements, path validation modules **should** be configured to accept any
- 41 valid path.
- 42 b) For systems with more significant security requirements (e.g., systems using
- 43 PKI to satisfy Level 3 or Level 4 e-Authentication), path validation modules
- 44 **should** be configured to only accept paths that are valid under appropriate
- 45 policies.

1

## 2 **2.5 User Guidance (Subscribers)**

3 In a PKI, the subject is the identity of the user associated with a public key. The subject  
4 may be a person or a device. For the purposes of this section, the term “user” is means  
5 either the person associated with a public key, or the administrator of a device associated  
6 with a public key.

7

8

1. Users **should** generate their own key pairs for digital signatures and authentication.

9

10

2. Users may generate their own key pairs for key establishment, or the key establishment key pairs may be imported from a trusted source.

11

12

13

3. Users **shall** protect the authenticators (e.g., the PIN or password) that control access to their private keys.

14

15

16

4. Users **shall** request the revocation of their certificates if they believe the authenticator or cryptographic module has been stolen, copied or compromised.

17

18

19

5. Users **shall** verify all CRLs before rejecting claimed revoked certificates in the CRLs.

20

21

22

6. Users **shall** control the disposition of “old” key pairs after certificates expire unless otherwise controlled in accordance with Federal agency policy and procedures.

23

24

25

a) Private signature keys **should** be destroyed after the corresponding certificate(s) expire.

26

27

b) Private key establishment keys need not be destroyed after the corresponding certificate(s) expire. The user **should not** destroy the private key establishment key until all symmetric keys established using this key have been recovered or otherwise protected (e.g., by encrypting under a different key). Premature destruction of private key establishment keys may prevent recovery of the subscriber’s plaintext data.

28

29

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## 3 Internet Protocol Security (IPsec)

### 3.1 Description

IPsec is a suite of protocols for securing Internet communications at the network layer and operates within the Internet Protocol (IP). It is frequently used to establish Virtual Private Networks (VPNs)<sup>18</sup>, requiring both parties to share keying material, and enabling telecommuters or travelers to gain secure access to their business networks. IPsec provides the cryptographic security functions for both versions 4 and 6 of the Internet Protocol.

IPsec operates by inserting one of two special IPsec headers after the IP header in each message. The Authentication Header (AH) provides integrity protection. The Encapsulating Security Protocol (ESP) Header provides confidentiality and/or integrity protection. Hereafter, the terms AH and ESP will be used as shorthand for messages using AH and ESP headers, respectively. Both ESP and AH provide data origin authentication, and optionally provide replay protection. AH protects the IP header and the data following the IP header. ESP, when applied directly to a packet (i.e., in transport mode), protects the data, but not the IP header. However, ESP in tunnel mode (with a new IP header inserted) does protect the original IP header. Furthermore, using ESP with automated keying protects the source and destination addresses in the IP header in either transport or tunnel mode. Since AH processing introduces unnecessary complexity, and since ESP can provide equivalent functionality, the use of AH is not recommended.

There have been three versions of IPsec.<sup>19</sup> All new systems **should** implement IPsec-v3<sup>20</sup>, as it has many enhancements not found in the previous versions. However, IPsec-v2 is still implemented in numerous current systems, despite the fact that it is obsolete.<sup>21</sup>

Two classes of key management methods are specified for IPsec: manual keying and automated keying. Manual keying involves an agreement (in an unspecified manner) by the parties in a communication on the IPsec protections to be applied and the symmetric keys to be used. This has a major downside in that it severely limits the scalability of the security solution and requires re-keying to be done in an unspecified manner. A Security Association (SA, i.e., a relationship between two or more entities that describes how each entity will use the security services to communicate securely) and its secret keys cannot be easily renewed in the cases where the SA expires, has been used for the maximum allowable volume of traffic, or if its keys are compromised.

To use automated keying, an automated negotiation between peers prior to exchanging IPsec-protected traffic determines the IPsec protections to be applied and the symmetric keys to be used. The same method can be used to maintain, delete, or renegotiate the SA

---

<sup>18</sup> See SP 800-77, "Guide to IPsec VPNs" [SP 800-77].

<sup>19</sup> There are no generally accepted names for *IPsec-v3* and *IPsec-v2*; these terms are used in this document to make the requirements more understandable

<sup>20</sup> IPsec-v3 is specified in RFC 4301, RFC 4302, RFC 4303 and RFC 4835.

<sup>21</sup> IPsec-v2 is specified in RFC 2401, RFC 2402 and RFC 2406.



1 (e.g., to rekey). This approach permits a decoupling of the key management mechanism  
2 from the other security mechanisms, thus facilitating the use of alternative key  
3 management methods without having to modify other security mechanisms.

4  
5 The preferred automated keying method is IKE, the Internet Key Exchange protocol that  
6 was designed specifically for use with IPsec. IKE generates the necessary keying material  
7 for IPsec via an authenticated secure channel between the two IKE peers. There are two  
8 versions of IKE in use: IKEv1 [RFC 2407, RFC 2408 and RFC 2409] and IKEv2 [RFC  
9 5996]; both versions perform mutual authentication, and establish and maintain security  
10 associations. SAs will be valid for a specified period of time or volume of traffic. IKEv1  
11 is still implemented in numerous current systems, despite the fact that it is obsolete.  
12 These two versions of IKE are not interoperable. IKEv2 was designed to be more reliable  
13 and efficient than IKEv1; therefore, IKEv2 **should** be used.

14  
15 Table 3-1 provides the IETF reference materials for versions 2 and 3 of IPsec.

16  
17 **Table 3-1. Summary of References for IPsec**

Version	Security Architecture	Privacy	Authentication	Automated Key Management
IPsec-v2	RFC 2401	RFC 2406	RFC 2402, RFC 2406	RFC 2407, RFC 2408, RFC 2409
IPsec-v3	RFC 4301	RFC 4303	RFC 4302, RFC 4303	RFC 5996

18  
19 The IPsec security mechanisms are not tied to any specific cryptographic algorithms; in  
20 fact, many algorithms and modes have IETF Requests For Comment (RFCs) describing  
21 their use with IPsec. This, however, can result in a situation where there are so many  
22 choices for typical system administrators to make that it is difficult to achieve  
23 interoperability. To improve interoperability in IPsec-v3, two cipher suites: VPN-A and  
24 VPN-B were specified [RFC 4308]. However, these two cipher suites are not NIST-  
25 approved cipher suites. Four additional cipher suites have been defined in RFC 6379  
26 [RFC 6379]: Suite-B-GCM-128, Suite-B-GCM-256, Suite-B-GMAC-128 and Suite-B-  
27 GMAC-256 and they are NIST-approved.

28  
29 Implementers may allow the individual selection of security algorithms (i.e., rather than  
30 selecting one of the pre-specified suites of algorithms) specified in the RFC 6379, but  
31 users must be aware that picking non-standard groupings of algorithms may result in  
32 limited interoperability. However, when IPsec is used in the context of a VPN, security  
33 policy can be centrally managed, thus ensuring interoperability without the use of pre-  
34 defined cipher suites. Current IETF algorithm guidance is under development at  
35 <http://tools.ietf.org/html/draft-ietf-ipsecme-esp-ah-reqts-07>.

1 **3.2 Security and Compliance Issues**

2 **3.2.1 Cryptographic Algorithms**

3 Table 3-2 below gives cryptographic algorithm recommendations for use within IPsec.  
 4 The algorithms that are specified for IKE are used to protect IKE’s own traffic. The  
 5 algorithms used in ESP and AH are used to provide IPsec protection to data traffic; for  
 6 these algorithms to be used within ESP or AH, IKE must be capable of negotiating their  
 7 use.

8  
 9 In Table 3-2 below, column four lists the IETF conformance requirements as specified in  
 10 the RFCs by using the three IETF requirement levels: MUST, SHOULD and MAY to  
 11 indicate whether the algorithm needs to be implemented. See RFC 2119 [RFC 2119] for  
 12 definitions of these requirement levels and further information on IETF Conformance  
 13 language. Column five, however, states Federal conformance requirements using two  
 14 levels: Mandatory and Optional. Mandatory means that the feature is required to be  
 15 available in an implementation, and Optional means that implementation of the technique  
 16 is permitted.

17  
 18 **Table 3-2. Cryptographic Algorithm Recommendations**

Protocol	Cryptographic Service	Algorithm/Mode	IETF Requirement (draft-ietf-ipsecme-esp-ah-reqts-01)	Federal Requirement
ESP	Encryption	TDEA in CBC mode	Under development, MAY is the current status.	Optional; if used, TDEA <b>shall</b> use three distinct keys
ESP	Encryption	AES with 128-bit keys in CBC mode	Under development, MUST is the current status.	Mandatory
ESP	Encryption	AES-128 in Counter mode	Under development, MAY is the current status.	Optional; if used, <b>shall</b> be used with integrity protection
ESP or AH	Integrity Protection	HMAC SHA1-96 (key strength <b>shall</b> be equal to or greater than 112 bits)	Under development, MUST is the current status.	Mandatory

Protocol	Cryptographic Service	Algorithm/Mode	IETF Requirement	Federal Requirement
ESP or AH	Integrity Protection	HMAC SHA-256-128 (key strength <b>shall</b> be equal to or greater than 112 bits)	[RFC 4868] SHOULD	Optional
ESP	Encryption and Integrity Protection	AES-128 in Galois/Counter Mode	[RFC 4106], [RFC 4835]	Optional
ESP	Encryption and Integrity Protection	AES-128 in Counter mode with CBC-MAC	[RFC 4309], [RFC 4835] MAY	Optional
ESP or AH	Integrity Protection	AES-128 in GMAC Mode	[RFC 4543]	Optional
IKEv1 or IKEv2	Encryption	TDEA in CBC mode	Under development, MAY is the current status.	Optional; if used, TDEA <b>shall</b> use three distinct keys
IKEv1 or IKEv2	Encryption	AES-128 in CBC mode	Under development, MUST is the current status.	Mandatory
IKEv1 or IKEv2	Pseudo-random function	HMAC-SHA1	[RFC 4109], RFC 4307 MUST	Mandatory
IKEv1 or IKEv2	Pseudo-random Function	HMAC-SHA-256	[RFC 4868] SHOULD	Optional
IKEv1 or IKEv2	Diffie-Hellman Group 24	2048-bit MODP	[RFC 5114]	Mandatory

Protocol	Cryptographic Service	Algorithm/Mode	IETF Requirement	Federal Requirement
IKEv1 or IKEv2	Diffie-Hellman Group 14	2048-bit MODP	[RFC 4109], RFC 4307 SHOULD	Optional
IKEv1 or IKEv2	Integrity	HMAC-SHA1-96 (key strength <b>shall</b> be equal to or greater than 112 bits)	[RFC 4109], [RFC 4307] MUST	Mandatory
IKEv1 or IKEv2	Integrity	HMAC-SHA256-128 key strength <b>shall</b> be equal to or greater than 112 bits)	[RFC 4868] SHOULD	Optional
IKEv1	Peer Authentication	2048-bit RSA with SHA256	[RFC 4109] SHOULD	Mandatory
IKEv1	Peer Authentication	DSA with SHA256	[RFC 4109] MAY	Mandatory
IKEv2	Peer Authentication	2048-bit RSA with SHA256	[RFC 5996] MUST	Mandatory
IKEv2	Peer Authentication	DSA with SHA256	[RFC 5996] MAY	Optional
IKEv1 or IKEv2	Peer Authentication	ECDSA-256 or ECDSA-384	[RFC 4754] MAY	Should

1  
2 In RFC 4835 [RFC 4835] and RFC 2410 [RFC 2410], ESP provides options for NULL  
3 integrity protection or NULL encryption, which means that either no integrity protection  
4 would be applied or no encryption would be used, respectively; however, RFC 4835  
5 specifies that at least one of them MUST be applied. In the RFCs, NULL integrity  
6 protection (often referred to as NULL authentication) is intended for use in situations  
7 where confidentiality is required without the need for integrity protection. NULL  
8 integrity protection **shall not**, and in fact cannot, be used with NULL encryption. ESP,  
9 for example, could send unencrypted packets, (encryption set to NULL), but would be  
10 required to integrity-protect them, for example, by using HMAC-SHA1. On the other  
11 hand, ESP could send packets encrypted with AES-128 in CBC mode, but omit the  
12 integrity check (integrity protection set to NULL).

13

1 However, to be compliant with this Recommendation, IPsec ESP-protected traffic **shall**  
2 always be integrity-protected, either through the use of an integrity-protection algorithm,  
3 such as HMAC-SHA1-96, or through the use of a combined-mode algorithm, such as  
4 AES-128 in Galois/Counter Mode. Therefore, encrypted ESP **shall not** be used with  
5 NULL integrity-protection.

6  
7 When IPsec-protected traffic is integrity-protected, an Integrity Check Value (ICV) is  
8 stored in the Integrity Check Value field of the ESP payload (see RFC 4303) or in the  
9 Integrity Check Value field of the Authentication Header (AH) (see RFC 4302); this field  
10 is referred to as the “Authentication Data” field in IPsec-v2 [RFCs 2406 and 2402].

11  
12 When HMAC is used for integrity protection, the length of the ICV value is at most the  
13 size of the output value of the hash function. For example, the ICV value for HMAC-  
14 SHA1-96 and HMAC-SHA256-128 is 96 and 128 bits, respectively (see RFC 4868 [RFC  
15 4868]).

16  
17 Although the IETF still recommends supporting AES-XCBC-MAC (see [RFC 3566 and  
18 RFC 4434] and <http://tools.ietf.org/html/draft-ietf-ipsecme-esp-ah-reqts-07>), and also  
19 allows the use of HMAC-MD5 (not shown in the table), neither is approved for use by  
20 the Federal government. As such, AES-XCBC-MAC and HMAC-MD5 **shall not** be used  
21 for integrity protection.

22  
23 A new class of algorithms, called combined-mode algorithms, appears in the above table.  
24 They can be negotiated by IKE and used within IPsec-v3 cipher suites. These algorithms  
25 provide both encryption and integrity protection. Two combined-mode algorithms have  
26 been approved for Federal government use: AES in Galois/Counter Mode (GCM) [RFC  
27 4106] and AES in counter mode with CBC-MAC (AES-CCM) [RFC 4309].

28  
29 There is also a variant of AES-GCM, referred to as AES-GMAC [RFC 4543], that  
30 provides integrity protection, but does not provide encryption. This mode may be used  
31 within either the ESP or AH header.

32  
33 The maximum size of the ICV for AES-CCM, AES-GCM and AES-GMAC is 16 bytes.  
34 Implementations **shall** support an ICV size of 16 bytes for these three algorithms [RFCs  
35 4309, 4106, 4543].

36  
37 AES-GCM, AES-CCM, AES-CTR, and AES-GMAC **shall not** be used with manually  
38 distributed keys. If the counter value, in AES-CTR or AES-CCM, or the IV value, in  
39 AES-GCM or AES-GMAC, is used for more than one packet with the same key, the  
40 security of the algorithm’s confidentiality mechanism is compromised. Since manual  
41 keying presents a major challenge to this limit, manually distributed keys **shall not** be  
42 used with these algorithms. Automated keying using IKE establishes secret keys for the  
43 two peers within each Security Association, with an extremely small probability of  
44 duplicate keys.

45  
46 In previous IETF guidance, single DES using the CBC mode [RFC 2405] was  
47 mandatory-to-implement; however, this algorithm **shall not** be used to protect  
48 information.

1  
2 IPsec allows the individual selection of security algorithms. As an example, an  
3 implementer using Table 3-2 and following the guidance of Part 1 of SP 800-57, could  
4 select the following algorithms to form an IPsec suite with an overall security strength of  
5 112 bits:

- 6 • ESP Encryption: AES in CBC mode
- 7 • ESP Integrity Protection: HMAC-SHA1
- 8 • IKEv2 Encryption: AES in CBC mode
- 9 • IKEv2 Pseudo-random function: HMAC-SHA1
- 10 • IKEv2 Diffie-Hellman group: 2048-bit MODP
- 11 • IKEv2 Integrity: HMAC-SHA1
- 12 IKEv2 Peer Authentication: 2048-bit RSA with SHA-256

13  
14 The Suite-B-GCM-128 and Suite-B-GCM-256 suites are both defined in RFC 6379. At  
15 present, these cipher suites are not widely available or deployed. SP 500-267 states that  
16 support for these cipher suites is optional. However, wherever practical, implementations  
17 **should** be procured that support these cipher suites, and they **should** be selected for use  
18 wherever very high performance and security strength are required. As discussed above,  
19 AES-GCM is a combined-mode algorithm that provides both encryption and integrity  
20 protection; therefore these suites provide integrity, despite the fact that the integrity  
21 mechanism is listed in RFC 6379 as NULL for both suites.

### 22 **3.2.2 Additional Recommendations**

- 23  
24 1. The Authentication Header (AH) **should not** be used in IPsec version 3.
- 25  
26 2. IKE **should** be used for automated key management to ensure a re-keying capability  
27 and scalability.
- 28  
29 3. Once an ESP Security Association has expired or is no longer in use, its ESP  
30 encryption keys **shall** continue to be protected by the system and kept secret as long  
31 as the data they were used to protect needs to be kept secret.
- 32

### 33 **3.3 Procurement Guidance**

34 These recommendations are written to assist individuals responsible for selecting security  
35 products that include IPsec for the security of the IP layer.

- 36  
37 1. Any IPsec system for use within the Federal government **should** include an IKE  
38 implementation for automated key management.
- 39  
40 2. IPsec implementations **shall** include approved algorithms for each IPsec security  
41 component.
- 42  
43 3. IPsec implementations **should** include the algorithms used in the Suite B cipher  
44 suites.
- 45

### 3.4 Recommendations for System Installers

Systems installers are those individuals that install products that include IPsec for security.

1. IKE **should** be used for automated key management within any IPsec system.
2. NULL encryption **shall** only be employed when integrity protection is required, but confidentiality is not needed.
3. Installers **should** select approved algorithms for each security component, as specified in Section 3.2.

### 3.5 Recommendations for System Administrators

System administrators are those individuals responsible for the day-to-day functioning of the security product containing IPsec. System administrators **shall**:

1. Ensure that end users are properly trained and that the organization's security policy is enforced.
2. Ensure that a key used by the product is protected throughout its lifespan.

### 3.6 Recommendations for End Users

An end user is the individual using a product that relies on IPsec for security. End users **shall**:

1. Be aware of and trained to follow the organization's security policy for using the product.
2. Operate their system as instructed by their organization and system administrator.

