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Stateless Hash-Based Signatures for Secure Shell (SSH)

Abstract

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

The RFC Editor will remove this note

About This Document

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

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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).

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

This document specifies how Sphincs+/SLH-DSA is used in SSH. This document specifies how Ed25519 and ML-DSA-65 may be used in SSH, 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 [NIST.FIPS.205] and [MOTHMA] name. These algorithms only support signing and not encryption.

SSH algorithm	SPHINCS+ identifier
"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

Table 1: SSH Public Key Algorithms (standalone)

The hybrids with Ed25519/Ed448 are as follows:

SSH algorithm	Mothma identifier
"ssh-ed25519-slh-dsa-shake-128s"	Mothma-Ed25519-SLH-DSA-SHAKE-128S

SSH algorithm	Mothma identifier
"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

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].

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].

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-sha2-256f	64	49856	THIS-RFC
ssh-slh-dsa-sha2-128s	FIXME	FIXME	THIS-RFC
ssh-slh-dsa-sha2-128f	FIXME	FIXME	THIS-RFC
ssh-slh-dsa-shake-128s	FIXME	FIXME	THIS-RFC
ssh-slh-dsa-shake-128f	FIXME	FIXME	THIS-RFC
ssh-slh-dsa-sha2-256s	FIXME	FIXME	THIS-RFC
ssh-slh-dsa-sha2-256f	FIXME	FIXME	THIS-RFC

Public Key Algorithm Name	Key Size	Signature Size	Reference
ssh-slh-dsa-shake-256s	FIXME	FIXME	THIS-RFC
ssh-slh-dsa-shake-256f	FIXME	FIXME	THIS-RFC
ssh-ed25519-slh-dsa-shake-128s	FIXME	FIXME	THIS-RFC
ssh-ed25519-slh-dsa-shake-128f	FIXME	FIXME	THIS-RFC
ssh-ed448-slh-dsa-shake-256s	FIXME	FIXME	THIS-RFC
ssh-ed448-slh-dsa-shake-256f	FIXME	FIXME	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-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](#) [\[NIST.FIPS.205\]](#) apply to all uses of Sphincs+/SLH-DSA, including those in SSH.

Cryptographic algorithms and parameters are usually broken or weakened over time. Implementers and users need to continuously 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-----
b3BlbnNzaC1rZXktdjEAAAABAG5vbmUAAAABbm9uZQAAAAAAAAABAAAAYwAAABtzc2gtc2x
oLWRz
YS1zaGEyLTl1NmYAAABAPS6Ma/U7TKh4/
I8HoTobiV+1sQnpkHZL7oztSTxgWojYTDYEYdQpwtY9
IjfwQDvK778DQCr9dx1gWb1HYDwYMAAAAQAS6f2dEun9nQAAABtzc2gtc2xoLWRzYS1zaGEyL
Tl1
NmYAAABAPS6Ma/U7TKh4/
I8HoTobiV+1sQnpkHZL7oztSTxgWojYTDYEYdQpwtY9IjfwQDvK778D
QCr9dx1gWb1HYDwYMAAAAIBIB//OALih6/
bAlOUGOGuaSKuK86lySusLX5xiqsPmJmE32DHkfIgg
mmvckaPbwnliYgLOmV/aAetfELu7XoqHPS6Ma/U7TKh4/I8HoTobiV+1sQnpkHZL7oztSTxgWojY
TDYEYdQpwtY9IjfwQDvK778DQCr9dx1gWb1HYDwYMAAAAahqYXNAa2FrYQECawQF
-----END OPENSSH PRIVATE KEY-----
```

13.2. Public-Key

Public key:


```
ssh-slh-dsa-sha2-256f
AAAAG3NzaC1zcGhpbmNzcGx1c0BvcGVuc3NoLmNvbQAAAEA9Loxr9TtMqHj8jwehOhujX7Wx
CemQdkvujO1JPGBaglhMNgRh1CnC3L0gl/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-----

