Secure Shell Maintenance
Internet-Draft
Intended status: Standards Track
Expires: 7 November 2026

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6 May 2026

# Stateless Hash-Based Signatures for Secure Shell (SSH)
## draft-josefsson-ssh-sphincs-02

## Abstract

This document describes the use of Sphincs+/SLH-DSA digital signatures, standalone and as a hybrid with Ed25519/Ed448, in the Secure Shell (SSH) protocol.

## About This Document

This note is to be removed before publishing as an RFC.

Status information for this document may be found at https://datatracker.ietf.org/doc/draft-josefsson-ssh-sphincs/.

Discussion of this document takes place on the SSHM Working Group mailing list (mailto:ssh@ietf.org), which is archived at https://mailarchive.ietf.org/arch/browse/ssh/. Subscribe at https://www.ietf.org/mailman/listinfo/ssh/.

Source for this draft and an issue tracker can be found at https://gitlab.com/jas/ietf-ssh-sphincs.

## Status of This Memo

Table of Contents



## 1. Introduction

Secure Shell (SSH) [RFC4251] is a secure remote-login protocol. It provides for an extensible variety of public key algorithms for identifying servers and users to one another.

Sphincs+ [SPHINCS] is a stateless hash-based digital signature system, standardized in [NIST.FIPS.205] as Stateless Hash-Based Digital Signature Algorithm (SLH-DSA). Additional SLH-DSA parameter sets are described in [NIST.SP.800.230.IDP].

EdDSA [RFC8032] is a digital signature system, with Ed25519 and Ed448 as common variants.

This document specify how Sphincs+/SLH-DSA is used in SSH in non-hybrid mode.

This document specify how EdDSA and SLH-DSA may be used in SSH in hybrid mode using the hybrid signature scheme from [MOTHMA].

## 2. Conventions Used In This Document

The descriptions of key and signature formats use the notation introduced in [RFC4251], Section 3, and the string data type from [RFC4251], Section 5. Identifiers and terminology from SPHINCS [NIST.FIPS.205] are used throughout the document.

## 3. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

## 4. Public Key Algorithms

This document describes a set of public key algorithm for use with SSH, as per [RFC4253], Section 6.6. The names of the algorithm in SSH are as follows, mapping it to the names used in [NIST.FIPS.205], [NIST.SP.800.230.IDP] and/or [MOTHMA]. These algorithms only supports signing and not encryption.

The non-hybrids are as follows:

| SSH algorithm | SPHINCS+ identifer |
|---|---|
| "ssh-slh-dsa-sha2-128s" | SLH-DSA-SHA2-128S |
| "ssh-slh-dsa-sha2-128f" | SLH-DSA-SHA2-128F |
| "ssh-slh-dsa-shake-128s" | SLH-DSA-SHAKE-128S |
| "ssh-slh-dsa-shake-128f" | SLH-DSA-SHAKE-128F |
| "ssh-slh-dsa-sha2-256s" | SLH-DSA-SHA2-256S |
| "ssh-slh-dsa-sha2-256f" | SLH-DSA-SHA2-256F |
| "ssh-slh-dsa-shake-256s" | SLH-DSA-SHAKE-256S |
| "ssh-slh-dsa-shake-256f" | SLH-DSA-SHAKE-256F |
| "ssh-slh-dsa-sha2-128-24" | SLH-DSA-SHA2-128-24 |
| "ssh-slh-dsa-shake-128-24" | SLH-DSA-SHAKE-128-24 |
| "ssh-slh-dsa-sha2-192-24" | SLH-DSA-SHA2-192-24 |
| "ssh-slh-dsa-shake-192-24" | SLH-DSA-SHAKE-192-24 |
| "ssh-slh-dsa-sha2-256-24" | SLH-DSA-SHA2-256-24 |
| "ssh-slh-dsa-shake-256-24" | SLH-DSA-SHAKE-256-24 |

Table 1: SSH Public Key Algorithms (standalone)

The hybrids with Ed25519/Ed448 are as follows:

| SSH algorithm | Mothma identifer |
|---|---|
| "ssh-ed25519-slh-dsa-shake-128s" | Mothma-Ed25519-SLH-DSA-SHAKE-128S |
| "ssh-ed25519-slh-dsa-shake-128f" | Mothma-Ed25519-SLH-DSA-SHAKE-128F |
| "ssh-ed448-slh-dsa-shake-256s" | Mothma-Ed448-SLH-DSA-SHAKE-256S |
| "ssh-ed448-slh-dsa-shake-256f" | Mothma-Ed448-SLH-DSA-SHAKE-256F |
| "ssh-ed25519-slh-dsa-sha2-128-24" | Mothma-Ed25519-SLH-DSA-SHA2-128-24 |
| "ssh-ed25519-slh-dsa-shake-128-24" | Mothma-Ed25519-SLH-DSA-SHAKE-128-24 |
| "ssh-ed448-slh-dsa-sha2-256-24" | Mothma-Ed448-SLH-DSA-SHA2-256-24 |
| "ssh-ed448-slh-dsa-shake-256-24" | Mothma-Ed448-SLH-DSA-SHAKE-256-24 |

Table 2: SSH Public Key Algorithms (hybrid)

SSH implementations MUST implement these signature algorithms.