## 4 Transport Layer Security (TLS)

This section was moved to SP 800-52 revision 1 and this document has been published at <http://csrc.nist.gov/publications/PubsSPs.html#800-52>.

## 5 Secure/Multipart Internet Mail Extensions (S/MIME)

### 5.1 Description

Secure/Multipurpose Internet Mail Extensions (S/MIME) provides a consistent way to send and receive secure Internet mail. S/MIME is a set of specifications that are defined by a series of IETF RFCs, namely RFC 5751 [RFC 5751], RFC 5652 [RFC 5652], RFC 2045 [RFC 2045], RFC 2046 [RFC 2046], RFC 2047 [RFC 2047], RFC 4288 [RFC

1 4288], RFC 4289 [RFC 4289] and RFC 2049 [RFC 2049]. S/MIME provides the  
2 following cryptographic security services for electronic messaging applications:

- 3
- 4 • Authentication of a sending party using digital signatures,
- 5 • Message integrity and non-repudiation of origin using digital signatures, and
- 6 • Confidentiality using encryption.
- 7

8 S/MIME, therefore, requires a suite of algorithms for creating digital signatures,  
9 generating hash values, establishing keys and encrypting the content of the e-mail, as  
10 well as some means of establishing and sharing digital identities. Federal  
11 implementations rely on a public key infrastructure, specifically X.509 PKI, to establish  
12 S/MIME user identities, to bind those identities to the user's public key through public  
13 key certificates, to provide digital signatures, to provide keys to be used for content  
14 encryption, or to establish symmetric keys for use on a per message basis. For detailed  
15 information on PKIs, see Section 2 of this Recommendation.

16  
17 Stored electronic mail encompasses key management issues associated with encrypted  
18 file integrity and with transmission over a network. It is therefore necessary 1) to  
19 establish pair-wise and/or multicast (sent to more than one recipient) key management  
20 relationships between the sender and receiver(s) and 2) to securely store the key(s)  
21 associated with encrypted e-mail until it is no longer necessary for a recipient to be able  
22 to decrypt or verify the integrity of the e-mail.

23  
24 S/MIME is not restricted to e-mail; it can be used with any transport mechanism that  
25 employs MIME protocols, such as the Hypertext Transfer Protocol (HTTP).

## 26 27 **5.2 Security and Compliance Issues**

28 S/MIME products can be implemented with different combinations of security features  
29 and a variety of cryptographic algorithms. Senders and receivers may have different  
30 capabilities and may be sending messages protected with algorithms of different  
31 strengths. This can lead to numerous interoperability issues. Federal clients using secure  
32 e-mail **shall** be able to perform the following:

- 33
- 34 • Send and receive signed messages,
- 35 • Send and receive encrypted messages,
- 36 • Send and receive signed and encrypted messages,
- 37 • Request, send and process signed receipts, and
- 38 • Process messages from secure e-mail list clients (includes suppressing receipts, as  
39 required, and nondisclosure of list recipients, as required).
- 40

41 Furthermore, Federal systems **shall**:

- 42 • Utilize cryptographic modules that are FIPS 140-1 or FIPS 140-2 certified,
- 43 • Support cryptographic Cipher Suite 1 (see Table 5-1 below), and
- 44 • Support X.509 certificates that conform to Federal PKI X.509 Certificates and the  
45 CRL Extensions Profile.
- 46



1 Federal clients **should** be capable of sending and processing e-mail with security labels  
 2 and securely binding senders' certificates to their signatures through the signing  
 3 certificate attribute as described in RFC 5035 [RFC 5035].<sup>22</sup>  
 4

5 The most widely accepted, standard S/MIME profile is RFC 5751. Not all cryptographic  
 6 algorithms available for use in support of the features in the profile are appropriate for the  
 7 protection of Federal government information. The S/MIME specifications allow the  
 8 selection of individual algorithms. However, a number of cipher suites have been  
 9 specified to define a specific combination of algorithms. Federal organizations **shall** use  
 10 approved algorithms within S/MIME implementations for key establishment and  
 11 transmitting messages. Tables 5-1 through 5-3 specify a variety of cipher suites that may  
 12 be used to protect Federal information and information systems (based on [SP 800-49],  
 13 [RFC 6318]). Any of the algorithms listed in the following tables may be used, in  
 14 accordance with security strength time frame restrictions given in Part 1 and SP 800-  
 15 131A [SP 800-131A] to protect Federal information in combinations other than those  
 16 displayed.  
 17

18 **Table 5-1: Cipher Suite 1**

Mechanism	Guidance
Digital Signatures	DSA with key sizes $\geq$ 2048 bits [FIPS 186-4]
Hash	SHA-256 [FIPS 180-4]
Key Agreement	Diffie-Hellman with key size $\geq$ 2048bits [SP 800-56A]
Encryption	AES-128 in CBC mode [FIPS 197] and [SP 800-38A]

19  
 20 **Table 5-2: Cipher Suite B, Level 1\***

Mechanism	Guidance
Digital Signatures	ECDSA with P-256 [X9.62]
Hash	SHA-256 [FIPS 180-4]
Key Agreement	ECDH with P-256 [SEC1]
Key Derivation	Based on SHA-256 [SEC1]
Key Wrap	AES-128 [RFC 3394]
Encryption	AES-128 in CBC mode [FIPS 197] and [SP 800-38A]

21 \*see [RFC 6318]

<sup>22</sup> Both of these services are defined in S/MIME V3 standards RFC 2634 [RFC 2634].

1

2 **Table 5-3: Cipher Suite B, Level 2\***

Mechanism	Guidance
Digital Signatures	ECDSA with P-384 [X9.62]
Hash	SHA-384 [FIPS 180-4]
Key Agreement	ECDH with P-384 [SEC1]
Key Derivation	Based on SHA-384 [SEC1]
Key Wrap	AES-256 [RFC 3394]
Encryption	AES-256 in CBC mode [FIPS 197] and [SP 800-38A]

3 \* see [RFC 6318]

4

5 Federal clients **shall** be supported by a Public Key Infrastructure with valid Federal PKI  
6 X.509 certificates for senders and receivers.

7

8 Cryptographic modules used in Federal systems **shall** comply with FIPS 140-2.

9

10 Federal S/MIME implementations may, in accordance with organizational policies, be  
11 capable of receiving messages protected with algorithm suites that are not approved for  
12 Federal use in sending protected messages. In those instances, users **should** be presented  
13 with a warning banner explaining that the cryptographic mechanisms used are weak and,  
14 therefore, that integrity and authentication cannot be assured.

15

### 16 **5.3 Procurement Guidance**

17 The following recommendations are for any individual that makes a purchasing decision  
18 for acquiring an S/MIME-enabled component.

19

- 20 1. In support of security and compatibility across the Federal government, all  
21 Federal information systems **shall** support Cipher Suite 1.
- 22 2. Procurement officials **should** buy products that support Cipher Suite B, either  
23 Level 1, Level 2, or both.
- 24 3. Federal clients **may** support RC2 for use only in the event that users receive  
25 correspondence encrypted with this weaker and unapproved algorithm.
- 26 4. Federal agencies **shall not** use SHA-1 for digital signature generation; however, it  
27 can be used for the verification of digital signatures signed using SHA-1.  
28 Cryptographic algorithm implementations **should** be modular so as to allow for  
29 new algorithms.  
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5. If an S/MIME client needs to generate a key pair, then the S/MIME client or some related administrative utility or function **shall** be capable of generating public/private key pairs on behalf of the user.

#### 5.4 Recommendations for System Installers

The system installer is the individual that installs the S/MIME application and performs the initial configuration of the system.

1. Federal clients **shall** be configured to support Cipher Suite 1 for interoperability as described above in Section 5.2.
2. Systems **shall** be configured so that they only permit the use of approved cryptographic algorithms and approved key sizes to encrypt or sign new messages.
3. Installers **should** install and configure S/MIME clients so that they default to the use of an approved cipher algorithm suite. Furthermore, installers **should** configure clients so that there is a straightforward means for end users to change default settings and select algorithms as needed for interoperability and in accordance with organizational needs and policies.
4. System installers **should** configure clients so that end users can use unique certificates for each security function (e.g., encryption, digital signatures) at their disposal.

#### 5.5 Recommendations for System Administrators

The System Administrator is the individual who runs the S/MIME application on a day-to-day basis and, on client implementations, interacts with the end user.

1. The system administrator **shall** ensure that end users are properly trained and that the organization's security policy is enforced.
2. Systems **shall** be maintained so that they only permit the use of approved cryptographic algorithms and approved key sizes to encrypt or sign new messages.
3. Administrators **should** maintain S/MIME clients so that they default to the use of an approved cipher algorithm suite. Furthermore, administrators **should** maintain a straightforward means for end users to change default settings and select algorithms as needed for interoperability and in accordance with organizational needs and policies.

- 1 4. System administrators **should** provide training for users on the relative security  
2 provided by various cryptographic algorithms and on organizational policies for  
3 their use.  
4
- 5 5. System administrators **should** provide end users with guidance on how  
6 certificates and keys are stored and managed, and identify the end user's related  
7 responsibilities.  
8

## 9 **5.6 Recommendations for End Users**

10 An end user is the individual using a client to access the system. Even within a centrally  
11 managed environment, end users may find that they have a significant amount of control  
12 over some of the security features within an SMIME implementation.  
13

- 14 1. Users **shall** operate their system as instructed by their organization and system  
15 administrators.  
16
- 17 2. Users **should** use unique certificates for each security function at their disposal.<sup>23</sup>  
18
- 19 3. Users **shall** protect their private keys from unauthorized disclosure.  
20
- 21 4. Users **should not** send the same message in both encrypted and plain text.  
22  
23  
24

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<sup>23</sup> If they have not been supplied with certificates by their home organizations, users can obtain certificates from a number of organizations via the web.

## 6 Kerberos

### 6.1 Description

The Kerberos authentication mechanism was developed at MIT to enable the secure authentication of users to Target Servers (TSs) over an unprotected network, where client software acts on behalf of a user<sup>24</sup>. The original design and implementation of Kerberos and its first three revisions (i.e., versions 1 through 4) was primarily the work of Steve Miller, Clifford Neuman, Jerome Saltzer and Jeffrey Schiller<sup>25</sup>. Kerberos is used for local logins, remote (over the network) authentication, and for client-to-TS requests. It can also be extended to provide for the establishment of cryptographic keys between a client and a TS. Kerberos has been designed so that a user and a TS rely on a trusted third party to provide assurance of each party's identity. This assurance is granted by means of tickets and authentication information, each encrypted with symmetric keys.

The trusted third party is a Key Distribution Center (KDC), which consists of an Authentication Server (AS) and a Ticket Granting Service (TGS). The AS and TGS may or may not reside on the same machine. The KDC has a database of user, TS, and TGS symmetric keys. All KDC symmetric keys are accessible by the TGS. The user's key is normally created by hashing a user's password with other information.

An overview of the Kerberos version 5 protocol is shown in Figure 6-1. The following is a simplification of the process (e.g., the generation of most keys and the use of most cryptographic operations are not specified). For example, tickets and authentication information are protected with checksums and encryption when transmitted.

1. A user logs onto a client by entering a password, from which a user symmetric key is generated.
2. The client, acting on behalf of the user, requests a Ticket Granting Ticket from the AS.
3. The AS generates a Ticket Granting Ticket, for a specified validity period, and sends it to the client.
4. The client provides the Ticket Granting Ticket to the TGS, along with his own authentication information, which includes the client identifier and a time stamp.
5. The TGS checks the authentication information and the validity period of the Ticket Granting Ticket. The TGS then generates a Target Server Ticket and sends it to the client.
6. The client sends authentication information and the Target Server Ticket to the TS.

---

<sup>24</sup> Note that a single client implementation may be used by multiple users, and a single user may use multiple client implementations (e.g., a user could access different workstations, each with its own client implementation).

<sup>25</sup> The design was based in part upon a protocol proposed by Needham and Schroeder [NEED] with modifications provided by Denning and Sacco [DENN]. For more detail on the goals, motivations, and rationale of Kerberos see [NEUM].

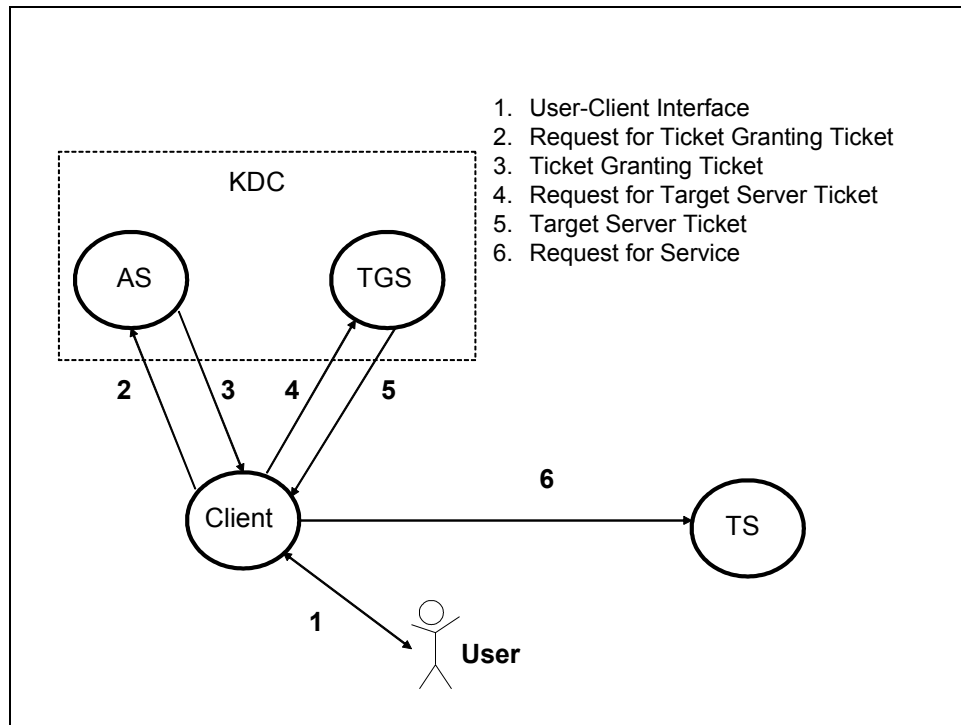
1 7. The TS checks the authentication information and the validity period of the Target  
2 Server Ticket; if the information is reasonable, the user is authenticated to the TS.

3

4 The protocol may be extended to authenticate the TS to the user, and a ticket may be re-  
5 used within its validity period.

6

7



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**Figure 6-1: The Kerberos Protocol**

10

11 Each TGS has its own “realm” of clients and TSs. However, different realms may be  
12 linked by the sharing of inter-realm keys between TGS's (see Figure 6-2). A client in  
13 Realm 1 wishing a service on a TS in Realm 2 may obtain a ticket from TGS1 that  
14 introduces the client to TGS2. This ticket is encrypted with the inter-realm key shared  
15 between TGS1 and TGS2. The client can then request a ticket from TGS2 for the desired  
16 service on the TS in Realm 2. Thus, realms may be networked to provide clients with  
17 inter-realm services.

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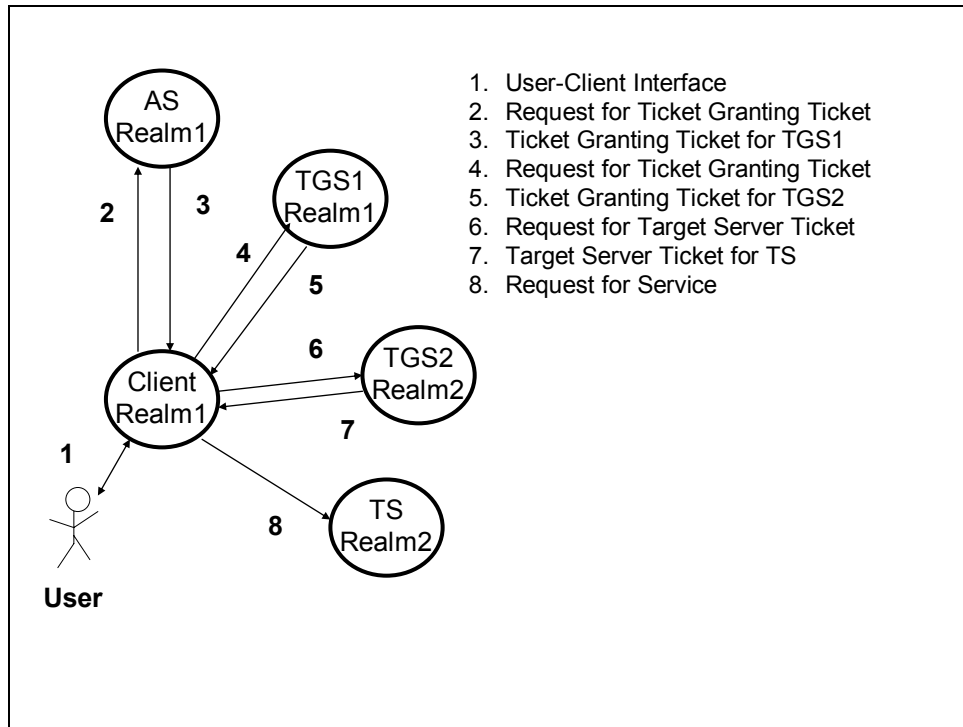
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**Figure 6-2: Cross-Realm Authentication**

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6 In an alternative Kerberos protocol between the client and the AS (as specified in RFC  
7 4556 [RFC 4556]), either both the user and the AS have key-establishment public key  
8 pairs with corresponding certificates, or the user has a key-establishment key pair and  
9 associated certificate, and the AS has a digital signature key pair and digital signature  
10 certificate. The user symmetric key can then be established between the client and the  
11 KDC in one of two ways:

- 12 1. using key agreement (e.g., Diffie-Hellman) between the AS and the client<sup>26</sup>, or
- 13 2. using key transport (e.g., RSA), where the AS generates the user symmetric key,  
14 and sends the key to the client<sup>27</sup>.

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Once the user symmetric key is established, the remainder of the protocol proceeds as  
previously described. In this case, the need for user symmetric keys generated from  
passwords can thus be avoided.

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Kerberos implementations may provide an additional authentication capability that is  
called pre-authentication, as described in RFC 6113 [RFC 6113]. TLS may also be  
implemented to protect all communication between the clients and KDCs as described in  
RFC 6251 [RFC 6251].

<sup>26</sup> In this case, both the user and the AS have key-establishment key pairs.

<sup>27</sup> In this case, the user has a key-establishment key pair, and the AS has a digital-signature key pair.

