

RFC-018: Zstd+Age Archive Format

Status: Implemented **Date:** January 2026 **Author:** Derrell Piper ddp@eludom.net **Implementation:** vault.scm

Abstract

This RFC specifies the Zstd+Age archive format for the Library of Cyberspace: a modern archive format combining Zstd compression with Age encryption, replacing gzip for cryptographic archives.

Motivation

The legacy cryptographic archive format uses gzip compression without encryption:

Aspect	gzip (legacy)	zstd + age
Compression speed	Slow	Fast (parallel)
Compression ratio	Good	Better
Encryption	None	Built-in (age)
Key compatibility	N/A	X25519/Ed25519 (SPKI aligned)
Streaming	Yes	Yes

Why change?

1. **Encryption at rest** – Archives contain potentially sensitive data
 2. **Faster compression** – Zstd is 3–5x faster than gzip
 3. **Better ratios** – Zstd typically achieves 10–20% better compression
 4. **Key alignment** – Age uses X25519/Ed25519, same curve family as SPKI
 5. **Parallel support** – zstd -T0 uses all cores
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Specification

Archive Creation Pipeline

```
git archive | tar --zstd | age -r <recipients> > archive.tar.zst.age
```

Or equivalently:

```
tar --zstd -cf - <files> | age -r <recipient1> -r <recipient2> > archive.tar.zst.age
```

Archive Restoration Pipeline

```
age -d -i <identity> < archive.tar.zst.age | zstd -d | tar -xf -
```

Manifest Format

```
(sealed-archive
 (version "1.0.0")
 (format zstd-age)
 (archive "vault-1.0.0.archive.tar.zst.age")
 (compression zstd)
 (encryption age)
 (recipients ("age1ql3z7hgy54pw3hyww5ayyfg7zqgvc7w3j2elw8zmrj2kg5sfn9aqmcac8p"))
 (hash "sha512:...")
 (signature "ed25519:..."))
```

File Extensions

Extension	Contents
.archive	S-expression manifest
.tar.zst.age	Encrypted, compressed tarball

Configuration

```
;; Set age recipients for encryption
(vault-config 'age-recipients
  ("age1ql3z7hgy54pw3hyww5ayyfg7zqgvc7w3j2elw8zmrj2kg5sfn9aqmcac8p"
   "age1..."))

;; Set age identity for decryption
(vault-config 'age-identity "~/.config/age/identity.txt")

;; Set default archive format
(vault-config 'archive-format 'zstd-age)
```

Performance Characteristics

Compression

Zstd default (-3):

Compression: ~400 MB/s
Decompression: ~800 MB/s
Ratio: ~3:1 (typical source code)

Zstd parallel (-T0):

Compression: ~400 MB/s × cores
Decompression: ~800 MB/s × cores

Gzip comparison:

Compression: ~30 MB/s
Decompression: ~200 MB/s
Ratio: ~2.5:1

Encryption

Age X25519:

Encrypt: ~1 GB/s (ChaCha20-Poly1305)
Decrypt: ~1 GB/s
Key size: 32 bytes (public), 32 bytes (private)

Age overhead:

Header: ~200 bytes per recipient
MAC: 16 bytes

Signature

Ed25519:

Sign: ~10 s
Verify: ~10 s
Signature: 64 bytes

Total Pipeline

10 MB archive:

Compress (zstd -T0): ~25 ms
Encrypt (age): ~10 ms
Hash (SHA-512): ~1 ms
Sign (Ed25519): ~10 s
Total: ~36 ms

vs gzip legacy:

Compress (gzip): ~300 ms
Hash (SHA-512): ~1 ms
Sign (Ed25519): ~10 s
Total: ~301 ms

Speedup: ~8x

Security Model

Encryption Layer (Age)

- **Algorithm:** X25519 + ChaCha20-Poly1305
- **Recipients:** Multiple allowed (each can decrypt)
- **Forward secrecy:** Ephemeral key per archive
- **Authenticity:** Poly1305 MAC

Signature Layer (SPKI)

- **Algorithm:** Ed25519
- **Scope:** Signs encrypted archive hash
- **Non-repudiation:** Signer cannot deny creating archive

Verification Order

1. **Verify signature** – Before decryption (fail fast on tampering)
2. **Verify hash** – Encrypted archive integrity
3. **Decrypt** – Only after signature verified
4. **Extract** – Only after successful decryption

Threat Mitigations

Threat	Mitigation
Eavesdropping	Age encryption (X25519 + ChaCha20)
Tampering	SHA-512 hash + Ed25519 signature
Replay attacks	Version + timestamp in manifest
Key compromise	Multiple recipients, key rotation
Chosen ciphertext	Poly1305 authentication

Compatibility

Age Identity Types

```
# Native age key
age1ql3z7hgy54pw3hyww5ayyfg7zqgvc7w3j2elw8zmrj2kg5sfn9aqmcac8p

# SSH key (age supports ssh-ed25519 and ssh-rsa)
ssh-ed25519 AAAAC3NzaC1lZDI1NTE5AAAAI...

# GitHub key (via age-plugin-github or ssh)
github:username
```

Platform Support

Platform	zstd	age
macOS	Homebrew	Homebrew
Linux	apt/yum	apt/yum or binary
FreeBSD	pkg	pkg
Windows	winget	winget or binary