## 5. Public Key Format

The "ssh-slh-dsa-sha2-256f" key format has the following encoding:

string "ssh-slh-dsa-sha2-256f"

string key

Here, ’key’ is the public key described in [NIST.FIPS.205], for the SLH-DSA-SHA2-256F algorithm, Section 10.1.

The other variants follow analogous, with the Mothma variants being per [MOTHMA], and some SLH-DSA variants per [NIST.SP.800.230.IDP].

## 6. Signature Algorithm

Signatures are generated according to the procedure in Sections 10.2 [NIST.FIPS.205], using the "pure" version of SLH-DSA-SHA2-256F.

## 7. Signature Format

The "ssh-ed25519" key format has the following encoding:

string "ssh-slh-dsa-sha2-256f"

string signature

Here, ’signature’ is the signature produced in accordance with the previous section.

The other variants follow analogous, with the Mothma variants being per [MOTHMA].

## 8. Verification Algorithm

Signatures are verified according to the procedure in [NIST.FIPS.205], Section 10.3, using the "pure" version of SLH-DSA-SHA2-256F.

The other variants follow analogous, with the Mothma variants being per [MOTHMA], and some SLH-DSA variants per [NIST.SP.800.230.IDP]..

## 9. SSHFP DNS Resource Records

Usage and generation of the SSHFP DNS resource record is described in [RFC4255]. This section illustrates the generation of SSHFP resource records for SLH-DSA/Sphincs+ keys, and this document also specifies the corresponding code point to "SSHFP RR Types for public key algorithms" in the "DNS SSHFP Resource Record Parameters" IANA registry [IANA-SSHFP].

The generation of SSHFP resource records keys for SLH-DSA/Sphincs+ is described as follows.

The encoding of SLH-DSA/Sphincs+ public keys is described in [NIST.FIPS.205], Section 10.1.

The public keys are short, so there is no need to use a hash algorithm to shorten them. We therefor describe a new "Fingerprint Type" value TBD2 to refer to the raw public-key value without hashing.

The SSHFP Resource Record for a SLH-DSA/Sphincs+ key fingerprint would, for example, be:

```
pqserver.example.com. IN SSHFP TBD1 TBD2 (
                 a87f1b687ac0e57d2a081a2f2826723
                 34d90ed316d2b818ca9580ea384d92401 )
```

Replace TBD1 and TBD2 with the values eventually allocated by IANA. There will be one TBD1 value per algorithm.

## 10. IANA Considerations

This document augments the Public Key Algorithm Names in [RFC4250], Section 4.11.3.

IANA is requested to add the following entry to "Public Key Algorithm Names" in the "Secure Shell (SSH) Protocol Parameters" registry [IANA-SSH]:

| Public Key Algorithm Name | Key Size | Signature Size | Reference |
|---|---|---|---|
| ssh-slh-dsa-sha2-128-24 | 32 | 3856 | THIS-RFC |
| ssh-slh-dsa-shake-128-24 | 32 | 3856 | THIS-RFC |
| ssh-slh-dsa-sha2-192-24 | 48 | 7752 | THIS-RFC |
| ssh-slh-dsa-shake-192-24 | 48 | 7752 | THIS-RFC |
| ssh-slh-dsa-sha2-256-24 | 64 | 14944 | THIS-RFC |
| ssh-slh-dsa-shake-256-24 | 64 | 14944 | THIS-RFC |
| ssh-slh-dsa-sha2-128s | 32 | 7856 | THIS-RFC |
| ssh-slh-dsa-shake-128s | 32 | 7856 | THIS-RFC |
| ssh-slh-dsa-sha2-128f | 32 | 17088 | THIS-RFC |
| ssh-slh-dsa-shake-128f | 32 | 17088 | THIS-RFC |
| ssh-slh-dsa-sha2-256s | 64 | 29792 | THIS-RFC |
| ssh-slh-dsa-shake-256s | 64 | 29792 | THIS-RFC |
| ssh-slh-dsa-sha2-256f | 64 | 49856 | THIS-RFC |