## 1 6.2 Security and Compliance Issues

- 2 1. Kerberos version 5 was initially specified in RFC 1510 [RFC 1510]. More  
3 recently, the security was updated in version 5; see RFC 4120 [RFC 4120] and  
4 RFC 6649 [RFC 6649]; however, many existing implementations still correspond  
5 to the initial RFC.
- 6 2. Many current Kerberos implementations based on RFC 1510 rely on DES for  
7 symmetric encryption functions. DES is no longer approved for use in protecting  
8 Federal government information and has been deprecated as well in Kerberos  
9 [RFC 6649].
- 10 3. If a keyless checksum computation is used for the data integrity of Kerberos  
11 messages, the integrity of the message may be inadequate.
- 12 4. Some Kerberos implementations rely solely on the entropy (i.e., randomness)  
13 provided by the user password to generate the symmetric client key (the client key  
14 is a hash of the user's password). Passwords, in general, do not provide enough  
15 randomness for generating a key. In such cases, a dictionary attack<sup>28</sup> is feasible. If  
16 passwords are used to generate cryptographic keys, they **should** be selected to  
17 maximize the difficulty of a password guessing attack, thus increasing the  
18 difficulty of an off-line dictionary attack; see SP 800-118 [SP 800-118].<sup>29</sup>
- 19 5. Compromising the client, KDC, or TS could compromise the symmetric keys that  
20 they contain and thereby compromise parts of the system. In particular, the KDC  
21 stores keying information for all the KDC users, the TGS, and any TS that  
22 communicates directly with the KDC TGS. These symmetric keys require  
23 protection that is commensurate with the protection required for the data that they  
24 protect (e.g., tickets, other keys, authentication information, and shared data).
- 25 6. The TGS has read-only access to the KDC database. If the TGS and database do  
26 not reside on the same machine, a secure channel is required for the TGS to obtain  
27 the required TS keys.
- 28 7. A failure of the AS or the TGS would prevent all AS users from obtaining new  
29 tickets and corresponding new services.
- 30 8. Clocks must be synchronized in order to accurately assess the validity of clock  
31 authentication information and tickets. If the TS's clock is running behind the  
32 clock of the KDC (or AS), then previous authentication information and tickets  
33 could be played back to the TS after they have expired.
- 34 9. If a Kerberos implementation has a TLS capability, then it **should** be used when  
35 the DH key agreement or RSA key transport method discussed above is not used.

---

<sup>28</sup> A **dictionary attack** is a technique for guessing a password by selecting candidate passwords from a list of words commonly found in a dictionary, or derived from words commonly found in a dictionary. Each selected candidate is tested as though it were the actual password until the result of the test indicates that the correct password has been selected.

<sup>29</sup> SP 800-118 Guide to Enterprise Password Management is currently under development. The current draft can be found at <http://csrc.nist.gov/publications/PubsSPs.html>.



1

## 2 **6.3 Procurement Guidance**

3 The following recommendations are for any individual that makes a purchasing decision  
4 for acquiring a Kerberos capability.

5

- 6 1. New procurements **shall** conform to version 5; see RFC 4120 and RFC 6649.
- 7 2. Government procurements **shall** specify the inclusion of approved symmetric key  
8 encryption algorithms (e.g., the Advanced Encryption Standard (AES)) RFC 3962  
9 [RFC 3962].
- 10 3. An approved MAC computation (e.g., HMAC-SHA1 or HMAC-SHA256-128)  
11 **shall** be available for data integrity with encryption (see RFC 3962 and  
12 <http://tools.ietf.org/html/draft-ietf-kitten-aes-cbc-hmac-sha2-00>).
- 13 4. Kerberos version 5 permits the use of smart cards or tokens (e.g., FIPS 201  
14 Personal Identity Verification cards, [FIPS 201]) to store a user's password.  
15 Passwords stored on tokens **shall** be randomly generated; therefore, when tokens  
16 are used, a means of generating random passwords and securely writing them on  
17 the token **shall** be available and the password generation function **shall** be a  
18 NIST-approved random number generation function, see [SP 800-90A]. When  
19 tokens are used, the manual entry of passwords **shall not** be permitted except to  
20 authenticate the user to the token.
- 21 5. If passwords are used to form user symmetric keys, then the password mechanism  
22 **shall** support the use of strong passwords (see SP 800-118), and an approved hash  
23 algorithm (e.g., SHA-1 or stronger) **shall** be used as the hash algorithm.
- 24 6. If passwords are generated by users, then the system software **shall** enforce a  
25 strong password policy in accordance with SP 800-118.
- 26 7. Kerberos with public key authentication and subsequent key establishment can  
27 provide stronger security than the use of password-based keys and **should** be  
28 available where PKI mechanisms are available. See RFC 4556 and RFC 5349  
29 [RFC 5349] for further information. Key-establishment methods (i.e., key-  
30 agreement or key-transport methods) used **shall** have at least 112 bits of security;  
31 see SP 800-57, Part 1 and SP 800-131A for further information.
- 32 8. TLS **should** be used when the system supports it.
- 33 9. Procurement officials **should** consider whether inter-realm networking is  
34 necessary and include the capability in the software if it's needed.
- 35 10. Cryptographic modules used by CAs, TSs and clients **shall** be validated at FIPS  
36 140-2 Level 1 or higher.

37

## 38 **6.4 Recommendations for System Installers**

39 The system installer is any individual(s) that installs a Kerberos capability and performs  
40 the initial configuration of the system.

41

- 1 1. Government systems **shall** be configured so that approved algorithms (e.g., AES)  
2 **shall** be used (see RFC 3962), and DES **shall not** be used [RFC 6649].
- 3 2. An approved MAC checksum (e.g., HMAC-SHA1 or HMAC-SHA256-128) **shall**  
4 be installed and used in all implementations for data integrity purposes; see RFC  
5 3962 and <http://tools.ietf.org/html/draft-ietf-kitten-aes-cbc-hmac-sha2-00>.
- 6 3. The AS, TGS, TSs, and clients **shall** use strong access control mechanisms<sup>30</sup>  
7 (physical and logical) for protecting and updating keys.
- 8 4. Kerberos version 5 permits the use of smart cards or tokens (e.g., FIPS  
9 201 Personal Identity Verification cards) to store a user's password.  
10 Passwords stored on tokens **shall** be randomly generated; therefore, when  
11 tokens are used, a means of generating random passwords by a NIST-approved  
12 random number generation function, see [SPs 800-90 A, B and C], and securely  
13 writing them on the token **shall** be used. When tokens are used,  
14 manual entry of passwords **shall not** be permitted except to authenticate  
15 the user to the token.
- 16 5. Kerberos with public key-based user authentication and key establishment can  
17 provide stronger security than password-based keys and **should** be installed where  
18 PKI mechanisms are available and the software has the capability. See RFC 4556  
19 for further information.
- 20 6. TLS **should** be used when the system supports it, see Section 4 for guidelines on  
21 using TLS.
- 22 7. If user passwords are generated by the system, the system **shall** generate strong  
23 passwords; see SP 800-118 [SP 800-118]. If passwords are used to form user  
24 symmetric keys, then an approved hash algorithm (e.g., SHA-1 or stronger) **shall**  
25 be used as the password-hashing algorithm.
- 26 8. If user passwords are used to generate cryptographic keys, the password  
27 mechanism **shall** be configured to use and require strong passwords; see SP 800-  
28 118.<sup>29</sup>
- 29 9. A backup AS and TGS **should** be provided so as to minimize the impact in case  
30 of operational failure or denial-of-service attacks.
- 31 10. Clocks **should** be synchronized periodically and whenever a new system is  
32 brought on-line<sup>31</sup>.

33

## 34 **6.5 Recommendations for System Administrators**

35 The System Administrator is any individual(s) who runs a system with a Kerberos  
36 capability on a day-to-day basis and interacts with the end user.

37

---

<sup>30</sup> Strong access control mechanisms either prevent or detect unauthorized attempts to access or replace sensitive data. These controls may be physical (e.g., locks, guards, or alarms) or logical (e.g., encryption, data integrity, or entity authentication).

<sup>31</sup> (see <http://www.nist.time.gov>).

- 1 1. System administrators **shall** ensure that users are properly trained and that the  
2 organization's security policy is enforced.
- 3 2. The AS, TGS, TS, and client **shall** be physically secured.
- 4 3. Tickets **shall** be encrypted or physically protected at the client, TS, and TGS sites.
- 5 4. If the passwords are generated by the user, then the system administrator **shall**  
6 develop a policy for selecting strong passwords that is enforced by the software;  
7 see SP 800-118.<sup>29</sup>
- 8 5. System clocks **shall** be periodically verified to ensure synchronization.

9

## 10 **6.6 Recommendations for End Users**

11 An end user is the individual using the Kerberos capability.

12

- 13 1. If user-selected passwords are allowed, they **shall** be generated in accordance  
14 with the organization's password policy.
- 15 2. Users **shall** protect their password from unauthorized disclosure. If a token  
16 containing a password or key is provided, users **shall** protect the token from  
17 unauthorized use. Users **shall** report the loss of physical tokens or the  
18 compromise of passwords.

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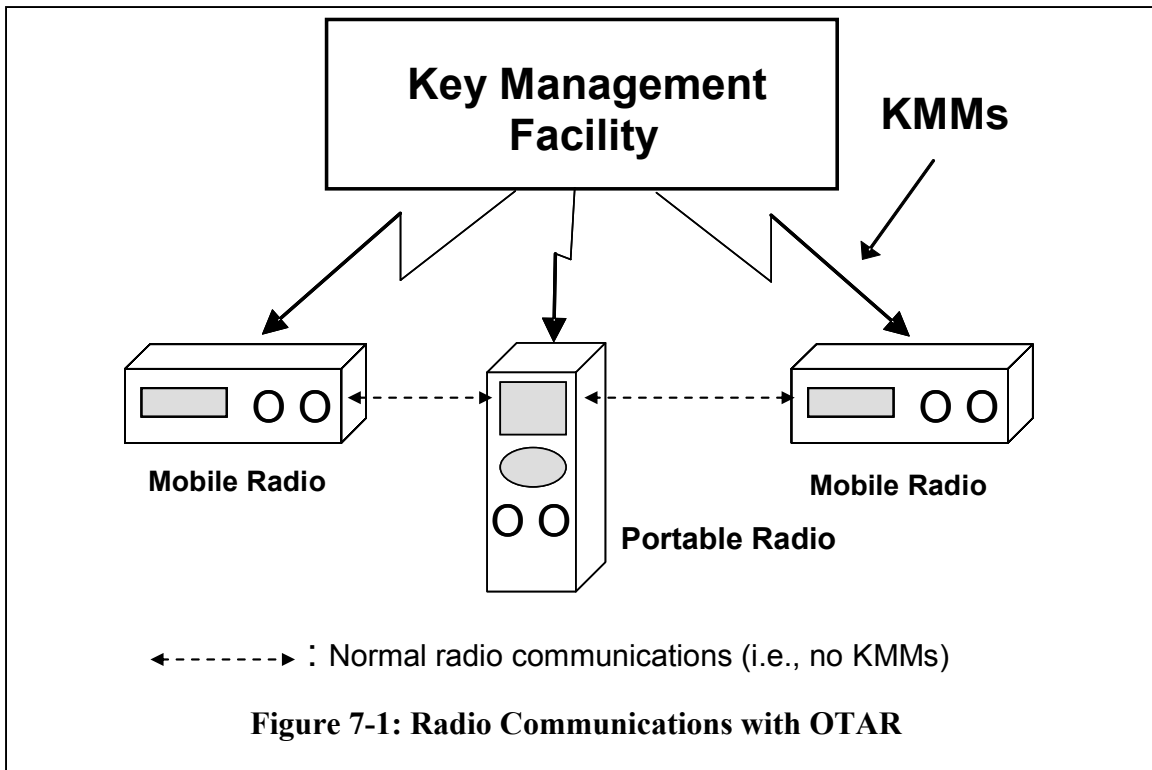
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2 **7 Over-The-Air Rekeying (OTAR) Key Management Messages**  
3 **(KMMs)**

4 **7.1 Description**

5 A key management protocol has been specified for over-the-air rekeying of digital radios  
6 (OTAR) [OTAR]. This protocol has been designed to handle several types of  
7 cryptographic security, one of which, Type 3, has been designed for unclassified,  
8 sensitive communications and is discussed herein. The only differences between the  
9 security types are the cryptographic algorithms used and the security requirements. The  
10 Type 3 algorithms and security requirements are addressed in both OTAR and OTAR1  
11 [OTAR1]<sup>32</sup>.

12  
13 For key management, a secure mobile system consists of Key Management Facilities  
14 (KMFs) and mobile radios that are subordinate to each KMF. Key Management  
15 Messages (KMMs) are exchanged between each KMF and its subordinate mobile radios  
16 (see Figure 7-1). Cryptographic keys are transferred from a KMF to a mobile radio and  
17 protected using a key-wrapping algorithm and key wrapping key; many of the KMMs are  
18 protected by encrypting the data in the messages; the integrity of the messages is  
19 protected using a Message Authentication Code (MAC).



**Figure 7-1: Radio Communications with OTAR**

20

<sup>32</sup> [OTAR] provides an overview of the key management techniques and the protocol. [OTAR1] specifies the general security requirements for transmitting Type 3 key management messages (KMMs), the requirements for wrapping the keys, the techniques used for KMM integrity and the mechanism used to protect against replay of the KMMs.

1  
2 Three general types of keys are used in OTAR: a Key-Wrapping Key (KWK)<sup>33</sup>, a  
3 Traffic-Encryption Key (TEK) and a key to be used for the computation of a Message  
4 Authentication Code (MAC).  
5

## 6 **7.2 Security and Compliance Issues**

### 7 **7.2.1 Cryptographic Algorithms**

8 Although the protocol has been designed to allow the use of any block cipher algorithm  
9 to apply the cryptographic protection, only three block cipher algorithms have been  
10 included in the specification: DES, TDEA and AES.  
11

12 Approval for DES has been withdrawn because DES no longer provides the security that  
13 is needed to protect Federal government information.  
14

15 TDEA, as specified in SP 800-67, uses three DES encryption/decryption operations with  
16 a “key bundle” consisting of three separate DES keys. Two versions of TDEA have been  
17 included in the OTAR specification: a one-key version, whereby all three keys are the  
18 same for compatibility with DES, and a three-key version (3-TDEA), whereby the three  
19 keys are different. Since DES is no longer considered secure, the one-key version of the  
20 TDEA is also no longer considered secure and **shall not** be used.  
21

### 22 **7.2.2 Message Authentication and Cryptoperiods**

23 A Message Authentication Code (MAC) is used to authenticate and protect the integrity  
24 of many of the KMMs as specified in OTAR1, using the CBC-MAC mode of operation.  
25 The security of a MAC depends, in part, on the block size of the MAC algorithm. AES  
26 has a larger block size than 3-TDEA, and so the security of AES CBC-MAC is better  
27 than 3-TDEA CBC-MAC. The OTAR documentation provides no guidance on the length  
28 of cryptoperiods (i.e., the number of messages or the length of time that a key may be  
29 used before it must be changed).  
30

31 For AES, the number of messages that can be authenticated using a given key is, in  
32 practice, not an issue. However, AES keys **shall** be periodically updated because of other  
33 threats to the system, e.g., lost radios or an undetected compromise of a key.  
34

35 When using 3-TDEA, no more than 1,000,000 messages **shall** be sent using a given key  
36 because of threats to the security of the algorithm. However, like AES, it may be prudent  
37 to update the 3-TDEA keys more frequently because of other threats to the system.  
38

---

<sup>33</sup> A Key Wrapping Key may also be referred to as a Key Encryption Key (KEK).

1    **7.2.3 Key Usage**

2    Part 1 of this Recommendation states that keys **shall** be used for only one purpose.<sup>34</sup>  
3    However, OTAR1 states that the key used to generate a MAC must be either a key  
4    reserved for authentication and integrity protection purposes, or a key derived from a  
5    Traffic-Encryption Key (TEK) using a key wrapping algorithm. In this latter case, note  
6    that the TEK might be used for both encryption and for key derivation. In order to  
7    comply with the recommendation to use a key for only one purpose, the MAC key **shall**  
8    be a key reserved for a single purpose.  
9

10   **7.2.4 Backup**

11   The KMF **should** backup all keying material shared with and among the mobile radios so  
12   that it can be recovered if necessary. When a key is no longer required, it **should** be  
13   deleted from both normal operational storage and backup storage.  
14

15   **7.2.5 Rekeying**

16   Procedures **shall** be in place to rekey all radios in the network in the event of a key  
17   compromise. If a radio is lost, procedures **shall** enable rekeying other radios in the  
18   network so that the lost radio no longer has the capability of communicating securely  
19   with other radios in the network.  
20

21   **7.2.6 Random bit generators**

22   Keys **shall** be generated at the KMF using an approved random bit generator that  
23   provides sufficient randomness for the desired security strength of the cryptographic  
24   processes. NIST-approved random bit generation methods are specified in SPs 800-90 A,  
25   B and C (under development) [SPs 800-90 A, B and C].  
26

27   **7.3 Procurement Guidance**

28   The following recommendations are for any individual(s) that makes a purchasing  
29   decision for acquiring OTAR equipment.

- 30
- 31   1. Procurements **shall** include the AES or TDEA algorithm.
  - 32
  - 33   2. If TDEA is provided in an implementation, the three-key version **shall** be included.
  - 34
  - 35   3. Procurements that include TDEA **shall** be capable of limiting the number of uses of a  
36    single TDEA key bundle to 1,000,000.<sup>35</sup>
  - 37
  - 38   4. KMFs and radios **shall** conform to OTAR and OTAR1.

---

<sup>34</sup> There is an allowed exception to this rule, but it does not apply to OTAR (see Section 5.2 in Part 1).

<sup>35</sup> See Section 7.2.2.

- 1
- 2 5. When keys are generated within KMFs, they **shall** be generated using approved
- 3 random bit generators.
- 4
- 5 6. Cryptographic modules used by the KMF and the mobile radios **shall** be validated at
- 6 FIPS 140-2 Level 1 or higher.
- 7
- 8 7. KMFs **shall** include backup and archive capabilities to support reconstitution of the
- 9 KMF in the event of a disaster (e.g., fire, earthquake).
- 10

#### 11 **7.4 Recommendations for System Installers**

12 The system installer is the individual(s) that installs an OTAR capability and performs  
13 the initial configuration of the system components.