U1NIU0IHAAAAAQAAAGMAAAAbc3NoLXNwaGluY3NwbHVzQG9wZW5zc2guY29tAAAAQD0ujG
v1O0yoePyPB6E6G4lftbEj6ZB2S+6M7Uk8YFqCWew2BGHUKcLcvSCX8EA7yu+/A0Aq/Xcd
YFm9R2A8GDAAAAAMbXktbmFtZXNwYWNIAAAAAAAAAAAAZzaGE1MTIAAHSDAAAAG3NzaC1zc
G
hpbmNzcGx1c0BvcGVuc3NoLmNvbQAAdGCZtK1w9NaIGAV9HcHArIgyCGRb/a+f8/EDt1bL
BHVvMQiGVR4guZ1g20dasKlxJznf8YqoYQeSXektX7ukD+Go+icRJoTQj7n0RaKjaWz/aM
P1iKeNN1hhfyOMP9nCzUKSBolcBe1lDnHTMZDuX7wUVTu4WTcd4WrTb5Qos+fxY2cBUM9p
QeUPm2WpwwkqVjpd8e4bG5ku2q4Q3jChsambOH5VqZI+khzQ5w3M+b1wMXfWVwEd8O7t+
+U
Nq/wqhFFSWvuiZ3OY9FgO04KsBC313OHv04jV83MalaKJLRpTXQl8YX/poz3WNeX3oIYV
23KZm3cBqfnq8xgvf281s46DNdfjNm69Qt6qfM54Ypc9IHYeX+Vb3S0o1NTRp8xGOM6b4S
uVp7ZG2/hOXvn0qg3eqDB5vMhEOeh/alwc4O9UvcxIMw5f7qEqk4keNB5lJrgsHcFaRdWd
X+v3PdMsFvouxreWnwaZvwNqGH4UdoUOKBA8Tbix7VqwMC1m9QgSIMTFAGirgW0Wsa4Kqz
7Yaxkjdsz7+b/+RLp+NSVriVQFxnZNw/QjRaKs7ca46MNXswq28T6ED6eFrXg68VMwQ2rY
7FlwKkUwq05u57Wrmc0pEQWDnt/n4nodVIGRxDqrvcFfxXN6MdgqMpA/kbqNKVGvRnOwJb
1p/1Bp28wavddPQdzmya1loaXYflhetqVATBnZoWPVIWhswol/LVyP/NpfWSBT70xBE/op
g82Fx0GvVa32WyA2Q1hrdoqnr9uS6ej5pa7rtO6lFHnEnRT+x2kcDXoqhYiWcUFPRESSfM
ppB0r7Gl6ljCdcoug4w7ujtmWdVIOYkb5cJGjK8/KwjOCdNne+ZHHUGt6tDowCeSsOZ8kM
7oDv/q2U2l67m5SUc8MpV+wFJSK7tKU35YzcYrZyH3nW8wllsUknlgSC50GdFkXKeMML5
QCD0Dqk3o5Sc+831Pe1zR4+rv7MU80xLcU2Hk8FRpNc/DQPzXkpQtv4YTxVlh4qjzrphRQ
8jtIjYU0N8WuFXvyD0TYWNIWM9Jui0zZl1CbalsvBJZ6hB1K1jNULzEDyF3nA722FjEbEq
aeqlgl9nw/tc3MF5MLx58XEh1DE7glT0R9FAx9mXZftjEk628qCqVzM7cjx3OdbuJ3330W
LfNpl74tXMYD55os4zAwHjQywt4chUXmcl+wFsdLWF4ielKwKIOG9999dSDXjhTSQBrWsl
eNIIM350BvPGUaPuu3/tOfes+3SCBu5P1D9RCMK5rhaZ2Pg2FVordq7VmmMTg/O0k0vonR
s1bB8rht0ugc00vcMdOnVOWmAVZIGHG5H4T/DcnmEazam8KsR/iwkpbn16OzY4VN19AA3
wCkvzoqh1TS0avoLwJLb2gi0n0m576Giyy/JnQkSijNzspFS/fNX+UaULAYW4uNRE+4EHT
ls6il574lTuPhhWLCbXm2HnZA9sjXNy/8Z+KtEl+xTaUj0kGzR49wL6+cNymjmHRQHicWO
l1uA9A/EitKLB16uqV7ktroYPumA+qSr8F2gsN5YtlUaq4qeod56gmlSPw366j+ByhSCMy
mTnRneUyp3p2Z4l5vnofnmgiNWb9+yLXtOMwSQM4o+nynEyEga/NApN0URIUezBThph/Eb