| | | | |
|---|---|---|---|
| ssh-slh-dsa-shake-256f | 64 | 49856 | THIS-RFC |
| ssh-ed25519-slh-dsa-sha2-128-24 | 64 | 3920 | THIS-RFC |
| ssh-ed25519-slh-dsa-shake-128-24 | 64 | 3920 | THIS-RFC |
| ssh-ed448-slh-dsa-sha2-256-24 | 121 | 15058 | THIS-RFC |
| ssh-ed448-slh-dsa-shake-256-24 | 121 | 15058 | THIS-RFC |
| ssh-ed25519-slh-dsa-shake-128s | 64 | 7920 | THIS-RFC |
| ssh-ed25519-slh-dsa-shake-128f | 64 | 17152 | THIS-RFC |
| ssh-ed448-slh-dsa-shake-256s | 121 | 29906 | THIS-RFC |
| ssh-ed448-slh-dsa-shake-256f | 121 | 49970 | THIS-RFC |

Table 3: SSH Public Key Code Points

IANA is requested to add the following entry to "SSHFP RR Types for public key algorithms" in the "DNS SSHFP Resource Record Parameters" registry [IANA-SSHFP]:

| Value | Description | Reference |
|---|---|---|
| TBD1 | SSH-SLH-DSA-SHA2-128S | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHA2-128F | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHAKE-128S | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHAKE-128F | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHA2-256S | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHA2-256F | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHAKE-256S | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHAKE-256F | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHA2-128-24 | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHAKE-128-24 | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHA2-192-24 | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHAKE-192-24 | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHA2-256-24 | THIS-RFC |
| TBD1 | SSH-SLH-DSA-SHAKE-256-24 | THIS-RFC |
| TBD1 | SSH-ED25519-SLH-DSA-SHAKE-128S | THIS-RFC |
| TBD1 | SSH-ED25519-SLH-DSA-SHAKE-128F | THIS-RFC |
| TBD1 | SSH-ED448-SLH-DSA-SHAKE-256S | THIS-RFC |
| TBD1 | SSH-ED448-SLH-DSA-SHAKE-256F | THIS-RFC |

Table 4: SSH DNS SSHFP RR Public Key Algorithm Types

IANA is requested to add the following entry to "SSHFP RR types for fingerprint types" in the "DNS SSHFP Resource Record Parameters" registry [IANA-SSHFP]:

| Value | Description | Reference |
|---|---|---|
| TBD2 | raw | THIS-RFC |

Table 5: SSH DNS SSHFP RR Fingerprint Types

## 11. Security Considerations

The security considerations of all references apply.

The security considerations in [RFC4251], Section 9 apply to all SSH implementations, including those using Sphincs+/SLH-DSA.

The security considerations in SPHINCS [NIST.FIPS.205] [NIST.SP.800.230.IDP] apply to all uses of Sphincs+/SLH-DSA, including those in SSH.

The security considerations in [MOTHMA] apply to the hybrid variants.

Cryptographic algorithms and parameters are usually broken or weakened over time. Implementers and users need to continously re-evaluate that cryptographic algorithms continue to provide the expected level of security.

## 12. Acknowledgments

The text of [RFC8709] was used as a template for this document.

## 13. Test vectors

The following illustrate test vectors using file formats used by, for example, OpenSSH.

### 13.1. Private Key

Private key:

```
-----BEGIN OPENSSH PRIVATE KEY-----
b3BlbnNzaC1rZXktdjEAAAAABG5vbmUAAAAEbm9uZQAAAAAAAAABAAAAYwAAABtzc2gtc2xoLWRz
YS1zaGEyLTI1NmYAAABAPS6Ma/U7TKh4/I8HoTobiV+1sQnpkHZL7oztSTxgWoJYTDYEYdQpwty9
IJfwQDvK778DQCr9dx1gWb1HYDwYMAAAAQAS6f2dEun9nQAAABtzc2gtc2xoLWRzYS1zaGEyLTI1
NmYAAABAPS6Ma/U7TKh4/I8HoTobiV+1sQnpkHZL7oztSTxgWoJYTDYEYdQpwty9IJfwQDvK778D
QCr9dx1gWb1HYDwYMAAAAIBlB//OALih6/bAIOUGOGuaSKuK86IySusLX5xiqsPmJmE32DHKfIgg
mmvckaPbwnliYgL0mV/aAetfELu7XoqHPS6Ma/U7TKh4/I8HoTobiV+1sQnpkHZL7oztSTxgWoJY
TDYEYdQpwty9IJfwQDvK778DQCr9dx1gWb1HYDwYMAAAAAhqYXNAa2FrYQECAwQF
-----END OPENSSH PRIVATE KEY-----
```