- 14
- 15 1. The KMF **shall** use and have strong physical and logical access control mechanisms
- 16 to protect the cryptographic keys (e.g., physical locks, alarms or password token).
- 17
- 18 2. Backup KMFs **shall** be provided.
- 19
- 20 3. A TEK **should not** be used for multiple purposes. Reserved MAC keys **should** be
- 21 used for message authentication and integrity protection.
- 22
- 23 4. Maximum cryptoperiods for each key type **shall** be determined at the KMF in
- 24 accordance with the organization's security policy and Section 7.2.2.
- 25
- 26 5. Radios **shall** be accounted for; in the case of a lost or stolen radio, an assessment of
- 27 the effect of a loss of the keys contained in that radio **shall** be made. The use of any
- 28 key contained in that radio **shall** be discontinued. Procedures **shall** be in place for
- 29 replacing these keys if used by the KMF or by other radios.
- 30
- 31 6. Implementations **shall** be configured to use the AES or TDEA algorithms, and to
- 32 disallow the use of DES.
- 33
- 34 7. If TDEA is provided and is to be used, the three-key version **shall** be used, and the
- 35 one-key version **shall not** be used.
- 36
- 37 8. For implementations using TDEA in which the cryptoperiod of a key bundle is
- 38 configurable, the cryptoperiod **shall** be set to a value less than 1,000,000 messages.
- 39

#### 40 **7.5 Recommendations for System Administrators**

41 The System Administrator is the individual who manages the OTAR system or its  
42 components on a day-to-day basis and interacts with the end users.

- 43
- 44 1. System administrators **shall** ensure that the organization's security policy is
- 45 enforced.

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2. System administrators **shall** protect the keying material from disclosure and modification.
3. Procedures **shall** be in place for replacing keys at the end of their cryptoperiod.
4. To maintain the availability of the KMF, system administrators **shall** ensure that sufficient information is stored in a secure location to reconstitute the KMF after a disaster.
5. Backup KMFs along with a strategy and procedures to transition from a primary KMF to a backup KMF, and from a backup KMF to the primary KMF **shall** be established.
6. System administrators **shall** train end users in the use of their radios and the procedures to be followed in the case of lost radios or suspected key compromises.
7. Audit logs **should** be maintained at the KMF with sufficient information to indicate which keys are shared by which radios.

21 **7.6 Recommendations for End Users**

22 An end user is the individual using a radio that has an OTAR capability.

- 24 1. End Users **shall** operate radios as instructed by their organization and system administrators.
- 26 2. End users **shall** protect their radios from loss and unauthorized access.
- 28 3. In the event that a radio is lost or a key is suspected of being compromised, end users **shall** immediately notify the system administrator in accordance with the organization's security policy.

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32  
33



## 8 Domain Name System Security Extensions (DNSSEC)

### 8.1 Description

The Domain Name System (DNS), as defined in [RFC 1034] and [RFC 1035], is the global hierarchical distributed database system for mapping Internet addresses, SMTP servers, and other information to a human-readable name. Its main purpose is handling mappings between host domain names and Internet addresses, but it can handle other forms of data as well, such as host system information, the geographic location of servers, even encoded digital certificates. DNS data is stored as individual Resource Records (RR) that associate a piece of data (e.g., IP address, mail server name) with a domain name and an identifying Resource Record type code (RR type). All the RRs for a particular organization are stored in an administrative unit called a zone. Multiple zones form a domain. A domain is hierarchical, in that one zone may act as a delegating parent to one or more child-delegated zones. For example, most Federal agencies are child delegations under the “.gov” parent zone.

Zone information is maintained on *authoritative* servers, which are distributed all over the Internet to answer queries according to the DNS network protocols. The DNS infrastructure is comprised of a small group (or single server) known as a primary master authoritative server that has a local zone database, and multiple secondary servers that obtain their copies of the zone database from the primary authoritative master server. Another set of components are *caching recursive* servers<sup>36</sup>, which query the authoritative servers and cache any replies. On the end user’s client system, software components known as resolvers make DNS queries to recursive caches and/or authoritative servers. Figure 8-1 depicts the relationship between the DNS components.

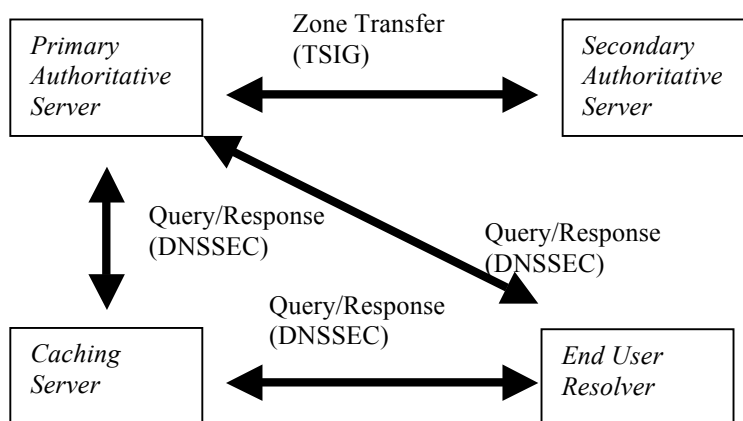


Figure 8-1: DNS Components

The basic DNS does not have many security features; see SP 800-81-2 [SP 800-81r2]. A suite of RFCs has been developed to provide security enhancements contained in three IETF documents, collectively called the DNS security extensions (DNSSEC) [RFC 4033,

<sup>36</sup> Caching Recursive Server is sometimes shortened to “caching server” or “recursive server”. However, the role remains the same.

1 RFC 4034, and RFC 4035]. DNSSEC provides a layer of authentication and integrity  
2 protection for any kind of data stored in the DNS, including data used by other protocols.  
3 For example, there are RR types allocated for storing Secure Shell (SSH) keys in the  
4 DNS, which then rely on DNSSEC to protect the integrity of that information.

### 5 **8.1.1 DNS Data Authentication**

6 Cryptographically generated public key-based digital signatures provide authentication  
7 for DNS data. Commonly, there will be two or more digital signature public-key pairs  
8 (which make up the key set) used to implement DNSSEC in a zone. One key pair is used  
9 to sign the zone data (referred to as the Zone Signing Key or ZSK), and a separate key  
10 pair is used to sign the zone key set (known as the Key Signing Key or KSK). While  
11 some zones may only use one key pair for both ZSK and KSK, it is not recommended for  
12 Federal agency zones. This KSK is also known as the Secure Entry Point (SEP) key for  
13 the zone – using it, a client can authenticate the ZSK (by validating the signature over the  
14 ZSK using the KSK public key), and then use the ZSK to authenticate the zone data. The  
15 KSK is also used to link the security chain<sup>37</sup> from the zone to its delegating parent. Since  
16 the KSK is used to link security from the zone (e.g. “example.gov”) to the delegating  
17 parent zone (e.g. “.gov”) [RFC 4035], it is often longer lived, and used infrequently (used  
18 only to sign the zone key set). Multiple digital signature algorithms can be supported, so  
19 there may be multiple keys (one for each algorithm), as there is no algorithm negotiation  
20 in DNSSEC, and clients may only understand certain digital signature algorithms. There  
21 is one mandatory-to-implement algorithm as defined by the IETF, so there is at least one  
22 agreed-upon digital-signature algorithm that all servers and clients will understand.

23  
24 Currently, both RSA using SHA-1 and SHA-256 have been specified and can be used  
25 with DNSSEC zones. Most modern implementations either support both or will do so  
26 after an upgrade. Zones deploying DNSSEC for the first time can start with RSA using  
27 SHA-256. Zones that initially deployed with RSA using SHA-1 **should** migrate to RSA  
28 (2048-bit RSA key) using SHA-256: see SP 800-131A for information about guidelines  
29 for using RSA with different key sizes and hash algorithms. However, both hash  
30 algorithms (i.e., SHA-1 and SHA-256) **should** be used to generate digital signatures for  
31 DNS data for a period of time to ensure that client systems that cannot validate RSA with  
32 SHA-256 can still authenticate DNS data. The length of this transition period depends on  
33 the widespread availability and deployment of client-system software that understands  
34 RSA with SHA-256.

### 35 **8.1.2 DNS Transaction Authentication**

36 Additional authentication mechanisms are used for server-server communication and  
37 administrative control. Transaction authentication is performed by computing an HMAC  
38 over the entire DNS message and a secret random string that is known by both  
39 authoritative DNS servers in the transaction, and transmitting the result in a Transaction  
40 Signature (TSIG) RR appended to the original message. Transaction authentication is

---

<sup>37</sup> The security chain (also referred to as “chain of authentication”) is the collection of digital signatures and public keys that can be used to trace a logical path from the data to be validated back to a trusted, installed public key on the client, see SP 800-81-2. This chain of public keys and signatures is similar to a PKI certificate chain (see Section 2.1), but entirely contained within the DNS.

usually used for special transactions, such as zone transfers or dynamic updates. A zone transfer is a special query type that is used to keep secondary authoritative servers up-to-date with the most recent version of the zone data. Dynamic update is a feature that allows an authorized administrator to add or delete DNS data by sending a specially formatted message. This is frequently used in local area networks where the Dynamic Host Configuration Protocol (DHCP) is used to assign IP addresses dynamically. The DHCP server may update the DNS server by sending a dynamic update message to reflect network changes.

The currently defined algorithms used in TSIG authentication are HMAC using SHA-1 and the SHA-2 family of hash algorithms (SHA-224, SHA-256, SHA-384 and SHA-512). The use of SHA-1 is acceptable for current security practices when using HMAC with a suitably random secret string. All DNS server administrators taking part in the transaction must agree on which algorithm and secret string size will be used for transaction authentication and must ensure that all parties have the same secret random string (which may include out-of-band transactions to distribute keys).

### 8.1.3 DNS Cryptographic Algorithms/Schemes, Modes and Combinations

DNS does not support algorithms in isolation, but specifies suites of algorithms and schemes. Algorithm/scheme combinations for zone data signing and for message authentication are provided in Tables 8-1 ([RFC 6944], [RFC 6605]) and 8-2 ([RFC 3645], [RFC 4635]):

**Table 8-1: Recommended Algorithm and Scheme Combinations for Zone Data Signing**

Suite	Authentication	Digest	IETF Status	Approved for Federal Use <sup>38</sup>
RSA_SHA-256	RSA	SHA-256	Recommended to Implement	YES
RSA_SHA-512	RSA	SHA-512	Recommended to Implement	YES
ECDSAP256SHA256	ECDSA	SHA-256	Recommended to Implement	YES
ECDSAP384SHA384	ECDSA	SHA-384	Recommended to Implement	YES

<sup>38</sup> Refer to Part 1 of this guide for approved key lengths and for algorithm lifetimes.

1 **Table 8-2: Recommended Message Authentication Algorithms**

Suite	IETF status	Approved for Federal Use
HMAC_SHA1	Mandatory	YES
HMAC_SHA-224	Optional	YES
HMAC_SHA-256	Mandatory	YES
HMAC_SHA-384	Optional	YES
HMAC_SHA-512	Optional	YES
GSS_TSIG <sup>39</sup>	Optional	YES

2  
 3 It should be noted that HMAC-MD5.SIG-ALG.REG.INT is a suite that is widely  
 4 implemented and often set as the default choice. However, it **shall not** be used for  
 5 Federal implementations. Since TSIG message authentication is used between servers  
 6 where there is an existing trust relationship, the administrators must agree on the method  
 7 used and the secret (random) string used with the TSIG method.

8  
 9 Due to message size constraints (See Section 8.1.4 below), large RSA keys may result in  
 10 DNS transaction failures that are often interpreted by clients as DNS failures. It is  
 11 recommended that, instead, a digital signature algorithm that has the same security  
 12 strength, but with smaller sized keys be used, such as ECDSA [RFC 6605]. It is  
 13 recommended that DNS administrators plan to migrate to ECDSA for zone signing by  
 14 October 1, 2015, or plan to migrate earlier as soon as it becomes available in DNS  
 15 software components.

16 **8.1.4 Special Considerations for Key Sizes**

17 There are some special considerations needed when choosing the size of the RSA  
 18 DNSSEC signing keys. Early deployments have shown that large RSA keys can result in  
 19 protocol issues, such as response messages that are too large to fit in a standard UDP  
 20 packet. DNSSEC requires the use of larger DNS packet sizes up to 4KB, but practical  
 21 limits are around 1500 bytes or less.

22  
 23 It is recommended that DNS administrators maintain 1024-bit RSA/SHA-1 and/or  
 24 RSA/SHA-256 ZSK's until Oct 1<sup>st</sup> 2015, or until it is proven that the majority of routers,  
 25 caches and other network middle boxes can handle packet sizes over 1500 bytes (if  
 26 before 2015). However, 1024-bit RSA keys are allowed until the 2015 date to  
 27 accommodate older versions of DNS clients that may be older network components that  
 28 cannot handle UDP packets with sizes over 1500 bytes. This is an exception to the  
 29 security guidance provided in SP 800-131A. However, this exception on RSA key sizes  
 30 does not apply to Key Signing Keys. KSK's **shall** follow the guidance set in Part 1 of this  
 31 Recommendation.  
 32

---

<sup>39</sup> Generic Security Service Algorithm for Secret Key Transaction Authentication (GSS-TSIG [RFC3645]) may be found in some server implementations.

1 It is recommended that zone administrators migrate DNSSEC zone signing algorithms to  
2 ECDSA by 2015 or when support for ECDSA appears in DNSSEC components,  
3 whichever is sooner.

4  
5 To minimize the risk when using 1024-bit RSA ZSK's with DNSSEC, ZSK's should be  
6 changed more frequently: every one to three months, with a signature validity period of  
7 five to seven days. The ZSK-rollover sequence discussed in the NIST Special Publication  
8 800-81 [SP 800-81r2] is recommended to maintain a valid chain of authentication in  
9 DNS data.

### 10 **8.1.5 Special Considerations for NSEC3**

11 There is a special variant to DNSSEC that minimizes the risk of information leakage and  
12 is known as the Hashed Next Secure (NSEC3) RR; see RFC 5155 [RFC 5155]. In  
13 DNSSEC, a client can map the contents of the zone by sending a series of queries for the  
14 Next Secure (NSEC) RR type found in error messages. These NSEC RRs provide signed  
15 proof that the queried name did not exist, but also provides two names that do exist in the  
16 zone as part of that proof. NSEC3 attempts to minimize this information leakage of zone  
17 names by using the hash values of the two existing names (currently using SHA-1 only).  
18 However, this requires the server and client to be able to perform multiple SHA-1 hash  
19 calculations during runtime; note that this method could be used to mount a Denial of  
20 Service attack against the server if multiple requests are made.

21 NSEC3 was designed to solve a specific class of information leakage that could lead to a  
22 complete mapping of network resources in a DNS zone. NSEC3 deployment risks are  
23 often greater than the usefulness provided by using NSEC3, unless there is an overriding  
24 need to deploy NSEC3 beyond zone content protection (examples include protecting  
25 personally identifying information that may be contained in the DNS). However, it is a  
26 good idea to use NSEC3-aware client software, because a client may access a zone that  
27 uses NSEC3 RRs with DNSSEC.

28 System installers and administrators **should** develop a transition plan to migrate from  
29 SHA-1 to SHA-256, and to do so when SHA-256 becomes available in major software  
30 distributions. This would involve deploying both SHA-1 and SHA-256-based NSEC3  
31 RRs until it is observed that SHA-256-aware implementations have become widely used  
32 in the Internet community.

### 33 **8.2 Security/Compliance Issues**

- 34 1. Even though 1024-bit RSA keys are allowed until October 1, 2015 to accommodate  
35 older versions of DNS clients, 2048-bit RSA keys are strongly recommended for use.
- 36 2. Although not strictly necessary to the specification, a Key Signing Key **should** be  
37 used to maintain security chains from the parent zone (e.g., .gov) to the zone (e.g.,  
38 nist.gov). This KSK **should** be securely transmitted to the delegating parent  
39 according to the policy and procedure established by the parent zone.

40 TSIG-shared secret strings **should** be random for use in providing integrity protection for  
41 DNS message transactions, and generated at appropriate security strengths. The system  
42 installers using the TSIG secret string **shall** agree on which TSIG algorithm to use.

### 1 **8.3 Procurement Guidance**

2 The following recommendations are for any individual that makes a purchasing decision  
3 for acquiring DNSSEC-capable components for their network infrastructure.

- 4
- 5 1. DNSSEC utilities **shall** use FIPS140-2-compliant cryptographic modules.
- 6 2. DNS server software **should** generate and serve NSEC3 RRs, if required by zone  
7 policy.
- 8 3. DNS server software **shall** use an approved random bit generator to generate random  
9 strings for use with TSIG message authentication using HMAC that is consistent with  
10 the hash-algorithm security-strength recommendations in Part 1.
- 11 4. DNSSEC-enabled versions of network applications **shall** be purchased as required by  
12 security policy, if available.
- 13 5. DNSSEC software implementing SHA-256 **shall** be included in procurements when  
14 available.

### 15 **8.4 Recommendations for System Installers**

16 The system installer is the individual(s) that installs a DNS component and performs the  
17 initial configuration of the component.

#### 19 **8.4.1 Recommendations for System Installers (Authoritative Servers)**

- 20 1. Authoritative server installers **shall** configure a DNS authoritative server to serve  
21 DNSSEC-signed zone data.  
22
- 23 2. Authoritative server installers **shall** use an approved random bit generator (as  
24 discussed in NIST Special Publication 800-90A) to create and configure an initial,  
25 random secret string for use with TSIG in transactions.  
26
- 27 3. Authoritative servers **shall** be configured to generate and sign zone data with a key  
28 pair that is consistent with the key size recommendations for digital signatures as  
29 specified in Part 1.
- 30 4. Authoritative servers **shall** be configured to generate and sign the key set with a key  
31 pair that is consistent with the key sizes recommended for digital signatures, as  
32 specified in Part 1.
- 33 5. Authoritative servers **shall** be configured to generate and use a random secret string  
34 for zone transfer-message authentication (via TSIG) between primary and secondary  
35 servers. The security strength of the random bit generator process **shall** support the  
36 security strength required by the servers.
- 37 6. Authoritative servers **shall** be configured to generate and use a separate shared secret  
38 string for dynamic update-message authentication (via TSIG). The security strength  
39 of the random bit generator process **shall** support the security strength required by the  
40 servers.

1 **8.4.2 Recommendations for System Installers (Caching Recursive**  
2 **Servers)**

- 3 1. Recursive caching server installers **shall** configure DNS servers to be DNSSEC-  
4 aware.  
5  
6 2. Recursive caching server installers **shall** install at least one public key used for  
7 DNSSEC validation. The key(s) **shall** be kept up-to-date to insure successful  
8 validations.