DmpbdqGy23tpjdrIYapy7RYuayS/BEEvBbXvMik0baYkli6P1VMMuuGnJIMLSzoUh1NT1E
zjh0GNNXmPDEOk7chX1JmCc99w5bpEXCLQ62d5JZWcZFsaET0nlLjq4TI3ueTVaCcsFnRu
XwvjE9/acnzfUFLT2bPwhNvaL/WqG/ncH+imxf9Pml7I9EXI9/hOu/Ua6gHIAUS/YyS+Le
ANr6L3GY8Nujzx+lteljw9d5E70U2fNlnwK8dedZ+99HUBz0juwglz0JJFeoPIABmt/24n
/OILN6V+/4S33Vr0T6SupG0qNCjXDcEcMLzx6P7BqOBCIWRhwMVkb7SPXXqmcFHiLIBXcE
Ro3AYUwsn7AxzVQ+tzJE0j5zyxHa8hnESrNv569xz/H0sKLZET4r96akb+uOaIVO6uba+O
AWF7YTVIfIItaQn5BXJUY5jS8L1Mo7r+2jshFFPRNGTG3jPPO1UOqhlRntILmeQzxn+dEB
h+iSi7V5wbFtKtjM4iKMYvdBDKJlsn8Y6rCA1PXGoHr6sAlyfQtZ7kS5qow738TGHhwr5R
jeWzd2zibwKDbOBMU60DHXr73AHdkBPAIzYp4eS9P+ITeLFU2vunuHC3lIzyqo0ZVaxaDv
ha0+/AjIMNld+tWEqXipkj9VcrDiPfYxdilWLTv+ZNI3OBOE+KOCrvIAqSqRKIXQfqougZD
bexgUnZfmap/oYEYkIKFhJQQiZ48vkK94CDa0zrBUqp9I5zjZnRKkjYWIqSNa7h66e6iPU
wiBba+znaxJPGBLjseAUeSE4/ThCm0zBcvBXr48fE7TrmvFkwMjgYTn77Vs0IVybmZWxSw
vlg/947tcF6aPpRZeJCYj56mkhdDGBiNpNMZSPKGEUOQ+PfXf3vNsEehkni9LqiPVdo77A
j78hCPqHFHLwOueW8QIhkWGM1/+9TM3X+Mo4fElyd5hQzd3PCTIVkaISHZPfhWc1ce6xEH
tTa95J3X5KtiLhW2Nc+BIR5y6j3C19IM8yCA4FD6tPOWirloYAVFgl3KgnAOMbCWS5/rAi
ZOiAGfnSIT9DoHTJubfQhICMvc7aQ/raxkWLoCkCliElla8YulqfnZaP1h9tf9F92Fdgru
4wMWU9p1O5bYGD5s+a7DVlyx2+ITaUKCDPfpB7cHV19Vacm/lqr5479YHu4JElu/ycqhq
/Pk5OEjsM1MzCqIVgVcwhz1mXJfMOWLyynKESW2X76RjyMCYgNUjFBeu+SD6FCcu9W3CPI
1sUVACDoWL1y91+7ISCSxOJfWAVO9Shwgp5sXN0URbCTxh1rUalEPPsCfQdnk//K2iz4y7
MbMvcTZIL1c1sExBzS717jzHU/xB/uxOLqVoyxqGjH0sAxUirt1sMDYFOXR2RsW2c8cZh
zsKxj5gbSHDp6rq9UgdQZHHJ75rs9r8ULb7beU4j9MKZnHgfeo4gXabJl282DoVjfUYyoo
7i037w9ZXrx/9j7PDvyUZTw+5qTTguZpyAQulqS9uOqKJkYJSjyErwC0MEsC8f0rom2Cm
W42biAB8RF0Sg+g7xOtek3edLbETUfVFR1Rinl6fw6W433SMNQzyFW49PGVs5MMg4UT8r6
ApG2slcQipV8qQoCzFvvJ6dMs9C+HIEicju6XFYhO9H3haOOkSVBye9RnDhedyL6BB12Hu
GCn3EsZW/eBEMzK56SoVWIMddC4l6mavDHdUATDRzP/ycw8ff9nF+baE3SONGuuZiFNir8
iRtPVaRxU3vUvFORSxXgm7SLvVW+TiXxTe08hMKHFGjH3mLF2U3AZhE5MjRxxvUeVBrpO3Q
HQinkPG39mMcF8Z2DKaYUumQimh/FAKg6ouIRRnz4/cF8PI43sF7KrB2PCxpyqLZeq8QGe