### 13.2. Public-Key

Public key:

```
ssh-slh-dsa-sha2-256f AAAAG3NzaC1zcGhpbmNzcGx1c0BvcGVuc3NoLmNvbQAAAEA9Loxr9TtMqHj8jwehOhu
JX7WxCemQdkvujO1JPGBaglhMNgRh1CnC3L0gl/BAO8rvvwNAKv13HWBZvUdgPBgw jas@kaka
```

### 13.3. Message

The namespace context string used is "my-namespace", and the message is (including final newline):

```
Hello world!
```

### 13.4. Signature

Signature:

```
-----BEGIN SSH SIGNATURE-----
U1NIU0lHAAAAAQAAAGMAAAAbc3NoLXNwaGluY3NwbHVzQG9wZW5zc2guY29tAAAAQD0ujG
v1O0yoePyPB6E6G4lftbEJ6ZB2S+6M7Uk8YFqCWEw2BGHUKcLcvSCX8EA7yu+/A0Aq/Xcd
YFm9R2A8GDAAAAAMbXktbmFtZXNwYWNlAAAAAAAAAAZzaGE1MTIAAHSDAAAAG3NzaC1zcG
hpbmNzcGx1c0BvcGVuc3NoLmNvbQAAdGCZtK1w9NaIGAV9HcHArlgyCGRb/a+f8/EDt1bL
BHVvMQiGVR4guZ1g20dasKIxJznf8YqoYQeSXEktX7ukD+Go+icRJoTQj7n0RaKjaWz/aM
P1iKeNN1hhfyOMP9nCzUKSBOlcBe1IDnHTMZDuX7wUVTu4WTcd4WrTb5Qos+fxY2cBUM9p
QeUPm2WpwkqVjpd8e4bG5ku2q4Q3jCHsambOH5VqZI+khzQ5w3M+b1wMXfWVwEd8O7t++U
Nq/wqhFFSWvuiZ3OY9FgO04KsBC313OHv04jJV83MaIaKJLRpTXQl8YX/poz3WNeX3oIYV
23KZm3cBqfnq8xgvf281s46DNdfJNm69Qt6qfM54Ypc9lHYeX+Vb3S0o1NTRp8xGOm6b4S
uVp7ZG2/hOXvn0qg3eqDB5vMhEOeh/alwc4O9UvcxIMw5f7qEqk4keNB5IJrgsHcFaRdWd
X+v3PdMsFvouxreWnwaZvwNqGH4UdoUOKBA8Tbix7VqwMC1m9QgSlMTFAGirgW0Wsa4Kqz
7YaxkJdsz7+b/+RLp+NSVriVQFxnZNw/QjRaKs7ca46MNXswq28T6ED6eFrXg68VMwQ2rY
7FlwKkUwq05u57Wrmc0pEQWDnt/n4nodVlGRxDqrvsCFxXN6MdgqMpA/kbqNKVGvRnOwJb
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g82Fx0GvVa32WyA2Q1hrdoqnr9uS6ej5pa7rtO6lFHnEnRT+x2kcDXoqhYiWcUFPrEssfM
ppB0r7Gl6IjCdcoug4w7ujtmWdVIOYkb5cJGjK8/KwjOCdNne+ZHhUGt6tDowCeSsOZ8kM
7oDv/q2U2I67m5SUc8MpV+wFJSK7tKU35YzcYrzYH3nW8wIlsUknlgsPC50GdFkXKeMML5
QCD0Dqk3o5Sc+831Pe1zR4+rv7MU80xLcU2Hk8FRpNc/DQPzXkpQtv4YTxVIh4qjzrpHrQ
8JtlJYU0N8WuFXvyD0TYWNIWM9Jui0zZl1CbaIsvBJZ6hB1K1jNULzEDyF3nA722FjEbEq
aeqlgI9nw/tc3MF5MLx58XEh1DE7glt0R9FAx9mXZftjEk628qCqVzM7cjx3OdbuJ3330W
```