9 **8.4.3 Recommendations for System Installers (Client Systems)**

- 10 1. Client systems **shall** be configured to send DNS queries to a DNSSEC-enabled  
11 caching recursive server.  
12 2. Client systems **should** be configured to use DNSSEC-enabled applications, if they are  
13 available.

14 **8.5 Recommendations for System Administrators**

15 The System Administrator is the individual who runs the DNS application on a day-to-  
16 day basis and interacts with the end user.

17 **8.5.1 Recommendations for System Administrators (Authoritative**  
18 **Server)**

- 19 1. The organization security policy regarding the Authoritative servers **shall** be  
20 enforced.  
21 2. Cryptographic keys **shall** be protected as specified in Part 1.  
22 3. System administrators **shall** replace zone data-signature Resource Records before the  
23 end of their validity period.  
24 4. Zone data-signature Resource Records **shall** be replaced if the private key associated  
25 with the public key is compromised, when the administrator of the DNS zone leaves  
26 the organization, and for other reasons listed in the organization's security policy.  
27 5. Administrators **shall** utilize methods for handling and protecting the private key (e.g.,  
28 using a smart card that requires appropriate user authentication).

29 Administrators **shall** follow the key lifecycle procedures found in NIST Special  
30 Publication 800-81, Secure Domain Name System (DNS) Deployment Guide.

31 **8.5.2 Recommendations for System Administrators (Caching**  
32 **Recursive Servers)**

- 33 1. Server administrators **shall** ensure that there is an organization security policy for  
34 using the Caching Recursive Server.  
35 2. Cryptographic keys **shall** be adequately protected (see Part 1).  
36 3. The trust anchors for DNS validating caches **should** be kept up to date.

1 **8.5.3 Recommendations for System Administrators (Client Systems)**

- 2 1. Server administrators **shall** ensure that there is an organization security policy for  
3 using the client systems.
- 4 2. Server administrators **shall** ensure that users are properly trained.

5 **8.6 Recommendations for End Users**

6 An end user is the individual using a client to access the system.

- 7
- 8 1. End users **shall** operate their client systems as instructed by their organization and  
9 system administrator.

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## 9 Encrypted File Systems (EFS)

### 9.1 Description

The encryption of data files and complete disk volumes presents a somewhat different set of key management issues than those for encryption of network-communicated data. While network communications security focuses on the privacy and integrity of information in transit, storage (e.g., file) security focuses on the privacy and integrity of persistent data and the secure sharing of this data. The key management guidance surrounding file and volume encryption are sufficiently similar to consolidate into a single section.

Unlike the previous sections, where the protocols and/or standards have been thoroughly studied by the network security community, the commercial solutions for file encryption utilize a wide variety of security schemes and methods for storing keys. Due to this range of solutions, this section will not be comprehensive, but will cover a variety of methods used for file encryption.

The most important questions that designers of a file encryption system must answer are:

- How are keys used in the system, and what protection are they afforded?
- Where are the keys stored on the system?
- Does the method scale upward for numerous user communities (without requiring an impractical number of keys to be stored)?

#### 9.1.1 Number of Keys Required

For an Encrypted File System, keys are used to encrypt a file or group of files. The system can either encrypt each file with a distinct symmetric key or encrypt a set of files using the same symmetric key. In the first case, it is very easy to provide access to a sharing user, for example, by simply giving the key to that user. In this way, only that single file can be accessed by the sharing user without providing access to any of the other files in the system. The drawback with this first method is that if many files are encrypted, the model can quickly become unwieldy, since a key is required for each encrypted file and must be provided to the sharing user.

In the second case, many fewer keys are required, which eases the key distribution process. However, when a sharing user requires access to a single file, giving access to that user is more problematic. By simply sending a key to the sharing user, access would be provided to all of the owner's<sup>40</sup> files that were encrypted using that key, rather than to the single file.

However, there are several cryptographic management actions that could be used to grant access to an individual file in the second case above. One option to limit access in this second system is for the owner or system to decrypt the file and re-encrypt it using a new key for transmission to the sharing user (e.g., using network security mechanisms and session keys). In the increasingly rare case of both users sharing a common file server,

---

<sup>40</sup> An owner could be an individual or a group of individuals or processes that share the key.

1 the decrypted and re-encrypted file would be placed in the sharing user's file space. This  
2 would require significant processing overhead and a key management protocol for  
3 exchanges between the owner and the sharing user, or between the file system  
4 management process and the sharing user. This process requires proper protection for  
5 these new keys at the same security strength as the original key protecting that file.

6  
7 Another option is for the sharing user to be provided with the encrypted file and the  
8 owner's decryption key that could be used to decrypt all of the owner's files, including  
9 the one provided to the sharing user. System overhead is reduced, and it may be possible  
10 to protect the key from third-party administrators, but it is unlikely that the owner would  
11 agree that the requester should be granted access to all files protected under the common  
12 key.

13  
14 Having provided more extreme examples in the previous two cases, the following is a  
15 more common approach that is used. In this case, each user on the system has an  
16 asymmetric key pair. Each owner's file is encrypted under a different randomly generated  
17 symmetric File Encrypting Key (FEK). The FEK is then encrypted using the public key  
18 of the owner and stored with the encrypted file. When the owner of a file wants to share it  
19 with another user, the owner decrypts the encrypted FEK (using her private key) and then  
20 encrypts the FEK using the sharing user's public key. The encrypted file and re-encrypted  
21 FEK can then be provided to the requester. This system has several advantages. First, the  
22 owner needs to manage only a single asymmetric key pair. Second, it permits easier file  
23 sharing between users. Third, it is very efficient because files do not have to be re-  
24 encrypted in order to be shared. Finally, the system need not manage any keys separately,  
25 since the asymmetric keys are managed by the owners, and the FEKs are stored in  
26 encrypted form with the files.

27  
28 The owner can, of course, use different keys to encrypt different files or sets of files. The  
29 fewer files that the owner chooses to encrypt with a given key results in more keys and  
30 associations (e.g., associations of keys with file identities, file groups, individual  
31 identities, or access groups) that would need to be maintained.

32  
33 Another important concept within an encrypted file system that must be considered is  
34 how data recovery is implemented. If a user loses his keys, without a data recovery  
35 capability within the system, the user's data is permanently lost. As such, it is vital that  
36 some form of data recovery, such as master administrator passwords, be included.<sup>41</sup> This  
37 requires a file encryption system that allows multiple passwords to decrypt the file, one  
38 of which is provided to the user, and the second is provided to the administrator, in the  
39 form of a master administrator password. Another possibility is that the administrator has  
40 a method of storing the user's passwords for use only when the user has lost or forgotten  
41 their password.

42  
43 When the scope of the system expands from a pair of individuals to a large network or  
44 internet-work, the factors associated with the management of keys can become unwieldy.  
45 Key management challenges associated with large systems include the following:

---

<sup>41</sup> The specifics of how data recovery is accomplished are beyond the scope of this document.

- Maintaining context in the face of global data placement (many owners and large quantities of data).
- Very large numbers of keys to manage and distribute.
- If numerous keys are stored in a single location within an EFS, that site provides an attractive target for an adversary – a single point of trust for a large domain.
- Difficulty in accounting for revoked users (individuals who have left an organization, whose subscriptions have expired, or otherwise **should not** be authorized to access the file any longer).
- Reassignment of ownership of protected data to another individual or organization.
- Recovery of data in the event of lost keys (e.g., the case of archived encrypted data that is encrypted and stored by an individual who has left the organization and cannot be found).
- A sharing user who has been provided the keys to a number of the owner’s files, then provides the keys, and the owner’s data, to additional users.

### **9.1.2 Access to Symmetric Keys used in File Encryption**

After the decision has been made about the number of files to be protected with a single symmetric key, key management questions can be considered. How does the File Encryption System generate the encryption keys? How will the keys be stored and protected? This section identifies common ways of answering these questions, as well as discussing their strengths and weaknesses. As technology advances, additional techniques will be developed, and as such, the list below is not complete nor should be considered mandatory.

Consider common answers to the important questions above. First, how do file encryption systems generate symmetric keys? A simple method is to derive the key from a password as described in SP 800-132 [SP 800-132]. In this case, the security of the system depends on the randomness of the password; normally, passwords do not contain enough randomness to be used for generating keys (i.e., they can be guessed relatively easily). A standard dictionary attack can often recover weak passwords, so a strong password is vital for the security of this type of system. It is preferable to utilize a good random bit generator within the system to generate keys. Approved random bit generators can be found in NIST Special Publications 800-90A, B and C.

Next, consider the question of how to protect the keys. There is a great deal of effort underway by the Trusted Computing Group (TCG) to develop secure storage of keys on computers. As this effort continues to mature, the Trusted Platform Module chip, through its key cache management, offers another format for protecting keys used in EFS.

Then, consider where these keys will be stored. If keys need to be stored, they could simply be stored on the computer itself or on a hardware token. Alternatively, the key could be split into two (or more) key components with, for example, one component stored on a hardware token and the other key component stored on the computer itself. If a split key is employed, the method used to combine the key components is important; performing an XOR operation on equal length key components is better than simply

1 concatenating the components. Common hardware tokens include smartcards. The  
2 advantage of using a hardware token is that if the user stores the hardware token away  
3 from the computer, and the key is split between the token and the computer, an adversary  
4 needs to recover both pieces of hardware to recover the key. Additional security may be  
5 provided by encrypting the key splits, perhaps by using a password.

6  
7 There are many permutations of answers to the questions above. Four examples of how  
8 these questions can be answered will be considered, along with the pros and cons of each  
9 system. It is important to consider the specific environment in which the File Encryption  
10 System will be used, as that will usually point to a specific type of system that is  
11 preferable for that case.

12  
13 The first example that will be considered is a file encryption system that uses a single  
14 symmetric key to encrypt every file on the system. This single key is generated using a  
15 method in SP 800-132 from a user's password.

16  
17 The second example is a system that utilizes per-file encryption keys, which are stored on  
18 the hard disk, encrypted by a key encryption key. The key encryption key (which is also  
19 used to decrypt each file encryption key) is securely stored on the hard drive (e.g., using  
20 the Trusted Platform Module (TPM) [TPM]).

21  
22 The third example is a system that utilizes per-file encryption keys that are split into two  
23 key components that will be XORed to recreate the key, with one key component stored  
24 on a hardware token and the other component derived from a password (e.g., using a  
25 method in SP 800-132 to derive the key).

26  
27 The fourth example uses per-file encryption keys, which are encrypted under the file  
28 owner's asymmetric private key as previously described. This system is common in  
29 current file-encryption packages, while the previous three are extreme to show the pros  
30 and cons of the systems more clearly.

31

1  
2

Method	Pros	Cons
Example 1: SP 800-132	<ul style="list-style-type: none"><li>- Least expensive solution.</li><li>- Utilizing a strong password can result in reasonable security.</li></ul>	<ul style="list-style-type: none"><li>- Less secure because the security is dependent only on the strength of the password.</li></ul>
Example 2: Key Encryption Key	<ul style="list-style-type: none"><li>- Secure storage directly in the computer.</li><li>- Secure from external software attack and physical threat.</li></ul>	<ul style="list-style-type: none"><li>- Relatively new technology.</li><li>- Keys are stored on the same computer as the file.</li></ul>
Example 3: Hardware Token	<ul style="list-style-type: none"><li>- Splits key.</li><li>- Requires two hardware pieces to decrypt.</li><li>- Highly secure if implemented correctly.</li><li>- If the files or token are lost, the files will stay secure.</li></ul>	<ul style="list-style-type: none"><li>- More expensive.</li><li>- If the token is lost, the files cannot be decrypted.</li></ul>
Example 4: Asymmetric user owned Key Encryption Key	<ul style="list-style-type: none"><li>- No plaintext keys stored in the computer.</li><li>- Efficient file sharing.</li><li>- Highly secure if a token is used.</li><li>- Compromise of a user's private key compromises only the user's files.</li></ul>	<ul style="list-style-type: none"><li>- Requires the user to manage their own key pair.</li><li>- Requires either a user password or a user token.</li></ul>

3 **9.2 Security and Compliance Issues**

- 4 1. Any encrypted file system **shall** employ approved cryptography if it is to be used for  
5 the protection of Federal government information.
- 6 2. Keys derived from passwords **shall** use strong passwords to maximize the difficulty  
7 of an off-line exhaustion attack; see SP 800-118.

8 **9.3 Recommendations for Procurement Officials**

9 The following recommendations are for any individual(s) that makes a purchasing  
10 decision for acquiring an EFS component.

- 11
- 12 1. An encrypted file system **shall** include a data-recovery capability (e.g., master  
13 administrator password) so that the data is not lost in the event that a user forgets his  
14 password or the user is unavailable. Data recovery is vital in this type of system.
- 15 2. Any EFS system that derives keys from passwords **shall** have the capability of  
16 enforcing the use of strong passwords.

- 1 3. To increase the security of encrypted file systems, the system **should** use a hardware  
2 token or a TPM for the storage of the keys.

### 3 **9.4 Recommendations for System Installers**

4 The system installer is the individual(s) that installs EFS components and performs the  
5 initial configuration of the components.

- 6  
7 1. When an EFS system that utilizes passwords for security is installed, the installer  
8 **shall** require that strong passwords be enforced by the EFS. This maximizes the  
9 difficulty of an off-line exhaustion attack.
- 10 2. The system installer **should** ensure that the database of keys is protected by  
11 encryption to ensure the security of the system. In addition, if the key is split by the  
12 EFS system, the key component stored on a hardware token **should** be protected.

### 13 **9.5 Recommendations for System Administrators**

14 The system administrator is the individual that manages the EFS on a day-to-day basis  
15 and interacts with the end user.

- 16  
17 1. The system administrator **shall** ensure that the organization's security policy is  
18 enforced.
- 19 2. Key recovery procedures **shall** be in place to ensure that users can recover their data  
20 if they lose their authentication information (password, token data, etc). A method for  
21 data recovery personnel to authenticate these users **should** be in place prior to the  
22 recovery of the user's keys or files.
- 23 3. If the EFS includes a master administrator password for use in data recovery by the  
24 system administrator, the system administrator **shall** utilize a strong password.
- 25 4. System administrators **shall** provide training and security guidance to the end users of  
26 the system that, at a minimum, focuses on passwords, data-recovery procedures, and  
27 user configuration of their system to utilize the authentication features within the  
28 system.

### 29 **9.6 Recommendations for End Users**

30 An end user is the individual that uses the EFS to secure and share their information.

- 31  
32 1. If user-selected passwords are used within the product, end users **shall** utilize strong  
33 passwords to maximize the difficulty of an off-line exhaustion attack.
- 34 2. End users **shall** follow guidance provided by the system administrator regarding the  
35 use of an Encrypted File System product.
- 36 3. End users **shall** inform a system administrator if they have lost their hardware token  
37 or forgotten their password.

38

## 1 **10 The Secure Shell (SSH)**

### 2 **10.1 Description**

3 SSH is a protocol between clients and servers for secure remote login and other secure  
4 network services over an insecure network or the Internet. The Internet Engineering Task  
5 Force (IETF) governs the SSH protocol, which is specified in [RFC 4251]<sup>42</sup>. The SSH  
6 protocol consists of three major components: the Transport Layer Protocol (specified in  
7 [RFC 4253]), the User Authentication Protocol (specified in [RFC 4252]) and the  
8 Connection Protocol (specified in [RFC 4254]).

#### 9 **10.1.1 Transport Layer Protocol (SSH-TLP)**

10 The Transport Layer Protocol provides server authentication, confidentiality, and  
11 integrity with perfect forward secrecy<sup>43</sup>. The establishment of an SSH connection is  
12 initiated using the Transport Layer Protocol (TLP), which negotiates the algorithms to be  
13 used and authenticates the server. TLP does not provide client authentication.

14 The algorithm-negotiation step of the protocol is used to determine the algorithms to be  
15 used by the client and server for key agreement (called key exchange in the protocol),  
16 server authentication, encryption and data integrity. The encryption and data-integrity  
17 algorithms that protect communications from the client to the server and from the server  
18 to the client are independently selected, i.e., the encryption algorithm protecting  
19 communication from the client to the server may be different than the encryption  
20 algorithm protecting communication from the server to the client.

21  
22 After the algorithm negotiation is completed, the TLP authenticates the server to the  
23 client in a key-exchange process (see Section 8 of RFC 4253) that provides keys and IVs  
24 for the selected cryptographic algorithms. The key-exchange process provides assurance  
25 that the server is the owner of the public key, but additional steps may be required to  
26 verify the server's identity; see Section 10.2.1.2 for a discussion on the verification of the  
27 server's public host key.

28  
29 The protocol provides data- integrity protection by choosing a MAC algorithm for each  
30 communication direction between the server and the client. However, the protocol also  
31 allows this service (i.e., data-integrity protection) to be disabled.

#### 32 **10.1.2 The User Authentication Protocol (UAP)**

33 The User Authentication Protocol authenticates the client to the server. After the TLP is  
34 completed, the server and the client communicate using an encrypted SSH tunnel<sup>44</sup> that  
35 uses the selected encryption algorithm(s) from the negotiation process and the keys from

---

<sup>42</sup> This section discusses SSH version 2, sometimes called SSH2 or SSH-2. SSH1 never became a standard protocol and was later replaced by the SSH2 protocol, which is the SSH protocol in RFC 4251.

<sup>43</sup> Perfect forward secrecy is a cryptographic property of a key-establishment method in which the compromise of a currently established session key or long-term private key does not cause the compromise of any earlier established session keys.

<sup>44</sup> An encrypted tunnel is an end-to-end communication connection where all of the data traffic going through the connection is encrypted.

1 the key exchange (see the SSH TLP protocol discussion in Section 10.1.1). Using the  
2 encrypted SSH tunnel, the server can securely perform any client authentication. The  
3 UAP provides a single authenticated tunnel for the SSH connection protocol.

### 4 **10.1.3 Connection Protocol (CP)**

5 The Connection Protocol (as specified in RFC 4254) multiplexes the encrypted tunnel  
6 used by SSH into several logical channels. The CP defines how interactive login sessions,  
7 remote execution of commands, forwarded TCP/IP connections, and forwarded X11  
8 [X11] connections can be run simultaneously over an established SSH Transport Layer  
9 and User Authentication connection.

## 10 **10.2 Security and Compliance Issues**

### 11 **10.2.1 TLP Issues**

#### 12 **10.2.1.1 Algorithm Negotiation**

13 In this step of the TLP, the algorithms to be used for the key exchange (i.e., key  
14 agreement), public key authentication, data encryption and message authentication are  
15 selected.