Fallback

If zstd or age unavailable, fall back to cryptographic format:

```
(if (and (command-exists? "zstd") (command-exists? "age"))
  (seal-archive version format: 'zstd-age)
  (seal-archive version format: 'cryptographic))
```

Implementation

seal-archive-zstd-age

```
(define (seal-archive-zstd-age version output)
  "Create zstd-compressed, age-encrypted archive with SPKI signature"

  (let ((recipients (vault-config 'age-recipients))
        (signing-key (vault-config 'signing-key))
        (encrypted-file (sprintf "~a.tar.zst.age" output)))

    ;; Require recipients
    (unless (pair? recipients)
```

```

(error "No age recipients configured"))

;; Build recipient args: -r key1 -r key2 ...
(let ((recipient-args
      (string-join (map (lambda (r) (sprintf "-r ~a" r)) recipients) " ")))

  ;; Create archive: git archive | zstd | age
  (let ((temp-tar (sprintf "/tmp/vault-~a.tar" version)))
    (run-command "git" "archive" "--prefix=vault/"
                  (sprintf "--output=~a" temp-tar) version)
    (system (sprintf "zstd -T0 -c ~a | age ~a > ~a"
                     temp-tar recipient-args encrypted-file))
    (delete-file temp-tar))

  ;; Sign the encrypted archive
  (when signing-key
    (let* ((archive-bytes (read-file-bytes encrypted-file))
           (archive-hash (sha512-hash archive-bytes))
           (signature (ed25519-sign signing-key archive-hash)))

      ;; Write manifest
      (with-output-to-file output
        (lambda ()
          (write `(sealed-archive
                   (version ,version)
                   (format zstd-age)
                   (archive ,encrypted-file)
                   (compression zstd)
                   (encryption age)
                   (recipients ,recipients)
                   (hash ,(blob->hex archive-hash))
                   (signature ,(blob->hex signature))))))))))

```

seal-restore-zstd-age

```

(define (seal-restore-zstd-age manifest verify-key target-dir identity)
  "Restore zstd+age encrypted archive"

  (let ((version (cadr (assq 'version (cdr manifest))))
        (archive-file (cadr (assq 'archive (cdr manifest))))
        (hash-hex (cadr (assq 'hash (cdr manifest))))
        (sig-hex (cadr (assq 'signature (cdr manifest))))
        (id-file (or identity (vault-config 'age-identity))))

    ;; Require identity

```

```

(unless id-file
  (error "No age identity configured"))

;; Verify signature first (before decryption)
(when verify-key
  (let* ((archive-bytes (read-file-bytes archive-file))
        (archive-hash (sha512-hash archive-bytes))
        (expected-hash (hex->blob hash-hex))
        (signature (hex->blob sig-hex))
        (pubkey (read-key-from-file verify-key)))

    (unless (equal? archive-hash expected-hash)
      (error "Archive hash mismatch"))

    (unless (ed25519-verify pubkey archive-hash signature)
      (error "Signature verification failed"))))

;; Decrypt and extract: age -d | zstd -d | tar -x
(system (sprintf "age -d -i ~a < ~a | zstd -d | tar -xf - -C ~a"
  id-file archive-file target-dir)))

```

Usage Examples

Create Encrypted Archive

```

;; Configure recipients
(vault-config 'age-recipients
  ("age1ql3z7hjy54pw3hyww5ayyfg7zqgvc7w3j2elw8zmrj2kg5sfn9aqmcac8p"))

;; Create archive
(seal-archive "1.0.0" format: 'zstd-age)
;; => vault-1.0.0.archive
;; => vault-1.0.0.archive.tar.zst.age

```

Restore Encrypted Archive

```

;; Configure identity
(vault-config 'age-identity "~/.config/age/identity.txt")

;; Restore with verification
(seal-restore "vault-1.0.0.archive"
  verify-key: "publisher.public"
  target: "./restored")

```

Command Line Equivalents

```
# Create
git archive --prefix=vault/ 1.0.0 | \
  zstd -T0 | \
  age -r age1ql3z7hgy54pw3hyww5ayyfg7zqgvc7w3j2elw8zmrj2kg5sfn9aqmcac8p \
  > vault-1.0.0.tar.zst.age

# Restore
age -d -i ~/.config/age/identity.txt < vault-1.0.0.tar.zst.age | \
  zstd -d | \
  tar -xf -
```

Migration

From Cryptographic to Zstd-Age

```
;; Re-archive existing releases with new format
(for-each
  (lambda (version)
    (seal-archive version format: 'zstd-age))
  (get-local-releases))
```

Backward Compatibility

Both formats can coexist. The manifest format field determines restoration method: - (format cryptographic) → seal-restore-cryptographic - (format zstd-age) → seal-restore-zstd-age

References

1. Zstd – Facebook’s compression algorithm
 2. Age – Modern encryption tool
 3. RFC-006 – Vault System Architecture
 4. RFC-004 – SPKI Authorization
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Changelog

- 2026-01-06 – Initial specification
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Implementation Status: Complete **Compression:** Zstd (parallel) **Encryption:** Age (X25519 + ChaCha20-Poly1305) **Signature:** Ed25519 (SPKI)