BDSb6LKgBEjIhC7mc/JMN4ee1g3IsLQrAHkD+Fx57wuzbKnmClaQ9773RP7XbGzt2ByzXB
m11uesOUYb1gHilH3EUIV3EnciYrZlLddakfy+UazDPsm7P3HZjY7Sks5UrS7eqRjh2JAv
bjzxdf+D9GKRdunXP7+QGdMJuJVHwUps0jvfjV7//4AAFN7btb7RK6rLVyuTFURQyU5gGk
VucVxBO9ilCwEiKfHfJUKOgQQjVy4v3J93PuYGvc5sj1dP50tLlglQ/AF72YBPo+I2j/o
4mXxYVrrz8sspSwrn9xnqQaLrBfrEUFvA50PvaYOS6gZfflGri0ky7q2xSnnxgEeePT1wL
s5VOvnbkJDjYMBROHZGK3oJA2ps89GgruoGtPbMP7+FEjClpeltHLovYOA6cQ15etQPS7V
mhVYPyAnImSF8MpZZFvDZL2w0qOS+AEonzZpZ28V9Eo7ygWsTbvQPe3vBtKBjPgpU2/6+F
f3YNgRvAlj2HTg55Sbmy/6aelLfcB7FaPxAYAKTqX2lHasf0cOMAAH9G7cQctmoUiDUwX2
2eIm/3/qB0FYOb98JM5/cDVxMYmokzxoC8VHFFvK9yRzhrxRBMrehXblZaaMQz6vAqGTGz
wagT9YkexUvjPx7iLlgt+Seegh4ckQYj09M19hcs89EjSs9mG85Ooon09eVdqQV0S3hr1v
fr8F952Gllz6524+446JPOOKPjGM+iP/oGahDwQnNTC8zYLx2OxHkXV0ytvSQ/urWgtjS4
z38Dmb2B/FPbMpfN0jDWC90mmhTmZvB6/GrQR8qqeBdfMIEUfgASmu5vT9nWMdpP4yGfMN
hS0bW28Et95FrV9487fc88yPZfSjXBvC8mm+q4m05jcE/X1E6Q6nmimMuyE44x16QqN7DH
w23AmqO7EakYQ4C03UFXQMZHlJE+IclhwhjG26A22+veDnojUxBEMJ8V6dHfZVkwYnNT9Q8
G56b+CKTbvScCoc7w0NMAmcodNRqPut3BPkA3zz41ezS+Yl0GwXNVUyBmX+uKGFxG6G+R
ED7b2+HTIXMI+kXWUbcij9uR8RBBRS3yWB9jrSht5rMeAyczzBd8rS6ozkcttNKz4ellp
krnFWFmbGj+/lfQvoOGdvzdedcy0RgfP+L334VviljFpgqT2BV5tooJ09KXiMpoY2aBKH
uY4SQzLmCj9eNqZnSMzjC+x+yPjSw53sXWruRg886sxeAgzSI/MAHMEOKtqmTPPD17EYKF
ziw4+W4nb4kC/mwFxmNjEqsju4u0kPs8sww/Z3WOCdEz3nW0Mymj3jxDJ/OfSb4jSCI3
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