- 16 1. The SSH server and client **should** choose the same NIST-approved cryptographic  
17 algorithms for both communication directions (data streams) for a particular  
18 cryptographic service. For example, the same encryption algorithm and MAC-  
19 generation algorithm **should** be used for both communication directions to  
20 provide confidentiality and integrity protection, respectively.

21 Note: The cryptographic algorithms selected for use depend on the algorithms that  
22 are supported by both the server and the client, and by the client's preference  
23 levels for these algorithms in each of its algorithm lists offered in the negotiation;  
24 the client's preference level is indicated by the order in which the algorithms are  
25 listed. See Section 7.1 of RFC 4253 for the defined procedure for selecting the  
26 cryptographic algorithms.

- 27  
28 2. Suite B cryptographic algorithms are recommended for use when supported by  
29 both the client and server systems. Suite B cryptographic algorithms are specified  
30 in [RFC 6239]. They are:
  - 31 • Key agreement (key exchange): ecdh-sha2-nistp256 and ecdh-sha2-nistp384  
32 (see Section 10.2.1.2).
  - 33 • Public key algorithm (for server and client authentications): x509v3-ecdsa-  
34 sha2-nistp256 and x509v3-ecdsa-sha2-nistp384 (see Section 10.2.1.3).  
35 The public keys are conveyed in X.509 version 3 certificates.
  - 36 • Encryption and MAC: AEAD\_AES\_128\_GCM and AEAD\_AES\_256\_GCM  
37 (see Sections 10.2.1.4 and 10.2.1.5).

#### 38 **10.2.1.2 Key Agreement /Key Exchange Algorithms**

39 Two families of Diffie-Hellman key-agreement/key-exchange algorithms have been  
40 specified for use in SSH: those based on finite fields and those based on elliptic curves.



- 1 • [RFC 4253] specifies two finite-field key-exchange methods: “diffie-hellman-  
2 group1-sha1” and “diffie-hellman-group14-sha1”. Since diffie-hellman-group1-  
3 sha1 uses 1024-bit keys, which provide less than 112 bits of security strength, it  
4 **shall not** be used. However, note that the use of SHA-1, in this case, is  
5 acceptable.
- 6 • RFC 4419 [RFC 4419] specifies two additional finite-field Diffie-Hellman key-  
7 exchange methods: "diffie-hellman-group-exchange-sha1" and "diffie-hellman-  
8 group-exchange-sha256". Although the modulus length (i.e., key size) that can be  
9 supported by these two methods is between 1024 and 8192 bits, a modulus length  
10 of at least 2048 bits **shall** be used.
- 11 • RFC 5656 [RFC 5656] specifies key-agreement options based on elliptic curves  
12 that can be used instead of the options described above. Two of the options are  
13 mandatory-to-implement for the Federal government when supporting Elliptic  
14 Curve Cryptography for SSH: ecdh-sha2-nistp256 and ecdh-sha2-nistp384. These  
15 options specify the use of elliptic curve Diffie Hellman with the appropriate,  
16 NIST-approved hash function and curve: ecdh-sha2-nistp256 specifies the use of  
17 SHA-256 and the nistp256 curve, while ecdh-sha2-nistp384 specifies the use of  
18 SHA-384 and the nistp384 curve (see RFC 5656). See FIPS 186-4 for information  
19 about the curves.

### 20 10.2.1.3 Public Key Authentication Algorithms

21 Public-key authentication algorithms are the digital-signature algorithms that can be used  
22 in the key exchange specified in Section 8 of RFC 4253 to perform server authentication.  
23 RFC 4253 specifies two digital signature algorithms: RSA and DSA (which is called  
24 “ssh-dss” in the RFC) using SHA-1 as the hash function for server authentication. It is  
25 important to note that according to SP 800-131A, SHA-1 is no longer allowed for  
26 generating digital signatures. However, in this protocol, SHA-1 is allowed for server  
27 authentication, as long as the public key size of the signing function (either RSA or DSA)  
28 is at least 2048 bits. The protocol allows a server’s public key to be used without  
29 validation (i.e., without obtaining assurance of public key validity). For Federal  
30 government use, the client **shall** obtain assurance of public key validity, as required in SP  
31 [800-89], before digital signature verification can be performed.

32  
33 Additional authentication algorithms for SSH are specified in RFC 5656. These use the  
34 Elliptic Curve Digital Signature Algorithm (ECDSA) using the curves specified in FIPS  
35 186-4. Table 10-1 identifies the requirements for the implementation of the ECDSA  
36 algorithm and the curves to be used by the Federal government.

37 **Table 10-1: Public Key Authentication Methods Using Elliptic Curves**

ECDSA	Hash Algorithm	IETF	Federal Government
ecdsa-sha2-nistp256	SHA-256	Mandatory	Mandatory
ecdsa-sha2-nistp384	SHA-384	Mandatory	Mandatory

38

1 [RFC 6187] specifies the use of X.509 version 3 certificates to convey public keys for the  
2 digital-signature algorithms. It also formally defines 2048-bit RSA with SHA-256 as a  
3 method for use in SSH. This combination provides 112 bits of security and is allowed. It  
4 is important to note that the hash algorithm used with the digital signature algorithms for  
5 authentication can be different than the hash function HASH in the key exchange and the  
6 key-derivation functions of SSH TLP.

#### 7 **10.2.1.4 Encryption Algorithms**

8 Several encryption algorithms are available for SSH; Federal government applications  
9 **shall** use NIST-approved algorithms. The currently specified encryption algorithms and  
10 mode(s) of operation for SSH that are NIST-approved are 3DES-CBC, AES-128-CBC,  
11 AES-192-CBC and AES-256-CBC (see [RFC 4253]), and AEAD\_AES\_128\_GCM and  
12 AEAD\_AES\_256\_GCM (see [RFC 5647]). 3DES-CBC is mandatory for IETF  
13 implementation.

14  
15 In the protocol, when either AEAD\_AES\_128\_GCM or AEAD\_AES\_256\_GCM is  
16 selected as the encryption algorithm for protecting an encrypted tunnel (client-to-server  
17 or server-to-client), it is also chosen as the MAC algorithm. A different algorithm or set  
18 of algorithms may be selected for communication in each direction. It should be noted  
19 that when AEAD\_AES\_128\_GCM or AEAD\_AES\_256\_GCM is chosen (for encryption  
20 and MAC generation), the algorithm is executed only once (rather than once for  
21 encryption and another time for integrity protection), because these modes provide both  
22 confidentiality and integrity protections at the same time.

23  
24 When AEAD\_AES\_128\_GCM or AEAD\_AES\_256\_GCM is used, the SSH packet-  
25 length field is not encrypted, but is processed as additional authenticated (plaintext) data.  
26 See [RFC 5647] for more details on using these algorithms in SSH.

#### 27 **10.2.1.5 Message Authentication Codes (MAC) Algorithms**

28 Several MAC algorithms are available for SSH; Federal government applications **shall**  
29 use NIST-approved algorithms. The currently specified MAC algorithms for SSH that are  
30 NIST-approved are HMAC-SHA1 (with MAC tags of 160 bits), HMAC-SHA1-96 (with  
31 MAC tags of 96 bits as specified in [RFC 4253]), AEAD\_AES\_128\_GCM and  
32 AEAD\_AES\_256\_GCM (see [RFC 5647]).

33  
34 As explained in Section 10.2.1.4, AEAD\_AES\_128\_GCM or AEAD\_AES\_256\_GCM  
35 can only be chosen as the MAC algorithm when also chosen as the encryption algorithm.

#### 36 **10.2.1.6 Public Host-Key Verification**

37 After the algorithm negotiation is completed, the TLP authenticates the server to the  
38 client in a key-exchange process (see Section 8 of RFC 4253). In this key exchange, a  
39 Diffie-Hellman (DH) key exchange is performed, producing two values: a DH value<sup>45</sup>  $K$   
40 and an exchange hash value called  $H$ .  $H$  is the hash value of  $K$  and other data (see Section  
41 8 of [RFC 4253] for a complete specification of  $H$ ). The generated  $H$  and  $K$  are  
42 subsequently used as inputs to a key-derivation function (see Section 7.2 of [RFC 4253])

---

<sup>45</sup> In the key-agreement schemes in SP 800-56A,  $K$  would be considered to be the shared secret.

1 for the specification of this function) to generate IVs and keys for the selected  
2 cryptographic algorithms.

3  
4 To prove that the server is actually the owner of the public key (called the public host key  
5 in the protocol), the server generates a digital signature using its private key (called the  
6 private host key in the protocol) on  $H$  (i.e., data that is known by both the client and the  
7 server). If the client can verify the digital signature using the public host key, then the  
8 client has assurance that the server is the owner of the public key. However, the identity  
9 of the server has not been verified unless the public host key is verified by the client  
10 before the signature on  $H$  is verified. See below.

11  
12 Verifying the public host key is performed by 1) comparing the server name and its  
13 public host key against a database of trusted server names and public host keys, or 2)  
14 using the public host key certificate (i.e., the server's public key certificate), or 3) using  
15 an out-of-band verification method using DNSSEC upon initiating SSH TLP<sup>46</sup>. A  
16 verification of the association between the public host key and the server name is  
17 essential to the security of the SSH connection. If the connection is not verified, then the  
18 connection is subject to a man-in-the-middle attack; details of this vulnerability are  
19 addressed in RFC 4251. Therefore, the association of a public host key (i.e., the server's  
20 key) to a server name **shall** be verified for every TLP session, and the TLP **shall** fail if  
21 the verification fails.

- 22 • When the first method of server authentication is used, and it is the only method  
23 available for the client, the protocol **shall** continue only when a match is found.  
24 Note that the protocol does not explicitly require the connection to fail when the  
25 public host key is not verified, however; this Recommendation requires a  
26 discontinuation of the protocol in this case.
- 27 • For the second method, the TLP specified in RFC 4253 allows the client to either  
28 a) accept the presented public key certificate without verification of the  
29 association between the public key and the server name, or b) verify the certificate  
30 and continue only if the public host key is verified (see Section 2 for details on  
31 how to verify a public key in a public key certificate). For Federal government  
32 use, option b) **shall** be used; that is, when this second method is used, the protocol  
33 **shall not** continue unless the server's certificate has been successfully verified.
- 34 • When an out-of-band verification method using DNSSEC is used (method three),  
35 the server's identity and public key **shall not** be accepted unless the fingerprint  
36 (hash value) of the public host key matches a fingerprint of the public key in the  
37 "SSHFP" resource record(s) of the server. "SSHFP" resource record(s) **shall** be  
38 verified before the fingerprint is accepted as a legitimate fingerprint. See RFC  
39 4255 for details about this method.

40 Other server-authentication methods may be defined later for the protocol.

41 It is important to note that the key exchange specified in Section 8 of RFC 4253 contains  
42 a Diffie-Hellman primitive specified in [SP 800-56A] that generates a shared secret. In  
43 [SP 800-56A], a complete key-agreement scheme contains a specific key-derivation  
44 method (e.g., a key-derivation function) that uses the shared secret to derive keying

---

<sup>46</sup> Details of the DNSSEC can be found in RFC 4255 [RFC 4255].

1 material. In SSH, the shared secret is provided, instead, to the key-derivation function  
2 specified in Section 7.2 of the RFC. This key-derivation function has been **approved** in  
3 [SP 800-135]. Therefore, the Diffie-Hellman key exchange in Section 8 of [RFC 4253],  
4 combined with the key-derivation function in Section 7.2 of the RFC is an **approved**  
5 key-agreement method for SSH TLP.

### 6 **10.2.2 UAP Issues**

7 There are many authentication methods that the server can use to authenticate the client.  
8 The required method that the server must support is public-key authentication, named  
9 “publickey” in the UAP (see Section 7 of RFC 4252). This requires the use of a digital-  
10 signature algorithm as specified in Section 10.2.1.3 except the digital signatures using  
11 SHA-1. SHA-1 digital signatures **shall not** be used for client authentication. See Section  
12 7 of RFC 4252 for specific details on how client authentication using one of the digital-  
13 signature algorithms is done. For Federal government applications, the digital-signature  
14 algorithms used for client authentication **shall** meet the requirements specified in SP 800-  
15 131A.

16  
17 Beside the “publickey” method, two other authentication methods have been defined for  
18 this protocol. The first method is using passwords. The second method is using the  
19 private key of a host system that is trusted by the server in this SSH connection; the latter  
20 method is called “host-based authentication”.

- 21 • For Federal government use, authentication using passwords **shall not** be used if  
22 the TLP does not provide an encrypted tunnel, because the password would be  
23 sent as cleartext.
- 24 • For the “host-based authentication” method (specified in Section 9 of RFC 4252),  
25 the client is a user of the host system that is attempting to authenticate to the  
26 server. In this method, the client knows the private signature key of the host. The  
27 client uses this private key to generate a digital signature on behalf of this host  
28 during the authentication process with the server in the SSH connection. The  
29 server verifies the digital signature to authenticate the host system. If the  
30 authentication is successful, and the client (user) is an authorized user associated  
31 with this host, then this user (the client) is considered to be authenticated by the  
32 SSH server. This “host-based authentication” method **should not** be used for  
33 client authentication because the method does not provide direct, cryptographic  
34 assurance of the identity of the client to the server - the server must trust the host  
35 system to obtain the correct identity of the client.

### 36 **10.3 Procurement Guidance**

37 The following recommendation is for any individual that makes a purchasing decision for  
38 acquiring SSH client and server implementations.

- 39 1. Client and server implementations **shall** support at least one of these NIST-  
40 approved encryption algorithms: AES-128-CBC, AES-192-CBC and AES-256-  
41 CBC, in addition to 3DES-CBC, which is already mandatory to implement for the  
42 protocol. Implementations that support all of these encryption algorithms **should**  
43 be selected.

- 1 2. When AEAD\_AES\_128\_GCM or AEAD\_AES\_256\_GCM is used in a  
2 negotiating encryption-algorithm list, it must also be in the corresponding MAC-  
3 algorithm list. An implementation **shall** either enforce this automatically or **shall**  
4 provide it as a configurable option.
- 5 3. Implementations **should** be chosen that support Suite B cryptographic algorithms  
6 as described in Section 10.2.1.1 above.
- 7 4. Client and server implementations **shall** support public-key authentication using  
8 public-key certificates.
- 9 5. Client and server implementations **shall** allow a protocol to be discontinued when  
10 the verification of the public-key-certificate fails.
- 11 6. Client implementations **shall** allow preference setting for implemented  
12 cryptographic algorithms.
- 13 7. Server implementations **shall** allow the configuration of the cryptographic  
14 algorithms to be used.
- 15 8. Server implementations **shall** be able to disallow the password-authentication  
16 method when encryption is not used in the client-to-server traffic direction.
- 17 9. Server implementations **shall** be able to disallow the “host-based authentication  
18 method”.

#### 19 **10.4 Recommendations for System Installers**

20 The system installer is the individual(s) that installs the SSH server and client  
21 applications and performs the initial configuration of the system. The system installer  
22 **shall**:

- 23 1. Install and/or configure the server and client to use only **approved** cryptographic  
24 algorithms.
- 25 2. Set the connection to fail when a public-key certificate is not verified at both  
26 sides: server and client.
- 27 3. Configure preferences in negotiating cryptographic-algorithm lists according to  
28 the organization’s security guidelines for the client. For example, if the  
29 organization prefers the use of AES-256, then AES-256 must be configured to  
30 have the highest preference among all of the available encryption choices.
- 31 4. Configure the use of only **approved** cryptographic algorithms by the server.
- 32 5. Consider disabling the “host-based authentication” option at the server if the  
33 server is not willing to communicate with all possible users/clients at the host  
34 machine.
- 35 6. When AEAD\_AES\_128\_GCM or AEAD\_AES\_256\_GCM is in a negotiating  
36 encryption-algorithm list, configure it to also be its companion MAC-algorithm if  
37 this is not done automatically.
- 38 7. Suite B cryptographic algorithms **should** be set with the highest preferences in the  
39 client-side application. This will result in the selection of Suite B cryptographic  
40 algorithms to be used when the server supports them.

1 The installer **shall** make sure that all of the cryptographic components and required plug-  
2 ins are installed so that cryptographic operations in SSH can function properly when  
3 protecting the data traffic.

#### 4 **10.5 Recommendations for System Administrators**

5 System administrators are those individuals responsible for the day-to-day functioning of  
6 the SSH server and client applications. System administrators **shall**:

- 7 1. Configure the client to verify the server's public-key certificate in the key-  
8 exchange protocol in TLP and discontinue the protocol if the verification fails.
- 9 2. Configure the server to authenticate the client by verifying the client's certificate,  
10 if provided, when a public-key algorithm for authentication is used in UAP.
- 11 3. Ensure that end users are properly trained to follow the organization's security  
12 policy for the selection, use and protection of passwords.
- 13 4. Ensure that the organization's security policy is enforced.
- 14 5. Ensure the protection of private key(s) associated with the server's certificate and  
15 the client's certificate from disposal, leaks or unauthorized access is/are properly  
16 configured.

#### 17 **10.6 Recommendations for End Users**

18 An end user is the individual using the SSH client application to securely connect to the  
19 SSH server. End users **shall**:

- 20 1. Be aware of and trained to follow the organization's security policy for using the  
21 product.
- 22 2. Operate their system as instructed by their organization and system administrator.

23

24

## 1 **Appendix A: Glossary**

2

3 The terms provided below are defined as they are used in this document. The same terms  
4 may be defined differently in other documents.

5

<b>Term</b>	<b>Definition</b>
Access control	Restricts access to resources only to privileged entities.
Access-control mechanism	A method for restricting access to some resource.
Approved	FIPS-approved and/or NIST-recommended. An algorithm or technique that is either 1) specified in a FIPS or NIST Recommendation, or 2) adopted in a FIPS or NIST Recommendation or 3) specified in a list of NIST approved security functions.
Archive	See Key-management archive.
Asymmetric-key algorithm	See Public-key cryptographic algorithm.
Authentication	A process that establishes the origin of information, or determines an entity's identity.
Authentication code	See Message Authentication Code.
Authorization	Access privileges granted to an entity; conveys an "official" sanction to perform a given security function or activity.
Availability	Timely, reliable access to information by authorized entities.
Backup	A copy of information to facilitate recovery, if necessary.
CBC-MAC	A mode of operation for block cipher algorithms.
Certificate	See public-key certificate.
Certification authority	The entity in a Public Key Infrastructure (PKI) that is responsible for issuing certificates, and exacting compliance to a PKI policy.
Checksum	A method used to protect the integrity of data by detecting errors in that data.
Ciphertext	Data in its encrypted form.
Compromise	The unauthorized disclosure, modification, substitution or use of sensitive data (e.g., keying material and other security related information).
Confidentiality	The property that sensitive information is not disclosed to unauthorized entities.