LfNpl74tXMYD55os4zAwhJQywt4chUXmcL+wFsdLWF4ieIKwKIOG9999dSDXjhTSQBrWsl
eNllM350BvPGUaPuu3/tOfes+3SCBu5P1D9RcMK5rhaZ2Pg2FVordq7VmmMTg/O0k0vonR
s1bB8rht0ugc00vcMdOnVOWmAVZlGHG5H4T/DcnmEazam8KsR/iwkpbhn16OzY4VN19AA3
wCkvzoqh1TS0avoLwjLb2gi0n0m576Giyz/JnQkSiJNzspFS/fNX+UaULAYW4uNRE+4EHT
ls6iI574ItuPhhWLCbXm2HnZA9sjXNy/8Z+KtEl+xTaUj0kGzR49wL6+cNymjmHRQHicWO
l1uA9A/EitKLB16uqV7ktroYPumA+qSr8F2gsN5YtlUaq4qeod56gmISPw366J+ByhSCMy
mTnRneUyp3p2Z4l5vnofnmgiNWb9+yLXtOMwSQM4o+nynEyEga/NApN0URIUezBThph/Eb
DmpbdqGy23tpjdrIYapy7RYuayS/BEEvBbXvMik0baYkli6P1VMMuuGnJIMLSzoUh1NT1E
zJh0GNNxmPDEOk7cHx1JmCc99w5bpEXCLQ62d5JZWcZFsaET0nlLjq4TI3ueTVaCcsFnRu
XwvjE9/acnzfUFLT2bPwhNvaL/WqG/ncH+iMxf9Pml7l9EXI9/hOu/Ua6gHlAUS/YyS+Le
ANr6L3GY8NuJzx+lteljw9d5E70U2fNInwK8dedZ+99HUBz0juwgIz0JJFeoPlABmt/24n
/OILN6V+/4S33Vr0T6SUpG0qNCJXDcEcMLzx6P7BqOBCIWRhwMVkb7SPXXqmcfHiLIBXcE
Ro3AYUwsn7AxzVQ+tzJE0j5zyxHa8hnESrNv569xz/H0sKLZET4r96akb+uOaIVO6uba+O
AWF7YTVIfIltaQn5BXJUY5jS8L1Mo7r+2JshFFPRNGTG3jPPO1UOqhlRntILmeQzxn+dEB
h+iSi7V5wbFtKtjM4iKMYvdBDkJlsn8Y6rCA1PXGoHr6sAlyfQtZ7kS5qow738TGHhwr5R
jeWzd2zibwKDbOBMU60DHXr73AHdkBPAIzYp4eS9P+ITeLFU2vunuHC3lIzyqo0ZVAxaDv
ha0+/AJiMNld+tWEqXipkJ9VcrDiPfYxdiWLTv+ZNl3OBOE+KOCRvlAqSqRKIXQfqougZD
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vIg/947tcF6aPpRZeJCYj56mkhdDGBiNpNMZSPKGEUOQ+PfXf3vNsEehkni9LqiPVdo77A
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W42bIAB8RF0Sg+g7xOtek3edLbETUfVFR1Rinl6fw6W433SMNQzyFW49PGVs5MMg4UT8r6
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iRtPVaRxU3vUFORSxXGm7SLvVW+TiXxTeO8hMKHFGjH3mLF2U3AZhE5MzRxvvUeVBrpO3Q
HQinkPG39mMcF8Z2DKaYUumQimh/FAKg6ouIRRnz4/cF8Pl43sF7KrB2PCxpyqLZeq8QGe
BDSb6LKgBEjIhC7mc/JMN4ee1g3lsLQrAHkD+Fx57wuzbKnmClaQ9773RP7XbGzt2ByzXB
m11uesOUYb1gHilH3EUIV3EnciYrzlLddakfy+UazDPsm7P3HZjY7Sks5UrS7eqRjh2JAv
bjzxdf+D9GKRdunXP7+QGdMJuJVHwUps0jvfjV7//4AAFN7btb7RK6rLVyuTFURQyU5gGk
VucVxBO9ilCwEiKFhfFJUkOgQQjVy4v3J93PuYGvc5sj1dP50tLlgIQ/AF72YBPo+l2j/o
4mXxYVrrz8sspSwrn9xnqQaLrBfrEUFvA50PvaYOS6gZffIGri0ky7q2xSnnxgEeePT1wL
s5VOvnbkJDJyMBROHZGK3oJA2ps89GgruoGtPbMP7+FEjClpeltHLovYOA6cQ15etQPS7V
mhVYPyAnlmSF8MpZZFvDZL2w0qOS+AEonzZpZ28V9Eo7ygWsTbvQPe3vBtKBjPgpU2/6+F
f3YNgRvAlj2HTg55Sbmy/6aelLfcb7FaPxAyAKTqX2lHasf0cOMAaH9G7cQctmoUiDUwX2
2eIM/3/qB0FYOb98JM5/cDVxMYmokzxoC8VHFFvK9yRzhrxRBmrehXbIzaaMQz6vAqGTGz
wagT9YkexUvjPx7iLIgt+Seegh4ckQYj09M19hcs89EjSs9mG85OoonO9eVdqQV0S3hr1v
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