Cryptographic key (key)	<p>A parameter used in conjunction with a cryptographic algorithm that determines its operation in such a way that an entity with knowledge of the key can reproduce or reverse the operation, while an entity without knowledge of the key cannot. Examples include:</p> <ol style="list-style-type: none"> <li>1. the transformation of plaintext data into ciphertext data,</li> <li>2. the transformation of ciphertext data into plaintext data,</li> <li>3. the computation of a digital signature from data,</li> <li>4. the verification of a digital signature,</li> <li>5. the computation of an authentication code from data,</li> <li>6. the verification of an authentication code from data and a received authentication code,</li> <li>7. the computation of a shared secret that is used to derive keying material.</li> </ol>
Cryptographic module	The set of hardware, software, and/or firmware in which approved security functions are implemented
Cryptoperiod	The time span during which a specific key is authorized for use or in which the keys for a given system or application may remain in effect.
Data integrity	A property whereby data has not been altered in an unauthorized manner since it was created, transmitted or stored. In this Recommendation, the statement that a cryptographic algorithm "provides data integrity" means that the algorithm is used to detect unauthorized alterations.
Decryption	The process of changing ciphertext into plaintext using a cryptographic algorithm and key.
DES	The Data Encryption Standard that was specified in FIPS 46 (now withdrawn).
Digital signature	<p>The result of a cryptographic transformation of data that, when properly implemented, provides the services of:</p> <ol style="list-style-type: none"> <li>1. origin authentication,</li> <li>2. data integrity, and</li> <li>3. signer non-repudiation.</li> </ol>
Distribution	See key distribution.
Encryption	The process of changing plaintext into ciphertext using a cryptographic algorithm and key.
Entity	An individual (person), organization, device or process.
Hash algorithm	See Hash function.



Hash function	A function that maps a bit string of arbitrary length to a fixed length bit string. Approved hash functions satisfy the following properties: <ol style="list-style-type: none"> <li>1. (One-way) It is computationally infeasible to find any input that maps to any pre-specified output, and</li> <li>2. (Collision free) It is computationally infeasible to find any two distinct inputs that map to the same output.</li> </ol>
Hash value	The result of applying a hash function to information.
Hash-based message authentication code (HMAC)	A message authentication code that uses an approved keyed-hash function.
Identifier	A bit string that is associated with a person, device or organization. It may be an identifying name, or may be something more abstract (for example, a string consisting of an IP address and timestamp), depending on the application.
Integrity	The property that sensitive data has not been modified or deleted in an unauthorized and undetected manner. In this Recommendation, the statement that a cryptographic algorithm "provides integrity" means that the algorithm is used to detect unauthorized modifications or deletions.
Key	See cryptographic key.
Key agreement	A key-establishment scheme whose resultant keying material is a function of information contributed by two or more participants, so that no party can predetermine the value of the keying material.
Key Bundle	A set of keys used during one operation, typically a TDEA operation.
Key component	A parameter used in conjunction with other key components in an approved security function to form a plaintext cryptographic key or perform a cryptographic function.
Key distribution	The transport of a key and other keying material from an entity that either owns or generates the key to another entity that is intended to use the key.
Key-encryption key	A cryptographic key that is used for the encryption or decryption of other keys.
Key establishment	A procedure that results in keying material that is shared among different parties.
Key management	The activities involving the handling of cryptographic keys and other related security parameters (e.g., IVs and passwords) during the entire life cycle of the keys, including their generation, storage, establishment, entry and output, and

	destruction.
Key-management archive	A function in the lifecycle of keying material; a repository containing keying material of historical interest.
Key pair	A public key and its corresponding private key; a key pair is used with a public-key algorithm.
Key recovery	Mechanisms and processes that allow authorized entities to retrieve keying material from key backup or an archive.
Key transport	A key-establishment procedure whereby one entity (the sender) selects a value for secret keying material and then securely distributes that value to another party (the receiver).
Key wrapping	A method of encrypting keys (along with associated integrity information) that provides both confidentiality and integrity protection using a symmetric key.
Keying material	The data (e.g., keys and IVs) necessary to establish and maintain cryptographic keying relationships.
Message Authentication Code (MAC)	A cryptographic checksum on data that uses a symmetric key to detect both accidental and intentional modifications of data.
Nonce	A time-varying value that has, at most, a negligible chance of repeating. For example, a nonce could be a random value that is generated anew for each instance of a nonce, a timestamp, a sequence number, or some combination of these.
Non-repudiation	A service that is used to provide assurance of the integrity and origin of data in such a way that the integrity and origin can be verified by a third party as having originated from a specific entity in possession of the private key of the claimed signatory.
Owner	For an asymmetric key pair, the entity that owns the private key, whether that entity generated the key pair or a trusted party generated the key pair for the entity.  In Encrypted File Systems, the file owner has control over the file and grants access of the file to others. A file may have one or more owners. An owner could be an individual or a group of individuals or processes
Password	A string of characters (letters, numbers and other symbols) that are used to authenticate an identity or to verify access authorization.
Payload	A part of the data stream representing the user information and user overhead in a communication.
Plaintext	Intelligible data that has meaning and can be understood

without the application of decryption.

Private key	<p>A cryptographic key, used with a public-key cryptographic algorithm that is uniquely associated with an entity and is not made public. In an asymmetric (public) cryptosystem, the private key is associated with a public key. Depending on the algorithm, the private key may be used to:</p> <ol style="list-style-type: none"><li>1. Compute the corresponding public key,</li><li>2. Compute a digital signature that may be verified by the corresponding public key,</li><li>3. Decrypt data that was encrypted by the corresponding public key, or</li><li>4. Compute a piece of common shared data, together with other information.</li></ol>
Protocol	<p>A special set of rules used by two or more entities that describe the message order and data structures for information exchanged between the entities.</p>
Public key	<p>A cryptographic key used with a public-key cryptographic algorithm that is uniquely associated with an entity and that may be made public. In an asymmetric (public) cryptosystem, the public key is associated with a private key. The public key may be known by anyone and, depending on the algorithm, may be used to:</p> <ol style="list-style-type: none"><li>1. Verify a digital signature that is signed by the corresponding private key,</li><li>2. Encrypt data that can be decrypted by the corresponding private key, or</li><li>3. Compute a piece of shared data.</li></ol>
Public-key (asymmetric) cryptographic algorithm	<p>A cryptographic algorithm that uses two related keys, a public key and a private key. The two keys have the property that determining the private key from the public key is computationally infeasible.</p>
Public-key certificate	<p>A set of data that uniquely identifies an entity, contains the entity's public key and possibly other information, and is digitally signed by a trusted party, thereby binding the public key to the entity.</p>
Public Key Infrastructure (PKI)	<p>A framework that is established to issue, maintain and revoke public-key certificates.</p>
Reconstitute	<p>Rebuilding a service system (possibly with a different infrastructure) using previously saved security information and/or keying material, rather than simply restarting a system from a backup.</p>
Rekey	<p>A new key replaces another key; the “value” of the new key is entirely independent of the “value” of the old key.</p>

Relying party	An individual or organization that relies on the certificate and the CA that issued the certificate to verify the identity of the user; the validity of the public key, associated algorithms and any relevant parameters; and the user's possession of the corresponding private key.
Secret key	A cryptographic key that is used with a secret-key (symmetric) cryptographic algorithm that is uniquely associated with one or more entities and is not made public. The use of the term "secret" in this context does not imply a classification level, but rather implies the need to protect the key from disclosure.
Security association	A relationship between two network entities in which security information is shared and used to support secure communication between the two entities.
Security services	Mechanisms used to provide confidentiality, data integrity, authentication or non-repudiation of information.
Self-signed certificate	A public-key certificate whose digital signature may be verified by the public key contained within the certificate. The signature on a self-signed certificate protects the integrity of the data, but does not guarantee authenticity of the information. The trust of self-signed certificates is based on the secure procedures used to distribute them.
<b>Shall</b>	This term is used to indicate a requirement of a Federal Information Processing Standard (FIPS) or a requirement that must be fulfilled to claim conformance to this Recommendation. Note that <b>shall</b> may be coupled with <b>not</b> to become <b>shall not</b> .
Shared secret	A value that is generated during a key-agreement scheme; the shared secret is used to derive keying material for a symmetric-key algorithm.
<b>Should</b>	This term is used to indicate a very important requirement. While the "requirement" is not stated in a FIPS, ignoring the requirement could result in undesirable results. Note that <b>should</b> may be coupled with <b>not</b> to become <b>should not</b> .
Signature verification	Uses a digital-signature algorithm and a public key to verify a digital signature.
Symmetric key	A single cryptographic key that is used with a secret (symmetric) key algorithm.
Symmetric-key algorithm	A cryptographic algorithm that uses one shared key, a secret key.
Threat	Any circumstance or event with the potential to adversely impact a system through unauthorized access, destruction,

	disclosure, modification of data or denial of service.
Triple DES/Triple DEA (TDEA)	Triple Data Encryption Algorithm, specified in SP 800-67.
3-TDEA	Three key TDEA as specified in SP 800-67.
Unauthorized disclosure	An event involving the exposure of information to entities not authorized access to the information.
User's name (in a certificate)	The name of the party authorized to use the private key associated with the public key in the certificate; the subject of the certificate.
X.509 public-key certificate	The public key for a user (or device) and a name for the user (or device), together with some other information, rendered unforgeable by the digital signature of the certification authority that issued the certificate, encoded in the format defined in the ISO/ITU-T X.509 standard.

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## Appendix B: Acronyms

AES	Advanced Encryption Standard
AH	Authentication Header
AS	Authentication Server
CA	Certificate Authority
CBC	Cipher Block Chaining
CBC-MAC	Cipher Block Chaining Message Authentication Code
CMVP	Cryptographic Module Validation Program
COTS	Commercial Off-the-Shelf
CRL	Certificate Revocation List
CTR	Counter Mode
DES	Data Encryption Standard
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DSA	Digital Signature Algorithm
EC	Elliptic Curve
ECDH	Elliptic Curve Diffie-Hellman
ECDSA	Elliptic Curve Digital Signature Algorithm
EFS	Encrypted File System
ESP	Encapsulating Security Protocol
FEK	File Encryption Key
GCM	Galois Counter Mode
GMAC	Galois Message Authentication Code
HMAC	Hash-based Message Authentication Code
HTTP	Hypertext Transfer Protocol
ICV	Integrity Check Value
IETF	Internet Engineering Task Force
IKE	Internet Key Exchange
IP	Internet Protocol
IV	Initialization Vector
KDC	Key Distribution Center
KMF	Key Management Facility
KMM	Key Management Message
KSK	Key Signing Key
KWK	Key Wrapping Key
LDAP	Lightweight Directory Access Protocol

MAC	Message Authentication Code
MD5	Message-Digest Algorithm 5
NSEC	Next Secure
NIST	National Institute of Standards and Technology
OCSP	Online Certificate Status Protocol
OMB	Office of Management and Budget
OTAR	Over The Air Rekeying
PIN	Personal Identification Number
PKCS	Public Key Cryptography Standard
PKI	Public Key Infrastructure
PRF	Pseudorandom Function
PVM	Path Validation Module
RA	Registration Authority
RFC	Request for Comment
RR	Resource Record
RSA	Rivest, Shamir, and Adleman.
SA	Security Association
SEP	Secure Entry Point
SHA	Secure Hash Algorithm
SMTP	Simple Mail Transfer Protocol
S/MIME	Secure/Multipart Internet Mail Extensions
SSL	Secure Socket Layer
TDEA	Triple Data Encryption Algorithm
TEK	Traffic Encryption Key
TCG	Trusted Computing Group
TGS	Ticket Granting Service
TLS	Transport Layer Security
TPM	Trusted Platform Module
TS	Target Server
TSIG	Transaction Signature
URL	Uniform Resource Locator
VPN	Virtual Private Network
XOR	Exclusive-Or operation
ZSK	Zone Signing Key

## 1 Appendix C: A Word to Novice End Users

2 Cryptographic keys are frequently categorized by the algorithms they are used with, the  
3 operations they are used to perform and by the number of times they can be used. Keys  
4 will either be asymmetric and used with an asymmetric algorithm, or symmetric and used  
5 with a symmetric algorithm. Asymmetric keys are generated as key pairs: a *private key*  
6 that must be kept secret, and a related *public key*, that may not be a secret. In general, the  
7 private key performs one operation, for example, a digital signature, and the public key  
8 does the complementary operation, in this case, signature verification. In the case of  
9 symmetric keys, end users need to treat the key as a secret shared value and use the same  
10 value for complementary cryptographic functions, such as encryption and decryption.

11  
12 Some asymmetric keys are static and intended for long-term use, while others are  
13 ephemeral and expire after their use with one message or session. The public key of a  
14 static asymmetric-key pair is often provided in a public-key certificate, while an  
15 ephemeral public key is not. Although the concept of static vs. ephemeral also applies to  
16 symmetric keys, a short-term symmetric key is often called a session key, rather than an  
17 ephemeral key. No specific terminology is used for a long-term symmetric key. An  
18 application or protocol may be supported by some combination of such keys.

19  
20 A PKI is the foundation of many current key-management processes and is used in many  
21 of the protocols or applications described in this Recommendation, as well as other  
22 security protocols and applications. Some understanding of the role of a PKI and *public*  
23 *key certificates* in key management is very helpful to setting up security protocols or  
24 applications properly. A long-term, or “static” public key is generally combined with the  
25 name of the key’s “owner” in an electronic document called a public-key certificate.  
26 While certificates can be self-issued and signed (that is, the party that created the key pair  
27 can sign his name and the public key with the corresponding private key), most  
28 certificates are digitally signed with the private key of a trusted entity called a  
29 Certification Authority.

30  
31 An end user may typically have one or more certificates, and may have different  
32 certificates for different applications, e.g., for e-mail and for authentication to web sites.  
33 As Federal Personal Identity Verification (PIV) cards are issued to Federal employees  
34 and contractors, most Federal users will have a personal smart card that contains one or  
35 more personal certificates issued to them by their agency. Other specific applications may  
36 require “soft” certificates, usually kept on the user’s computer, and possibly issued by  
37 commercial CAs. For example, browser products, such as Internet Explorer, Firefox or  
38 Safari, typically implement a mechanism to generate key pairs, send the public keys to a  
39 CA and return a public-key certificate for that key to the browser. The certificates are  
40 then kept in a user-certificate store on the user’s computer, which can be managed in a  
41 manner similar to a root-certificate store (see Section 2). The process and interfaces for  
42 generating keys, and for requesting, downloading and installing certificates are specific to  
43 both the individual user client product and, sometimes, to the CA itself; however, the  
44 websites of CAs often have pages that guide the user through the key generation and  
45 certificate issuance process for the common browser products. Users can share  
46 certificates via e-mail or public-key infrastructures, smart cards or other memory tokens.

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1 Similarly, secure web servers have TLS server certificates, with certain specific  
2 characteristics; note that, although Federal users are required to use TLS rather than SSL,  
3 the certificates are identical. The *Subject Name* in these certificates follows specific rules  
4 so that the domain name of the server is included in the Subject Name field of the  
5 certificate. Commercial CAs sell TLS certificates, and, where it is important to reach a  
6 general population of non-government users, it may be desirable to get a TLS certificate  
7 from a CA that has its root certificate widely distributed “out of the box” in the certificate  
8 stores of Microsoft Windows, Macintosh OS X, and the various Mozilla browsers. This  
9 will allow most users to verify the server certificate. However, it is important to review  
10 the certificate policy and choices that may be available from the CAs selling TLS  
11 certificates for use on Federal agency web servers in order to ensure that the certificates  
12 meet the requirements stated herein and in SP 800-57, Part 1.

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## 1 **Appendix D: References**

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- COMMO N “X.509 Certification Policy for the U.S. Federal PKI Common Policy Framework”, Federal Public Key Infrastructure Policy Authority, Version 3647-1.3, December 2007.
- COMMO N PROF “X.509 Certificate and Certificate Revocation List (CRL) Extensions Profile for the Shared Secret Providers (SSP) Program” Federal PKI Policy Authority Shared Service Provider Working Group, January 2008
- DENN D. Denning and G. M. Sacco, “Timestamps in Key Distribution Protocols”, CACM 24(8), pp. 533-536, August 1981.
- FIPS 180-4 “Secure Hash Standard (SHS)”, Federal Information Processing Standard 180-4, National Institute of Standards and Technology, US Department of Commerce, March 2012.
- FIPS 186-4 “Digital Signature Standard”, Federal Information Processing Standard 186-4, National Institute of Standards and Technology, U.S. Department of Commerce, July 2013.
- FIPS 197 “Advanced Encryption Standard (AES)”, Federal Information Processing Standard 197, National Institute of Standards and Technology, U.S. Department of Commerce, November 2001.
- FIPS 201 “Personal Identity Verification (PIV) of Federal Employees and Contractors”, Federal Information Processing Standard 201, National Institute of Standards and Technology, U.S. Department of Commerce, March 2006.
- FPKI PROF “Federal Public Key Infrastructure (PKI) X.509 Certificate and CRL Extensions Profile” Booz-Allen & Hamilton and National Institute of Standards and Technology, October 2005.
- NEED Roger M. Needham and Michael D. Schroeder, “Using Large Networks of Computers,” Communications of the ACM, Vol. 21 (12), pp. 993-999, December 1978.
- NEUM B. Clifford Neuman and Theodore Y. Ts’o, “An Authentication Service for Computer Networks,” IEEE Communications Magazine, Vol. 32 (9), pp. 33-38, September 1994.
- NISTIR 7924 Harold Booth and Andrew Regenscheid, “Reference Certificate Policy”, NIST, (Draft) NISTIR 7924, April 2013.
- OMB 04-04 “MEMORANDUM TO THE HEADS OF ALL DEPARTMENTS AND AGENCIES RE: E-Authentication Guidance for Federal Agencies”, M-04-04, December 16, 2003

- OTAR “Project 25 Digital Radio Over The Air Rekeying (OTAR) Protocol”, TIA/EIA-102.AACA-2001, April 2001.
- OTAR1 “Project 25 Digital Radio Over The Air Rekeying Protocol: Addendum 1 - Key Management Security Requirements for Type 3 Block Encryption Algorithms”, TIA/EIA 102.AACA-1, November 2002.
- PKCS-7 Kaliski, B., "PKCS #7: Cryptographic Message Syntax Version 1.5", RFC 2315, IETF, March 1998.
- PKCS-10 “PKCS #10 v1.7: Certification Request Syntax Standard” RSA Laboratories May 2000
- RFC 1034 P. Mockapetris “Domain Names – Concepts and Facilities” RFC 1034 November 1987.
- RFC 1035 P. Mockapetris “Domain Names – Implementation and Specification” RFC 1035 November 1987
- RFC 2045 N. Freed and N. Borenstein, “Multipurpose Internet Mail Extensions (MIME) Part One:Format of Internet Message Bodies” RFC 2045, November 1996.
- RFC 2046 N. Freed and N. Borenstein, “MIME Part 2: Media Types” RFC 2046, November 1996.
- RFC 2047 K. Moore, “MIME Part Three: Message Header Extensions for Non-ASCII Text” RFC 2047, November 1996.
- RFC 2049 N. Freed and N. Borenstein, “MIME Part Five: Conformance Criteria and Examples”, RFC 2049, November 1996
- RFC 2119 S. Bradner, “Key words for use in RFCs to Indicate Requirement Levels”, RFC 2119, March 1997.
- RFC 2246 T. Dierks and C. Allen, “The TLS Protocol Version 1.0”, RFC 2246, January 1999 (obsoleted by RFC 4346).
- RFC 2401 S. Kent and R. Atkinson, "Security Architecture for the Internet Protocol", RFC 2401, November 1998 (obsoleted by RFC 4301).
- RFC 2402 S. Kent and R. Atkinson, "IP Authentication Header", RFC 2402, November 1998 (obsoleted by RFC 4302 and RFC 4835).
- RFC 2404 C. Madson and R. Glenn, "The Use of HMAC-SHA-1-96 within ESP and AH", RFC 2404, November 1998.
- RFC 2405 C. Madson and N. Doraswamy, "The ESP DES-CBC Cipher Algorithm with Explicit IV", RFC 2405, November 1998.

- RFC 2406 S. Kent, and R. Atkinson, "IP Encapsulating Security Payload (ESP)", RFC 2406, November 1998 (obsoleted by RFC 4303 and RFC 4835).
- RFC 2407 D. Piper, "The Internet IP Security Domain of Interpretation for ISAKMP", RFC 2407, November 1998 (obsoleted by RFC 5996).
- RFC 2408 D. Maughan, et. al., "The Internet Security Association and Key Management Protocol (ISAKMP)", RFC 2408, November 1998 (obsoleted by RFC 5996).
- RFC 2409 Harkins, D., Carrel, D., "The Internet Key Exchange (IKE)", RFC 2409, November 1998 (obsoleted by RFC 5996).
- RFC 2410 R. Glenn and S. Kent, "The NULL Encryption Algorithm and its Use with IPsec", RFC 2410, November 1998.
- RFC 2451 R. Pereira, and R. Adams, "The ESP CBC-Mode Cipher Algorithms", Internet Advisory Board, Internet Engineering Task Force, RFC 2451, November 1998.
- RFC 2631 E. Rescorla, "Diffie-Hellman Key Agreement Method", RFC 2631, June 1999.
- RFC 2634 P. Hoffman "Enhanced Security Services for S/MIME" RFC 2634, June 1999.
- RFC 3394 R. Housley and J. Schaad, "Advanced Encryption Standard (AES) Key Wrap Algorithm", RFC 3394, September 2002.
- RFC 3447 J. Jonsson, and B. Kaliski, "Public-Key Cryptography Standards (PKCS) #1: RSA Cryptography Specifications Version 2.1", RFC 3447, February 2003.
- RFC 3566 S. Frankel and H. Herbert, "The AES-XCBC-MAC-96 Algorithm and its Use with IPsec", RFC 3566, September 2003.
- RFC 3602 S. Frankel, R. Glenn, and S. Kelly, "The AES-CBC Cipher Algorithm and its Use with IPsec", RFC 3602, September 2003.

- RFC 3645 S. Kwan et als., “Generic Security Service Algorithm for Secret Key Transaction Authentication for DNS (GSS-TSIG)”, RFC 3645, October 2003.
- RFC 3686 R. Housley, “Using Advanced Encryption Standard (AES) Counter Mode with IPsec Encapsulating Security Payload (ESP)”, RFC 3686, January 2004.
- RFC 3962 K. Raeburn, “Advanced Encryption Standard (AES) Encryption for Kerberos 5”, RFC 3962, February 2005.
- RFC 4033 R. Arends, R. Austein, M. Larson, D. Massey, and S. Rose, “DNS Security Introduction and Requirements”, RFC 4033, March 2005.
- RFC 4034 R. Arends, R. Austein, M. Larson, D. Massey, D., and S. Rose, “Resource Records for the DNS Security Extensions”, RFC 4034, March 2005.
- RFC 4035 R. Arends, R. Austein, M. Larson, D. Massey, and S. Rose, “Protocol Modifications for the DNS Security Extensions”, RFC 4035, March 2005.
- RFC 4106 J. Viega and D. McGrew, “The Use of Galois/Counter Mode (GCM) in IPsec Encapsulating Security Payload (ESP)”, RFC 4106, June 2005.
- RFC 4109 P. Hoffman, “Algorithms for Internet Key Exchange version 1 (IKEv1)”, RFC 4109, May 2005.
- RFC 4120 Neuman, C., Yu, T., Hartman, S., Raeburn, K., “The Kerberos Network Authentication Service (V5)”, RFC 4120, July 2005.
- RFC 4210 Adams, C., Farrell, S., Kause, T., Mononen, T., “Internet X.509 Public Key Infrastructure Certificate Management Protocol (CMP)”, RFC 4210, September 2005.
- RFC 4251 T. Ylonen and C. Lonvick, “The Secure Shell (SSH) Protocol Architecture”, RFC 4251, January 2006.
- RFC 4252 T. Ylonen and C. Lonvick, “The Secure Shell (SSH) Authentication Protocol”, RFC 4252, January 2006.
- RFC 4253 T. Ylonen and C. Lonvick, “The Secure Shell (SSH) Transport Layer Protocol”, RFC 4253, January 2006.
- RFC 4254 T. Ylonen and C. Lonvick, “The Secure Shell (SSH) Connection Protocol”, RFC 4254, January 2006.

- RFC 4288 N. Freed and J. Klensin, "Media Type Specifications and Registraton Procedures", RFC 4288, December 2005.
- RFC 4289 N. Freed and J. Klensin, "Multipurpose Internet Mail Extensions (MIME) Part Four: Registration Procedures", RFC 4289, December 2005.
- RFC 4301 S. Kent and K. Seo, "Security Architecture for the Internet Protocol", RFC 4301, December 2005.
- RFC 4302 S. Kent, "IP Authentication Header", RFC 4302, December 2005.
- RFC 4303 S. Kent, "IP Encapsulating Security Payload (ESP)", RFC 4303, December 2005.
- RFC 4307 J. Schiller, "Cryptographic Algorithms for use in the Internet Key Exchange Version 2 (IKEv2)" RFC 4307, December 2005.
- RFC 4308 P. Hoffman, "Cryptographic Suites for IPsec", RFC 4308, December 2005.
- RFC 4309 R. Housley., "Using Advanced Encryption Standard (AES) CCM Mode with IPsec Encapsulating Security Payload (ESP)", RFC 4309, December 2005.
- RFC 4346 T. Dierks and E. Rescorla, "The Transport Layer Security (TLS) Protocol Version 1.1" RFC 4346, April 2006 (obsoleted by RFC 5246).
- RFC 4434 P. Hoffman, "The AES-XCBC-PRF-128 Algorithm for the Internet Key Exchange Protocol (IKE)", RFC 4434, February 2006.
- RFC 4511 J. Sermersheim, Ed., "Lightweight Directory Access Protocol (LDAP): The Protocol", RFC 4511, June 2006.
- RFC 4512 K. Zeilenga, "Lightweight Directory Access Protocol (LDAP): Directory Information Models", RFC 4512, June 2006.
- RFC 4543 D. McGrew, and J. Viega, "The Use of Galois Message Authentication Code (GMAC) in IPsec ESP and AH", RFC 4543, May 2006.
- RFC 4556 L. Zhu and B. Tung, "Public Key Cryptography for Initial Authentication in Kerberos (PKINIT)", RFC 4556, June 2006.
- RFC 4635 D. Eastlake, "HMAC SHA TSIG Algorithm Identifiers", RFC 4635, August 2006.
- RFC 4835 V. Manral, "Cryptographic Algorithm Implementation Requirements for Encapsulating Security Payload (ESP) and Authentication Header (AH)", RFC 4835, April 2007.

- RFC 4868 S. Kelly and S. Frankel, "Using HMAC-SHA-256, HMAC-SHA-384, and HMAC-SHA-512 with IPsec", RFC 4868, May 2007.
- RFC 5019 A. Deacon and R. Hurst, "The Lightweight Online Certificate Status Protocol (OCSP) Profile for High-Volume Environments", RFC 5019, September 2007.
- RFC 5035 P. Hoffman, "Enhanced Security Services (ESS) Update: Adding CertID Algorithm Agility", RFC 5035, August 2007.
- RFC 5155 B. Laurie, G. Sisson, R. Arends and D. Blacka. "DNSSEC Hashed Authenticated Denial of Existence". RFC 5155, March 2008.
- RFC 5246 T. Dierks and E. Rescorla, "The Transport Layer Security (TLS) Protocol Version 1.2", RFC 5246, August 2008.
- RFC 5272 M. Myers and J. Schaad, "Certificate Management Messages over CMS", RFC 5272, June 2008.
- RFC 5280 D. Cooper, S. Santesson, S. Farrell, S. Boeyen, R. Housley, and W. Polk, "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", RFC 5280, May 2008.
- RFC 5349 L. Zhu, K. Jaganathan and K. Lauter, "Elliptic Curve Cryptography (ECC) Support for Public Key Cryptography for Initial Authentication in Kerberos (PKINIT)", RFC 5349, September 2009.
- RFC 5430 M. Salter, E. Rescorla and R. Housley, "Suite B Profile Transport Layer Security (TLS)", RFC 5430, March 2009.
- RFC 5647 K. Igoe and J. Solinas, "AES Galois Counter Mode for the Secure Shell Transport Layer Protocol", RFC 5647, August, 2009.
- RFC 5652 R. Housley, "Cryptographic Message Syntax (CMS)", RFC 5652, September 2009.
- RFC 5656 D. Stebila and J. Green, "Elliptic Curve Algorithm Integration in the Secure Shell Transport Layer", RFC 5656, December 2009.
- RFC 5751 B. Ramsdell, "Secure/Multipurpose Internet Mail Extensions (S/MIME) Version 3.2 Message Specification", RFC 5751, January 2010.
- RFC 5996 C. Kaufman, P. Hoffman, Y. Nir and P. Eronen, "Internet Key Exchange Protocol Version 2 (IKEv2)", RFC 5996, September 2010.

- RFC 6113 S. Hartman and L. Zhu, “A Generalized Framework for Kerberos Pre-Authentication”, RFC 6113, April 2011.
- RFC 6187 K. Igoe and D. Stebila, “X.509v3 Certificates for Secure Shell Authentication”, RFC 6187, March 2011.
- RFC 6239 K. Igoe, “Suite B Cryptographic Suites for Secure Shell (SSH)”, RFC 6239, May 2011.
- RFC 6251 S. Josefsson, “Using Kerberos Version 5 over the Transport Layer Security (TLS) Protocol”, RFC 6251, May 2011.
- RFC 6318 R. Housley and J. Solinas, “Suite B in Secure/Multipurpose Internet Mail Extensions (S/MIME)”, RFC 6318, June 2011.
- RFC 6379 L. Law and J. Solinas, “Suite B Cryptographic Suites for IPsec”, RFC 6379, October 2011.
- RFC 6605 P. Hoffman and W.C.A. Wijngaards, “Elliptic Curve Digital Signature Algorithm (DSA) for DNNSEC”, RFC 6605, April 2012.
- RFC 6649 L. Astrand and T. Yu, “ Deprecate DES, RC4-HMAC-EXP, and Other Weak Cryptographic Algorithms in Kerberos”, RFC 6649, July 2012.
- RFC 6944 S. Rose, “Applicability Statement: DNS Security (DNSSEC) DNSKEY Algorithm Implementation Status”, RFC 6944, April 2013.
- RFC 6960 S. Santesson et al., “X.509 Internet Public Key Infrastructure Online Certificate Status Protocol – OCSP”, RFC 6960, June 2013.
- RFC 7030 M. Pritikin et al., “Enrollment over Secure Transport”, RFC 7030, October 2013.
- SEC1 Standards for Efficient Cryptography Group, “Elliptic Curve Cryptography”, 2000. [See <http://www.secg.org/collateral/sec1.pdf>].
- SP 800-32 D. Kuhn, V. Hu, W. Polk, and S. Chang, “Introduction to Public Key Technology and the Federal PKI Infrastructure”, National Institute of Standards and Technology, NIST Special Publication 800-32, February 2001.
- SP 800-38A M. Dworkin, “Recommendations for Block Cipher Modes of Operation”, National Institute of Standards and Technology, NIST Special Publication 800-38A, December 2001.



- SP 800-49 C. Chernick, “Federal S/MIME V3 Client Profile”, National Institute of Standards and Technology, NIST Special Publication 800-49, November 2002.
- SP 800-52 T. Polk et als., “Guidelines for the Selection, Configuration and use of Transport Layer Security (TLS) Implementations”, NIST SP 800-52 Rev. 1, April 2014.
- SP 800-56A E. Barker, L. Chen, M. Smid and A. Roginsky, “Recommendation for Pair-Wise Key Establishment Schemes Using Discrete Logarithm Cryptography National Institute of Standards and Technology, NIST Special Publication 800-56A, (Revision 2), May 2013.
- SP 800-56B E. Barker, L. Chen, A. Regenscheid and M. Smid, “Recommendation for Pair-Wise Key Establishment Schemes: Using Integer Factorization Cryptography”, National Institute of Standards and Technology, NIST Special Publication 800-56B, August 2009.
- SP 800-57, Part 1 NIST Special Publication (SP) 800-57, Part 1, Recommendation for Key Management: General, (Revision 3) July 2012.
- SP 800-67 E. Barker and W. Barker, “Recommendation for the Triple Data Encryption Algorithm (TDEA) Block Cipher”, National Institute of Standards and Technology, NIST Special Publication 800-67, Revision 1, January 2012.
- SP 800-77 S. Frankel, K. Kent, R. Lewkowski, A. Orebaugh, R. Ritchey, St. Shama, “Guide to IPsec VPNs”, National Institute of Standards and Technology, NIST Special Publication 800-77, December 2005.
- SP 800-81r2 R. Chandramouli and S. Rose, “Secure Domain Name System (DNS) Deployment Guide”, National Institute of Standards and Technology, NIST Special Publication 800-81-2, September 2013.
- SP 800-90A E. Barker and J. Kelsey, “Recommendation for Random Number Generation Using Deterministic Random Bit Generators (Revised)”, 2<sup>nd</sup> Draft NIST Special Publication 800-90A, April 2014.
- SP 800-90B E. Barker and J. Kelsey, “DRAFT Recommendation for the Entropy Sources Used for Random Bit Generation”, Draft NIST Special Publication 800-90B, September 2013.
- SP 800-90C E. Barker and J. Kelsey, “DRAFT Recommendation for Random Bit Generator (RBG) Constructions”, Draft NIST Special Publication 800-90C, September 2013.

- SP 800-89 E. Barker, "Recommendation for Obtaining Assurances for Digital Signature Applications", NIST SP 800-89, November 2006.
- SP 800-118 K. Scarfone and M. Souppaya, "Guide to Enterprise Password Management", NIST Special Publication 800-118, (Draft) April 2009.
- SP 800-131A E. Barker and A. Roginsky, "Transitions: Recommendation for Transitioning the Use of Cryptographic Algorithms and Key Lengths", NIST Special Publication 800-131A, January 2011.
- SP 800-132 M. Turan, E. Barker, W. Burr, and L. Chen, "Recommendation for Password-Based Key Derivation", Part 1: Storage Applications, December 2010.
- SP 800-135 Q. Dang, "Recommendation for Existing Application-Specific Key Derivation Functions", NIST SP800-135, Rev. 1, December 2011.
- TPM TCG TPM Specification Version 1.2 Revision 103 including Design Principles, Structures of the TPM, and Commands.
- X9.62 ANSI X9.62, "Public key cryptography for the financial services industry: The Elliptic Curve Digital Signature Algorithm (ECDSA)", November 2005.
- X11 Window System: <http://www.linfo.org/x.html> and <http://www.x.org/releases/X11R7.6/doc/index.html>
- X.509 Path [http://csrc.nist.gov/groups/ST/crypto\\_apps\\_infra/documents/NIST\\_Recommendation\\_for\\_X509\\_PVMs.pdf](http://csrc.nist.gov/groups/ST/crypto_apps_infra/documents/NIST_Recommendation_for_X509_PVMs.pdf)

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## Appendix E: Revision Changes

This revision updates cryptographic requirements for the protocols and applications in the document so that the required security strengths as specified in SP 800-131A can be achieved. This revision also adds the security-related updates from the protocols addressed in the document. In addition, this revision adds a new section for Secure Shell (SSH). Specific changes in this revision include the following.

In Section 2:

- 1) Additional clarification about the recommended algorithms and key sizes for digital signature and key establishment certificates has been added.
- 2) 1024-bit RSA and DSA are no longer approved for generating digital signatures after 2013.

In Section 3:

- 1) Information about VPN-cipher suites has been updated to include the Suite-B VPN cipher suites.
- 2) Table 3-2 and the cryptographic algorithms recommendation have been revised.

In Section 4:

- 1) A revision of the TLS section will be in SP 800-52 revision 1 in the future.

Section 5:

- 1) The discussion of the cipher suites (ALSSs) has been updated. New requirements in using these cipher suites have been added to meet the security requirements specified in SP 800-131A.
- 2) In Section 5.3, item 3. The “should” was changed to “may”.

Section 6:

- 1) A requirement for 112 bits of security after the year 2013 has been stated for public key authentication and key establishment.
- 2) Support for using TLS for authentication and key establishment has been added.

Section 7:

In Section 7.2.3, two occurrences of “should” changed to “shall” in this version.

Section 8:

- 1) A “should” requirement has been added for migrating to 2048-bit RSA with SHA-256 by the end of 2013.
- 2) Approval for RSA and DSA with SHA-1 for zone-data signing has been limited to the end of 2013; see Table 8-1.
- 3) Message authentication algorithms have been revised in Table 8-2.

Section 9: no major changes in this section.

Section 10: new section.